Mineral Resource Report 97

2014

GEOLOGY AND MINERALOGY OF URANIUM AND THORIUM IN THE READING PRONG OF BERKS, LEHIGH, AND NORTHAMPTON COUNTIES, PENNSYLVANIA

Robert C. Smith, II
John H. Barnes

COMMONWEALTH OF PENNSYLVANIA
Tom Corbett, Governor
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES
Ellen Ferretti, Secretary
OFFICE OF CONSERVATION AND TECHNICAL SERVICES
Nathan Flood, Deputy Secretary
BUREAU OF TOPOGRAPHIC AND GEOLOGIC SURVEY
George E. W. Love, Director

Mineral Resource Report 97

GEOLOGY AND MINERALOGY OF URANIUM AND THORIUM IN THE READING PRONG OF BERKS, LEHIGH, AND NORTHAMPTON COUNTIES, PENNSYLVANIA

by Robert C. Smith, II, and John H. Barnes
Bureau of Topographic and Geologic Survey

pennsylvania
DEPARTMENT OF CONSERVATION AND NATURAL RESOURCES

PENNSYLVANIA GEOLOGICAL SURVEY

FOURTH SERIES

HARRISBURG

2014

This report can be viewed at the
Bureau of Topographic and Geologic Survey website at
www.dcnr.state.pa.us/topogeo

Suggested citation: Smith, R. C., II, and Barnes, J. H., 2014, Geology and mineralogy of uranium and thorium in the Reading Prong of Berks, Lehigh, and Northampton Counties, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 97, 177 p.

1989 PREFACE

Concern about energy resources and environmental quality, starting in the 1970s, led to investigations of uranium and thorium occurrences in the Reading Prong of Pennsylvania in the 1980s and the publication of this report. Although the occurrence of uranium-bearing minerals in this geologically complex region has long been known, uranium has not been economically exploited because of the small size or low grade of the occurrences. In 1976, a new look at this region appeared warranted by improvements in exploration and mining techniques and unknown future economic conditions. Increased awareness of the possible deleterious effects that continued exposure to low-level, natural radiation might have on the public also suggested that more information on the sources of such radiation in this region was needed.

The significance of uranium and thorium occurrences in the Reading Prong is complicated by the urban nature of parts of it, and by population growth, especially in the rural areas. This greatly decreases the likelihood of mining, but correspondingly increases the need to identify uranium occurrences.

The information in this report should be of use to future mineral explorers and others engaged in interpreting the geology of the Reading Prong. It will also be of use to planning agencies and public-health authorities as they weigh the multifaceted problems that arise in the further development of those portions of this region that contain above-normal amounts of naturally occurring radioactive materials, including radon. The carborne gamma-flux survey that was conducted as a part of this study has already been used in public-health activities conducted by the commonwealth. Geologists, petrologists, health physicists, mineral collectors, students, and others interested in the general geology of this region should also find this report to be helpful.

2014 PREFACE

This report was originally written and submitted for publication in 1989. Circumstances intervened to sidetrack its full publication until now, although data from it were freely shared with agencies that are charged with protecting the health of residents in the region as awareness of the hazard of indoor radon in the region grew. For example, a map of the Reading Prong showing generalized gross gamma-flux data obtained during the carborne survey conducted as a part of this study was issued in 1985. The likelihood that there will be commercial development of the uranium resources in this region, which was already low for the reasons stated above, is now even lower. However, the environmental quality issues that also prompted the undertaking of this project have not disappeared and remain as relevant now as they were when the project was first undertaken.

As one reads this report, it must be kept in mind that the work was done mainly in the late 1970s. The data are still valid; however, the interpretations do not reflect revisions in the classification of granites that have occurred since this study was completed. Also, quantitative analytical techniques and computational tools that are available now were not available at the time of the research. We hope that, despite these shortcomings, the report will be of value to those who seek to better understand the occurrences of uranium and thorium in the Reading Prong.

ACKNOWLEDGMENTS

Partial support for this project was supplied by the USGS (U.S. Geological Survey) under grant 14–08–001–G–572 in the amount of $28,815. The USGS also provided trace-element analyses of 65 samples. Richard I. Grauch, former USGS U-Th Branch Chief, encouraged the initial proposal, coordinated the trace-element analyses, reviewed the thin-section petrography, and provided a helpful review of the manuscript. His patience with project modifications and delays is gratefully acknowledged.

Administrative support was provided by George E. W. Love, present State Geologist, Donald M. Hoskins, former State Geologist, and the late Arthur A. Socolow, former State Geologist. Dr. Socolow graciously provided a critical review of the manuscript. The late John H. Way, Jr., and the late Bernard J. O'Neill, Jr., formerly of the Bureau of Topographic and Geologic Survey, and Pasquale Pontoriero assisted with portions of the carborne scintillometer survey. Leslie T. Chubb, also formerly of the bureau, assisted with the carborne survey, prepared the rock samples for analysis, and reviewed the bureau's record of water wells in the Reading Prong.

Professional assistance with rock sampling and scintillometer-survey plotting during the summer of 1980 was provided by James O. Rumbaugh. David Costolnick assisted with the detailed geophysical grids during the summer of 1981.

D. C. Stromswold, formerly of Bendix Field Engineering Corporation, calibrated the portable gamma-ray spectrometer using the calibration pads at Walker Field Airport, Grand Junction, Colo., and provided equations for the calculation of percent eK, parts per million eU, and parts per million eTh.

An overview of the complexity of the geology of the Reading Prong was obtained from lectures and publications by Avery A. Drake, Jr., USGS, who also reviewed the final manuscript. Constructive review was also provided by Arthur W. Rose of The Pennsylvania State University and the late Arthur Montgomery. Samuel W. Berkheiser, Jr., formerly of the Bureau of Topographic and Geologic Survey, provided an internal review and assisted with the preparation of numerous figures.

Anne B. Lutz, formerly of the Bureau of Topographic and Geologic Survey and now an active volunteer at the bureau, edited the report and prepared the text, tables, and illustrations for publication. Thomas G. Whitfield of the bureau digitized Plate 1 and prepared it for publication.

DEDICATION

This report on uranium and thorium in the Reading Prong is dedicated to the late Dr. Arthur A. Socolow, who was Director of the Bureau of Topographic and Geologic Survey throughout the study. Dr. Socolow encouraged the study of potential mineral resources in Pennsylvania to determine their economic potential as well as to document their existence for unforeseen needs such as providing background data for environmental studies.

Thus, it was with Dr. Socolow's encouragement that a proposal to fund this study was submitted to the U.S. Geological Survey on June 28,1978, and carborne gross gamma-flux surveying began on March 14, 1979, Albert Einstein's 100th birthday. As a result of these surveys, in April 1985, the Bureau of Topographic and Geologic Survey was able to respond to county health officials with details down to the level of naming individual streets of great concern for indoor radon. That same month, the bureau was able to promptly interpret the mineralized shear zones at a house in Colebrookdale Township, Berks County, which came to the authorities' attention as having an exceptionally high level of indoor radon. To Dr. Socolow's credit, this turned out to be in the same general region of the Reading Prong, to the northeast of the Oley Valley, where he had observed active uranium prospects in the mid-1950s. Three months later, under Dr. Socolow's direction, a generalized gross gamma-flux map of the Reading Prong was released to relevant Pennsylvania state senators, representatives, planning commissions, and public libraries.

Photograph by Carl Socolow

[BLANK PAGE]

CONTENTS

	Page
1989 preface	iii
2014 preface	iii
Acknowledgments	iv
Dedication	v
Abstract	1
Introduction	1
Location and setting	1
Regional geology	4
Structure	4
Thickness	6
Aeromagnetic, gravity, and aeroradiometric data	8
Previous uranium-thorium studies	8
Occurrences hosted by gneiss and the Hardyston Formation in the main portion of the Reading Prong	9
Skarn- and gneiss-hosted occurrences in the Chestnut Hill area	15
Phase I: Carborne scintillometer gamma-ray anomaly survey	19
Methods	19
Anomaly locations	21
Efficacy of method	22
Phase II: Anomaly rock sampling and analyses	23
Site selection and location	23
Sampling methods	23
Sample preparation	24
Trace-element analyses and geochemistry	24
Elements and methods	24
Trace elements	27
Barium	31
Boron	33
Copper	33
Lanthanides	33
Lead	34
Molybdenum	34
Nickel	34
Niobium	35
Rubidium	35
Strontium	36
Thorium	36
Tin	36
Uranium	36
Vanadium	37
Zirconium	38
Petrology and mineralogy	38
Major and minor elements and methods	38
K_2O–Na_2O–CaO	38
Medians	38
Mineralogic estimates and methods	40
Deposit types	44
Subdivision of the 47 "granitic" rock samples	44
B-bearing alaskitic quartz monzonite suite (moderately potassic)	46
Mo-bearing granodiorite (relatively sodic) and Mo-bearing quartz monzonite suites (intermediate alkalis)	50

Page

Phase II: Anomaly rock sampling and analyses *(Continued)*
Deposit types *(Continued)*
Allanite-bearing pegmatite . . . 53
"Byram" granitic rocks . . . 55
Hardyston Formation basal conglomerates . . . 55
Skarns . . . 58
Phase III: Follow-up studies of selected occurrences . . . 60
Selection criteria . . . 60
Field methods . . . 60
Reduction of gamma-ray spectrometer data . . . 61
Contact metamorphic serpentine-phlogopite host . . . 62
Quarry L, Northampton County . . . 62
C. K. Williams quarry, north part, Northampton County . . . 68
Granitic host . . . 74
Chapel Hill anomaly, Berks County . . . 74
Forgedale Route anomaly, Berks County . . . 80
Hoch-Frederick anomaly, Lehigh County . . . 86
Korn-Stelts anomaly, Lehigh County . . . 92
Limeport Road anomaly, Lehigh County . . . 99
Oley Road anomaly, Berks County . . . 106
Swoveberg Hill anomaly, Northampton County . . . 112
Summary and conclusions . . . 119
Suggestions for additional studies . . . 121
References . . . 121
Factors for converting International System units (SI) to inch-pound units . . . 124
Appendix 1. Locations of significant gamma-ray anomalies from carborne survey . . . 125
Appendix 2. Summary of rock-sampling sites of Phase II . . . 148
Appendix 3. Analytical procedures . . . 163
Atomic absorption and flame emission . . . 163
Semiquantitative X-ray diffraction . . . 163
Appendix 4. Rare elements in titanite from Chestnut Hill, Northampton County . . . 171
Introduction . . . 171
Samples . . . 171
Separation and analyses . . . 171
Discussion . . . 171
Appendix 5. Mineral species . . . 174

ILLUSTRATIONS

FIGURES

Figure 1. Photograph of the Reading Prong from Oley Valley . . . 2
2. Location map of the study area in the Reading Prong section . . . 3
3. Map showing the nappe-tectonic units of the Reading Prong . . . 5
4. Photograph of South Mountain, Lehigh County . . . 6
5. Photograph showing gneissic compositional layering at Bushkill Drive, Northampton County . . . 7
6. Map showing previously known uranium occurrences in the Reading Prong . . 10
7. Map and radiometric traverse of mineralized shear zones near the headwaters of Monocacy Creek, Berks County . . . 14
8. Map showing previously known radioactive anomalies in the Chestnut Hill area of the Reading Prong, Northampton County . . . 17

Page

Figure 9. Example of road log for radiometric survey, and typical gamma-radiation strip chart . . . 20
10. Photograph of the scintillation counter and chart recorder . . . 21
11. Transfer of chart recorder data to 7.5-minute quadrangle maps . . . 22
12. Lanthanide distributions . . . 35
13. Plot of Pb vs. U for 47 Reading Prong granitic samples . . . 36
14. Plot of U vs. U/Th for 47 granitic samples from the Reading Prong, with samples for Phase III indicated . . . 37
15. Plot of K_2O–Na_2O–CaO for 47 granitic, 5 skarn, and 3 basal Hardyston Formation samples . . . 41
16. Photomicrograph of a thin section of sample RP15, from the Bushkill Drive anomaly, showing tourmaline in microcline . . . 46
17. Plots of K_2O–Na_2O–CaO . . . 48
18. Histogram of the uranium content of each suite . . . 50
19. Photograph of tourmaline in B-bearing alaskitic quartz monzonite at Saint Anthonys Nose, Northampton County . . . 51
20. Photograph of east end of Chestnut Hill, Northampton County, known as Saint Anthonys Nose . . . 51
21. Photograph of roadcut at Antietam reservoir, Berks County, that contains coarse-grained molybdenite . . . 52
22. Photomicrograph of thin section of sample RP14, from the Dogwood Lane anomaly, showing allanite-(Ce) and zircon crystals . . . 54
23. Photomicrograph of thin section of sample RP8, from the Water Street anomaly, showing a partial titanite rim on opaque Fe-Ti oxides adjacent to allanite-(Ce) . . . 54
24. Histogram of the U/Th ratio of the 26 “Byram” samples . . . 57
25. Photograph of fossil placer layer at the base of the Hardyston Formation, Lehigh County . . . 57
26. Photomicrograph of thin section of sample RP34, the Hardyston Formation at South Mountain Park, showing tourmaline and zircon . . . 58
27. Photomicrograph of thin section of sample RP43, from the East Lafayette Street talc quarry in Easton, showing deformed phlogopite . . . 59
28. Map of total gamma counts at the Quarry L anomaly . . . 63
29. Map of radiometric equivalent U at the Quarry L anomaly . . . 64
30. Map of radiometric equivalent Th at the Quarry L anomaly . . . 65
31. Map of radiometric K at the Quarry L anomaly . . . 66
32. Map of total magnetic flux at the Quarry L anomaly . . . 67
33. Map of total gamma counts at the northern C. K. Williams quarry anomaly . . . 69
34. Map of radiometric equivalent U at the northern C. K. Williams quarry anomaly . . . 70
35. Map of radiometric equivalent Th at the northern C. K. Williams quarry anomaly . . . 71
36. Map of radiometric K at the northern C. K. Williams quarry anomaly . . . 72
37. Photomicrograph of thin section of sample RP4, from the C. K. Williams quarry, showing outline of euhedral titanite altered to TiO_2 . . . 73
38. Map of total gamma counts at the Chapel Hill anomaly . . . 75
39. Map of radiometric equivalent U at the Chapel Hill anomaly . . . 76
40. Map of radiometric equivalent Th at the Chapel Hill anomaly . . . 77
41. Map of radiometric K at the Chapel Hill anomaly . . . 78
42. Photomicrograph of thin section of sample RP37, from Chapel Hill, showing a large anhedral garnet crystal . . . 79
43. Photomicrograph of thin section of sample RP37, from Chapel Hill, showing reddish-brown hematite(?) along plagioclase twin planes . . . 79

Page

Figure 44. Sketch maps of total gamma counts at the Forgedale Route anomaly 81
45. Sketch maps of radiometric equivalent U at the Forgedale Route anomaly ... 82
46. Sketch maps of radiometric equivalent Th at the Forgedale Route anomaly .. 83
47. Sketch maps of radiometric K at the Forgedale Route anomaly 84
48. Photomicrograph of thin section of sample RP16, from the Forgedale Route anomaly, showing zircon and allanite-(Ce) 85
49. Map of total gamma counts at the Hoch-Frederick anomaly 87
50. Map of radiometric equivalent U at the Hoch-Frederick anomaly 88
51. Map of radiometric equivalent Th at the Hoch-Frederick anomaly 89
52. Map of radiometric K at the Hoch-Frederick anomaly 90
53. Map of total magnetic flux at the Hoch-Frederick anomaly 91
54. Map of total gamma counts at the Korn-Stelts anomaly 93
55. Map of radiometric equivalent U at the Korn-Stelts anomaly 94
56. Map of radiometric equivalent Th at the Korn-Stelts anomaly 95
57. Map of radiometric K at the Korn-Stelts anomaly 96
58. Map of total magnetic flux at the Korn-Stelts anomaly 97
59. Photomicrograph of thin section of sample RP23, “Heller’s 2 boulders,” showing possible uraninite surrounded by a possible secondary uranium mineral 98
60. Map of total gamma counts at the Limeport Road anomaly 100
61. Map of radiometric equivalent U at the Limeport Road anomaly 101
62. Map of radiometric equivalent Th at the Limeport Road anomaly 102
63. Map of radiometric K at the Limeport Road anomaly 103
64. Map of total magnetic flux at the Limeport Road anomaly 104
65. Photomicrograph of thin section of sample RP6, from the Limeport Road anomaly, showing allanite-(Ce) containing uraninite(?) 105
66. Photomicrograph of thin section of sample RP6, from the Limeport Road anomaly, showing probable xenotime 105
67. Map of total gamma counts at the Oley Road anomaly 107
68. Map of radiometric equivalent U at the Oley Road anomaly 108
69. Map of radiometric equivalent Th at the Oley Road anomaly 109
70. Map of radiometric K at the Oley Road anomaly 110
71. Map of total magnetic flux at the Oley Road anomaly 111
72. Map of total gamma counts at the Swoveberg Hill anomaly 113
73. Map of radiometric equivalent U at the Swoveberg Hill anomaly 114
74. Map of radiometric equivalent Th at the Swoveberg Hill anomaly 115
75. Map of radiometric K at the Swoveberg Hill anomaly 116
76. Map of total magnetic flux at the Swoveberg Hill anomaly 117
77. Photomicrograph of thin section of sample RP52, from the Swoveberg Hill anomaly, showing probable uraninite and a probable secondary uranium mineral .. 118
78. Photomicrograph of thin section of sample RP38, from Schweyer’s quarry, showing euhedral allanite and titanite 172

PLATE

(separate file)

Plate 1. Map of the Reading Prong, Pennsylvania, showing locations of gamma-ray anomalies detected by carborne survey, sample locations, and locations of follow-up studies.

TABLES

Page

Table 1. Relationship of occurrences shown in Figure 6 to sample numbers for the present study . . . 11
2. Host-rock description and location of allanite-(Ce) samples from the Reading Prong and related areas . . . 12
3. X-ray fluorescence analyses, in weight percent, of allanite-(Ce) samples from the Reading Prong and related areas . . . 13
4. Analyses of four samples from the Oley area, Berks County . . . 15
5. Analyses of zircon separates from the Reading Prong and other areas in Pennsylvania and New Jersey . . . 16
6. Quantitative analyses for U and Th, with other criteria for evaluating the significance of occurrences examined in Phase II . . . 25
7. Results of flame-emission analyses for Ba, Rb, and Sr . . . 27
8. Trace-element data . . . 28
9. Semiquantitative lanthanide (rare-earth) analyses of rock samples . . . 30
10. Medians of trace-element contents for Reading Prong mineralized rock types with some comparative data from Turekian (1977) . . . 32
11. Median lanthanide contents of Reading Prong mineralized rock types with some comparative data from Turekian (1977) . . . 33
12. Quantitative major- and minor-element analyses by atomic absorption and flame emission . . . 39
13. Medians of major and minor oxides for Reading Prong "granitic" rocks . . . 41
14. Semiquantitative estimates of some major and minor minerals in RP1 through RP65, and names of significant accessory minerals . . . 42
15. Medians of semiquantitative estimates of mineralogy for Reading Prong "granitic" samples . . . 44
16. CIPW normative calculations of median analytical values in percent . . . 45
17. Classification of B-bearing alaskitic quartz monzonite suite via feldspar concentrations calculated from flame-emission determinations of percent K_2O and percent Na_2O . . . 47
18. Medians of trace-element concentrations for Reading Prong "granitic" rocks . 49
19. Classification of Mo-bearing granodiorite and Mo-bearing quartz monzonite suites via feldspar concentrations calculated from flame-emission determinations of percent K_2O and percent Na_2O . . . 52
20. Classification of "Byram" granitic rocks via feldspar concentrations calculated from flame-emission determinations of percent K_2O and percent Na_2O . . . 56
21. Relative peak heights recorded by X-ray diffraction for minerals in skarns of Chestnut Hill . . . 59
22. Locations of significant gamma-ray anomalies from carborne survey . . . 125
23. Summary of rock-sampling sites . . . 149
24. Values assumed for international reference samples used as standards for atomic absorption and flame emission . . . 164
25. Analytical conditions for atomic absorption and flame emission . . . 165
26. X-ray diffraction peaks used for semiquantitative mineralogical analyses . . . 166
27. Materials used in standard mixtures for semiquantitative X-ray diffraction . . . 167
28. Standard mixtures used in calibration of semiquantitative X-ray diffraction . . 168
29. Test of accuracy of semiquantitative X-ray diffraction method using standards as unknowns . . . 170
30. Test of precision of semiquantitative X-ray diffraction method using sample RP6 . . . 170

Page

Table 31. Summary of titanite concentrates prepared from three locations along Chestnut Hill, Northampton County 172
32. Analyses of 1.0-ampere magnetic fraction titanite concentrates from three locations along Chestnut Hill, Northampton County 173
33. Some mineral species from the Reading Prong identified by X-ray powder diffraction 174

GEOLOGY AND MINERALOGY OF URANIUM AND THORIUM IN THE READING PRONG OF BERKS, LEHIGH, AND NORTHAMPTON COUNTIES, PENNSYLVANIA

by
Robert C. Smith, II,[1] and John H. Barnes

ABSTRACT

The Reading Prong section of the New England physiographic province is an 800-square-kilometer (300-square-mile) upland in eastern Pennsylvania underlain by largely Grenvillian-age gneisses, many of which appear to be of metasedimentary origin. A carborne gamma-flux survey of the area showed count rates of 80 counts per second or greater along 2.7 percent of drivable roads, as opposed to background rates of about 40 counts per second, and resulted in the discovery and sampling of 36 new uranium-thorium occurrences having median uranium and thorium contents of 68 and 180 parts per million, respectively, as determined from analyses of rock composites. Similar samples from 17 previously known occurrences have median uranium and thorium contents of 58 and 220 parts per million. Maps of the carborne gamma-flux data seem to indicate that the Reading Prong is composed of several terranes, as evidenced by the generally low radiometric readings in the northwestern portion, a higher radiometric flux in the southeastern portion, and a much higher flux in an outlier to the northeast known as Chestnut Hill. The boundaries of these terranes appear to correspond in part to nappe boundaries previously proposed by others. Many of the richer occurrences having ≥200 parts per million uranium and uranium/thorium ratios ≥0.5 are located in the stratigraphically relatively intact Chestnut Hill outlier and along a possible northeast-trending nappe boundary between the radiometrically lower Irish Mountain nappe and the more radioactive Applebutter nappe, as used herein. Gamma-ray spectrometer and magnetometer ground studies at several of these richer occurrences suggest that they may extend for tens, but not hundreds, of meters. High gamma flux may be of concern if continuing human activities occur at some sites.

Plots of K_2O–Na_2O–CaO for rock composites show that the samples can be divided into lowermost Cambrian(?) Hardyston Formation basal placers, Middle Proterozoic serpentine-phlogopite skarn samples, and a heterogeneous group of granitic gneiss samples assumed to be of Middle Proterozoic age. Hardyston Formation placer samples were found to contain up to 65 parts per million uranium over a 10-centimeter stratigraphic thickness, serpentine-phlogopite samples up to 0.11 percent uranium over 1.2 meters, and granitic gneiss samples up to 1 percent uranium over 20 centimeters. The presence of boron or molybdenum in the latter group permits a separation into two subgroups, leaving a third, somewhat igneous-appearing subgroup of granites that may correspond to a mineralized equivalent of the so-called Byram gneiss.

Low uranium prices, small size of occurrences, and population density make the development of uranium occurrences in the study area unlikely at this time. However, a small economic potential may exist for rare earths contained in allanite-(Ce) near Shanesville, or for other rare metals contained in titanite and sulfides in a skarn zone that may continue from Chestnut Hill northeast into less developed areas.

[1]Retired (present address, Mechanicsburg, Pa.)

INTRODUCTION

LOCATION AND SETTING

The Reading Prong section of the New England physiographic province is a 300 ± 10-mi^2 (780-km^2) northeast-southwest-trending region of rolling hills in eastern Pennsylvania (Figure 1). It occupies portions of eastern Berks, southern Lehigh, and Northampton Counties, and a small portion of northern Bucks County. It is near the cities of Reading, Allentown, Bethlehem, and Easton (Figure 2).

Figure 1. Photograph of the Reading Prong rising 600 feet (180 m) above the Oley Valley, Berks County. View is toward the east.

The Reading Prong is considered to be the southwestern extension of the New England physiographic province. Immediately to the east it is known as the New Jersey Highlands and farther east as the Hudson Highlands of southeastern New York and western Connecticut. In Pennsylvania, it has also been called the Durham-Reading Hills, after towns at the eastern and southwestern limits in Pennsylvania. The hills of the Reading Prong separate the Great Valley section of the Ridge and Valley physiographic province on the northwest from the Gettysburg-Newark Lowland section of the Piedmont physiographic province on the southeast.

As noted by Drake (1969, p. 51; 1970, p. 279), the area is unglaciated, deeply weathered, and has a lack of rock exposures that is "appalling." This latter observation has been verified by Young (1978) and the present authors.

Altitudes in the Reading Prong range from approximately 150 feet (45 m) and 200 feet (60 m) at the Delaware and Schuylkill Rivers, respectively, to approximately 1,050 to 1,150 feet (230 to 350 m), the highest point being Topton Mountain at 1,240 feet (380 m). The Reading Prong is about 48 miles (75 km) long, and from 5 to 7 miles (8 to 11 km) wide. It is usually considered to include several outliers, among them, from southwest to northeast, Neversink Mountain, Camelhump, Chestnut Hill, and several smaller hills. The intermontane Oley and Saucon valleys (Plate 1), underlain by Cambrian-Ordovician carbonate rocks, are excluded because of their lower elevations and distinct geology. The 21-mi^2 (54-km^2) Little South Mountain or Womelsdorf outlier at the junction of Berks, Lancaster, and Lebanon Counties, several miles to the west of the study area, was largely excluded from the present study because it falls outside the USGS- (U.S. Geological Survey-) Pennsylvania Geological Survey cooperative project area in the Newark 1- x 2-degree quadrangle. Also, preliminary reconnaissance suggested the presence there of only a few weak gamma-ray anomalies.

The average annual precipitation of 43 inches (110 cm) at Bethlehem (Wood and others, 1972) is consistent with other measuring stations that surround the Reading Prong. Actual precipitation at the higher elevations may be a few inches (several cm) greater.

Population density within the Reading Prong proper is low to moderate. The largest community is Alsace Manor, with a population of about 300. As of the 1980 census, Pike Township, Berks County, had the lowest population within the Reading Prong with 1,056 people, and Upper Milford Township, Lehigh County, the highest with 5,013. Typical townships in the Reading Prong have areas of 16 mi^2 (40 km^2), yielding population densities on the order of 200 persons per square mile (approximately 75 per km^2), including towns.

The study was undertaken to gain a better understanding of the extent and nature of the U and Th occurrences that have long been known to exist in this region, both from the point of view of possible future exploitation and that of current concerns for public health.

The method chosen was a three-phase study. Phase I consisted of collecting gamma-flux data along every drivable road in the Reading Prong using a carborne scintillation detector. Phase II involved the collection and chemical and mineralogical analysis of samples from sites identified during Phase I as having an anomalously high gamma flux, as well as other

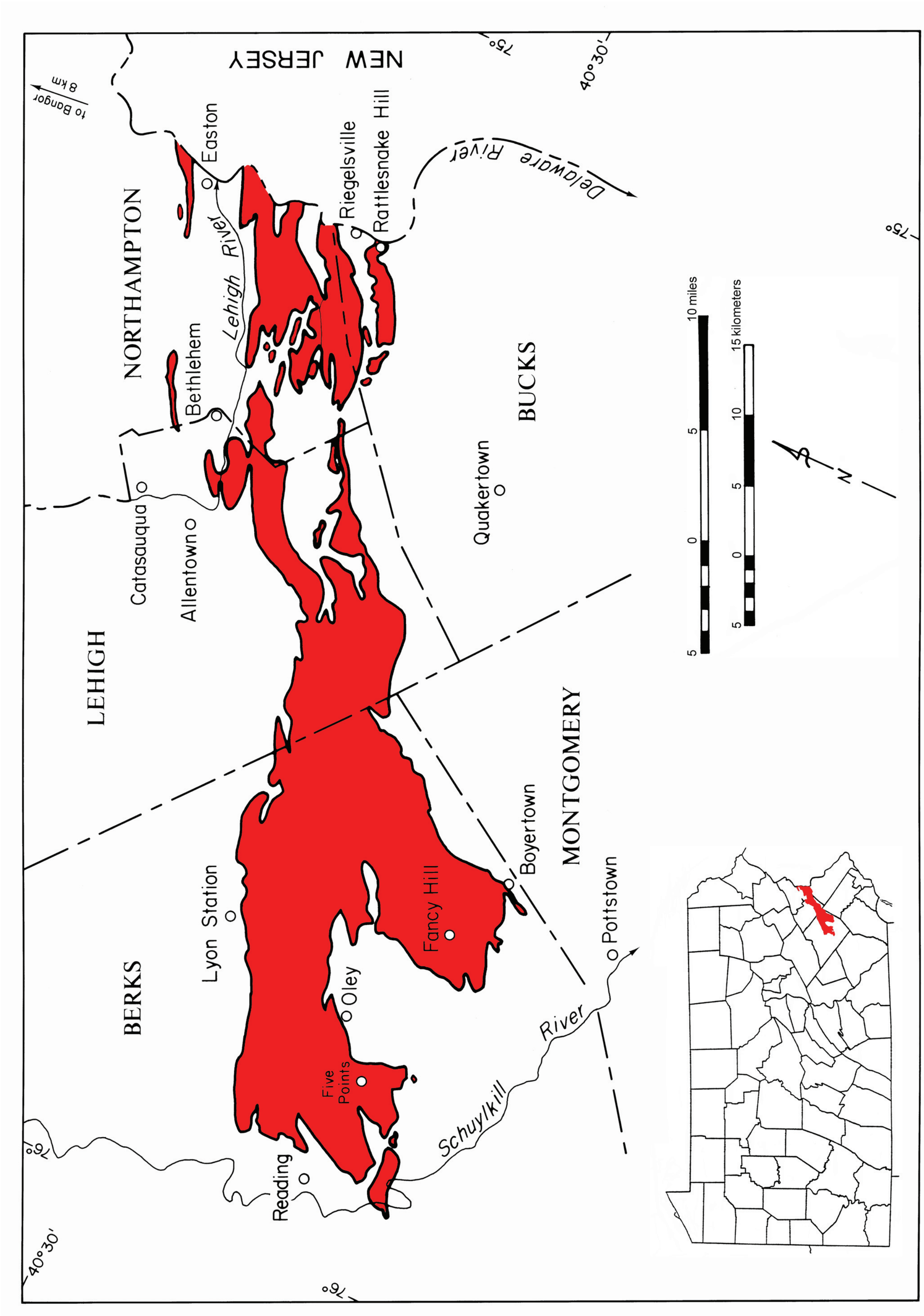


Figure 2. Location map of the study area in the Reading Prong section of the New England physiographic province in eastern Pennsylvania.

sites known to have enrichments of uranium and thorium. Phase III involved revisiting a limited number of sites, selected primarily on the basis of uranium content, U/Th ratio, and accessibility, for more detailed study, including detailed mapping of eU, eTh, (equivalent U and equivalent Th, following standard usage reflecting the fact that determinations of uranium and thorium are made from the radioactive decay of progeny, rather than from the elements in question directly) and K, using a portable gamma-ray spectrometer, and of magnetic flux.

REGIONAL GEOLOGY

Structure

The Reading Prong of Pennsylvania, and the Great Valley, lie in the Taconides (Drake, 1980), the region dominated by structures associated with the Taconic Orogeny, circa 450 Ma. The Reading Prong consists primarily of the Precambrian crystalline core of a nappe system emplaced during the later portion of the orogeny.

In an overview of the regional geology of the Reading Prong, Drake (1980) noted that emplacement of allochthonous klippen during the Taconic was followed by recumbent folding and associated thrust faulting, in response to northwest-directed stress, resulting in a series of northeast-plunging nappes (Drake, 1970). These nappes were thrust-faulted and further compressed into a series of crystalline-cored antiforms in the Alleghanian Orogeny, circa 300 Ma (Drake, 1980). Drake cited a personal communication from L. D. Harris (1979) that this entire portion of the Taconides is allochthonous above a master sole fault at a depth of about 9 miles (15 km) in areas west of the Delaware River. MacLachlan (1979) presented a more detailed discussion of Taconic nappes and other structures in the western portion of the Reading Prong.

Drake (1978) termed the group of alpine-type northeast-plunging nappes as the Reading Prong nappe megasystem. D. B. MacLachlan of the Pennsylvania Geological Survey (personal communication, 1983) tentatively divided the Pennsylvania portion of the Reading Prong into four nappe-tectonic units, the boundaries of which have been modified herein to fit the gross gamma data from Phase I of the present study (Figure 3). The structurally lowest, unexposed Lyon Station-Paulins Kill nappe unit is overlain by the Irish Mountain unit and that, in turn, is perhaps overlain by the Applebutter thrust sheet or nappe. The Precambrian core east of Saucon Valley and two outliers to the north are reported to be portions of the Musconetcong nappe. Although MacLachlan defined the nappe boundaries on the basis of associated Cambrian and Ordovician sedimentary rocks, only the crystalline cores are discussed below and shown in Figure 3. In general, these nappe units are believed to be separated from one another by southeast-dipping thrust faults.

Drake (1978) defined the Lyon Station-Paulins Kill nappe unit, the northernmost nappe of the Reading Prong, on the basis of aeromagnetic and geologic data. This definition involved interpretation of the work of Bromery and Griscom (1967), who proposed a subsurface block of crystalline rocks based on aeromagnetic data. The nappe extends from Lyon Station, Berks County, at least to Branchville, N.J. Based on calculations from the aeromagnetic data, the crystalline core of the nappe extends at least from Lyon Station north-northeast to Bangor, a distance of 45 miles (70 km) (Drake, 1978, p. 3).

Drake (1978) estimated that the crystalline core of the Lyon Station-Paulins Kill nappe has a depth of 1 mile (1.6 km) at Catasauqua, Lehigh County, placing it beyond the scope of this report. Based on depths of 8 to 11 miles (12 to 17 km) for the first basement seismic reflection near Lyon Station (V. E. Gwinn, personal communication to A. A. Drake, 1966), the Lyon Station-Paulins Kill nappe is not tied to basement.

The Irish Mountain nappe unit was reported by MacLachlan (1979; personal communication, 1983) to constitute the northwest half of the exposed Reading Prong (Figure 4) from Reading to the Saucon Creek water gap at Hellertown. Based on MacLachlan's data, Faill (personal communication, 1980) included the Womelsdorf outlier within this nappe. However, the presence of muscovite-bearing pegmatite (Geyer and others, 1963) containing trace beryl suggests some affinity of the outlier with the Honeybrook Upland, 30 miles (50 km) to the southeast. The Irish Mountain nappe is named for a 1,040-foot-(320-m-) high hill on the northwest edge of the Reading Prong. The Irish Mountain nappe of MacLachlan is the same as the South Mountain nappe of Drake (1978, p. 18).

Based in part on the previously cited personal communication from MacLachlan, and in part on the gross gamma signature (Phase I of this study), the present interpretation is that the crystalline rocks of the Applebutter nappe probably constitute the southeast portion of the Reading Prong from Reading to the south side of Saucon Valley (Figure 3). This nappe was named for Applebutter Hill, an 840-foot-(260-m-) high ridge on the southwest side of Saucon Valley. Based on the mapping of Buckwalter (1959, 1962) in the Reading and Boyertown 15-minute quad-

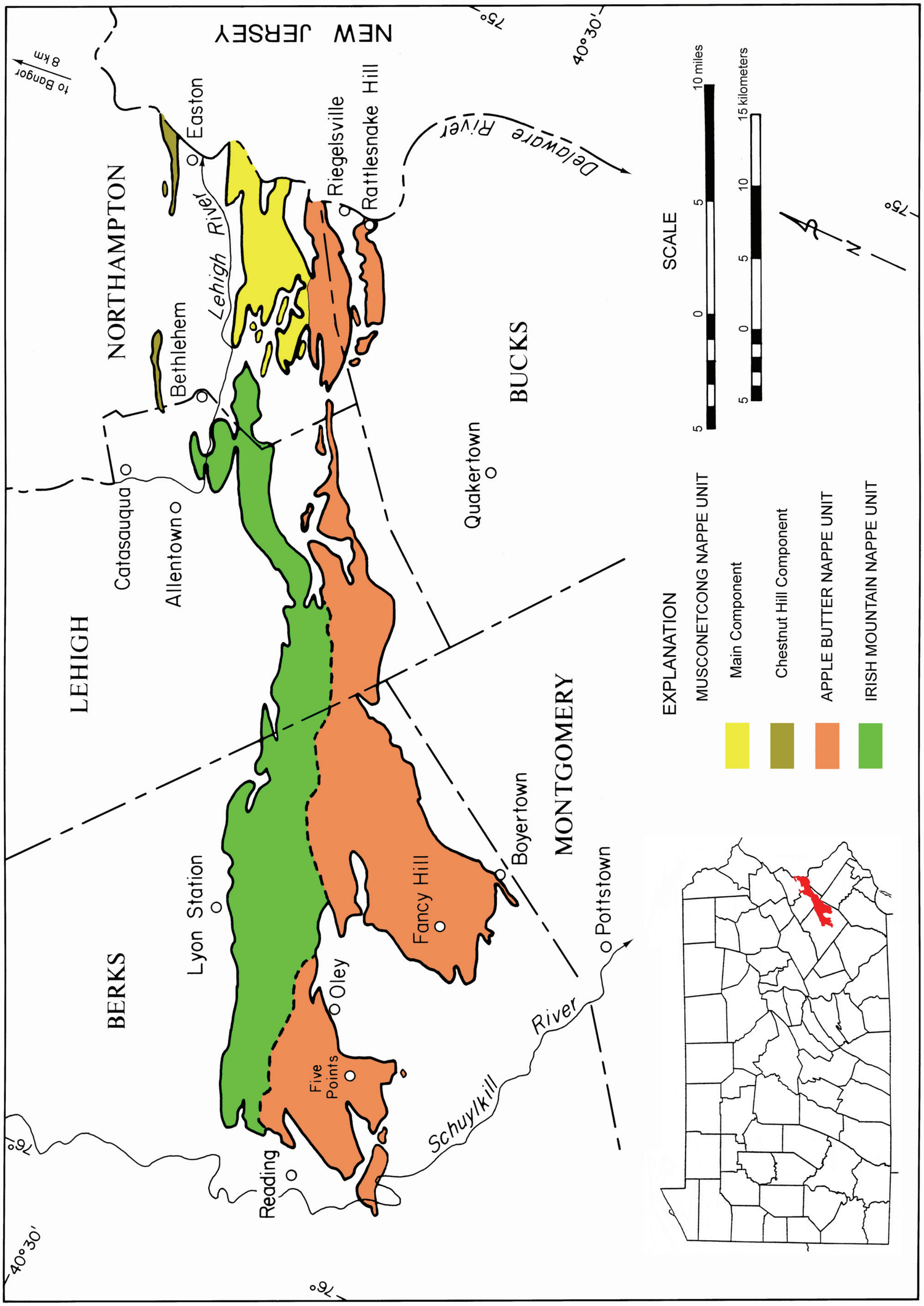


Figure 3. Location map showing the nappe-tectonic units of the Reading Prong section that are exposed at the surface.

Figure 4. Photograph of South Mountain, Lehigh County, believed to be part of the Irish Mountain nappe, looking northwest across the Saucon Valley toward the gap through which Pa. Route 309 and the planned Interstate 78 pass. The Reading Prong constitutes the hills in the background that stand about 600 feet (180 m) above the valley floor.

rangles, the Applebutter nappe may contain more graphitic gneiss than the Irish Mountain nappe.

The Musconetcong nappe unit was reported by Drake (1978) to constitute the portion of the Reading Prong east of Saucon Valley, including the Camelhump, Pine Top, and Chestnut Hill outliers to the north. It is separated from the Irish Mountain and Applebutter nappes by the Black River fault (Drake, 1978, p. 18) or fault system. MacLachlan (1979) noted that the Musconetcong nappe may structurally underlie the Irish Mountain nappe. Based on the gross gamma signature, ubiquitous boron (Phase II of the present study), and the abundance of metasedimentary rocks, the crystalline rocks on Chestnut Hill are postulated to be distinct from the main portion of the Musconetcong nappe to the south.

Drake (1970) noted that lithologic boundaries and gneissic foliation within the Reading Prong typically trend northeast-southwest and dip to the southeast (Figure 5). This trend also holds true for relict bedding, such as that observed near Bushkill Gap during the present study. Drake (personal communication, 1988) discerned at least three phases of folding in the Precambrian. The most common folds are isoclinal, are overturned to the northwest, and plunge to the northeast.

Thickness

The thickness of the crystalline portion of the Reading Prong has been tested by drilling at several locations. Drake (1969, p. 102 and Fig. 17) and Epstein and others (1967) reported that diamond drilling in hornblende granite on Rattlesnake Hill (Drake and others, 1967) (Figure 3), 0.65 km (0.4 mi) west-northwest of Monroe, Bucks County (40°34'26"N/ 75°12'02"W), penetrated overturned Leithsville Formation at 392 feet (120 m) and continued in that formation to its total depth of 476 feet (145 m). Drake (1969, p. 102) also noted that a nearby water well collared in Precambrian rock on the western extremity of Rattlesnake Hill penetrated the Leithsville Formation at about 280 feet (86 m).

Ratcliffe and Burton (1985) reported the results of deepening this hole from the original 476 feet (145 m) to 900 feet (275 m). They summarized the core as follows: "From 476 feet to 731 feet highly cataclastic and strongly foliated blue-green, pale-grey and dark grey dolostone [Leithsville Formation(?)] is present." From about 711 to 736 feet (217 to 225 m), a mylonitic Hardyston Formation quartzite is found. Highly cataclastic gneiss begins at 736 feet, but cataclastic structures die out downward in the core, and

Figure 5. Photograph of the east side of Bushkill Drive, Northampton County, showing typical gneissic compositional layering dipping to the south (right). A geologist stands at the site from which sample RP15 was collected.

from 800 to 900 feet (245 to 275 m), less-sheared biotite and hornblende granite gneiss were found.

The Bud Garber No. 1 water well, located in the saddle of Fancy Hill (Figure 3), 0.98 mile (1.6 km) west-northwest of the intersection at Worman, Berks County (40°19'46"N/75°41'47"W), was collared in Cambrian Hardyston Formation at an elevation of about 950 feet (290 m). It penetrated Precambrian gneiss at about 140 feet (43 m) and continued in gneiss until completion at 2,505 feet (760 m). This hole is located only 0.43 mile (0.7 km) northwest of Paleozoic limestone. Thus, the Reading Prong is moderately thick in this area, and the boundary is probably moderately steep.

Drake (personal communication, July 27, 1983) reported a 1,000-foot (305-m) diamond-drill core in hornblende granite, 0.57 miles (0.93 km) east of Five Points, Berks County (40°21'40"N/75°49'32"W). Except for the bottom 8 feet (2.4 m), which consisted of diabase of unknown age, the hole remained in Precambrian crystalline rocks. Diabase of probable Paleozoic age can be observed in outcrop 2.4 miles (3.8 km) to the west. The Five Points drill hole is 0.32 mile (0.50 km) from the edge of the Reading Prong overlooking the west side of Oley Valley.

In 1976, the New Jersey Zinc Company core-drilled two holes in search of sphalerite on the property of Eastern Industries. Hole No. 1, drilled 1.67 miles (2.65 km) east of the Five Points drill hole, remained in Paleozoic carbonates for its total depth of 2,500 feet (762 m). Hole No. 2, drilled 1.34 miles (2.08 km) southeast of the Five Points hole, remained in Paleozoic carbonates for its total depth of 1,470 feet (448 m). The respective latitude and longitude of holes No. 1 and No. 2 are 40°21'44"N/75°47'38"W and 40°21'20"N/75°48'04"W. Thus, the Oley Valley is not underlain by crystalline rock at shallow depths in these areas.

Gault and Hamilton (1953) described a 1,137-foot (347-m) water well, churn-drilled by Bud Garber's father in Oley, Berks County (Figure 3), 2.57 miles (4.1 km) northeast of the Five Points diamond-drill hole. The hole is located in the northwest corner of Oley Valley, specifically about 100 feet (~30 m) southwest of the main road from Pricetown at Clarence H. Sheaffer's store in Oley (40°23'22"N/75°47'36"W). The hole penetrated Martinsburg Formation from 0 to about 610–635 feet (0 to 186–194 m), where it presumably crossed a tectonic contact into various quartz-pink feldspar-gray plagioclase-hornblende-biotite(?)-chlorite granitic gneisses that continued to the bottom.

Aeromagnetic, Gravity, and Aeroradiometric Data

Bromery and Griscom (1967) presented aeromagnetic data at a scale of 1:125,000 for southeastern Pennsylvania. The contours for the Reading Prong typically have a "birds-eye maple" pattern, presumably due to the distribution of magnetite. Typical distances between "eyes" are a few miles (several km). Particularly strong anomalies, described by Socolow (1974), are near known magnetite deposits southeast of Emmaus (11,290 gamma in the general area of sample RP31 of this study [Plate 1]) and at Rittenhouse Gap (11,220 gamma). Perhaps coincidentally, these are the only two molybdenite-rich magnetite deposits known in the Pennsylvania portion of the Reading Prong.

Bromery and Griscom (1967) noted subsurface Precambrian rocks beneath a thin cover of Paleozoic sedimentary rocks between Reading and Maiden Creek, between Springtown and Riegelsville, and between Lobachsville and Earlville (Plate 1). The deeper Lyon Station-Paulins Kill nappe of Drake (1978) was believed to be responsible for a broad anomaly trending southwest from north of Bethlehem and was concluded to pass beneath the exposed Precambrian gneiss. Except for subsurface areas, the magnetic anomalies tend to end rather abruptly.

Based on the association of low-amplitude magnetic anomalies and gravity highs in the Little South Mountain (Womelsdorf) area versus high-amplitude magnetic anomalies and gravity lows in the main Reading Prong, Bromery and Griscom (1967) concluded that the rocks in the two areas have distinctly different physical properties. The low-amplitude magnetic anomalies suggested to them that the granitic rock comprising Little South Mountain is thin. Qualitative examination of the published data using similar interpretations suggests that areas of the Reading Prong southwest of Oley, northwest of Boyertown, and between Springtown and Riegelsville could also be thin. As noted in the "Thickness" section, however, the granitic rock in the area west of Boyertown is moderately thick (>2,505 feet or 0.76 km).

MacLachlan (1979) qualitatively smoothed the aeromagnetic data of the Reading 15-minute quadrangle and, by comparison with better-known areas, inferred thicknesses on the order of 2,000 feet (600 m) for the Precambrian of the Temple and Fleetwood 7.5-minute quadrangles.

Fisher and others (1979) noted that aeromagnetic anomalies of the southwest end of the Reading Prong only locally extend beneath the Paleozoic rocks. They contrasted this with the situation at the northeastern end of the Reading Prong, between New Milford and Harrison, N.Y., where the anomalies and presumably the Precambrian rocks clearly plunge beneath the Paleozoic section. Their interpretation tends to agree with that of Dallmeyer (1974), who noted the apparent geological differences between the opposite ends of the Reading Prong.

The residual gravity compilation map of Lyons and O'Hara (1982) indicated a major gravity low over a large area that includes the Reading Prong of Pennsylvania. Gravity values appear to range from about minus 60 mGals (milligals) to less than minus 70 mGals. These data tend to suggest a thick sedimentary cover in the area with few high-density rocks such as basalt; that is, the Precambrian rocks of the Reading Prong are not basement.

An aeroradiometric survey of the Reading Prong was included in the NURE (National Uranium Resource Evaluation) conducted by the U.S. Department of Energy (LKB Resources, 1978). The survey was conducted using a grid with a spacing of 3 miles (4.8 km) between east-west flight lines and 18 miles (29 km) between north-south flight lines. Although this spacing is too coarse for the present study, some relationships to certain anomalies included in the present study were noted.

PREVIOUS URANIUM-THORIUM STUDIES

For more than 100 years, geologists have known of and described occurrences of uranium, thorium, and accessory minerals containing these elements, such as allanite-(Ce), molybdenite, monazite, and zircon, in the Reading Prong, the earliest description appearing to be that of allanite by Genth (1855). That Genth did not note that allanite contained uranium[1] is not remarkable, in that uranium was isolated chemically for the first time only 14 years earlier by Peligot in 1841 (Hammond, 1972, p. B–35). The first recognition of uranium as an unknown element in pitchblende was by Klaproth in 1789, and thorium was discovered by Berzelius in 1828 (Hammond, 1972, p. B–33 and B–35). By coincidence, it was in the same year that Genth published his identification of allanite that the German glassblower, Heinrich Geissler, constructed the first evacuated glass vessels contain-

[1] Smith (1967) reported that allanite-(Ce) from the Reading Prong contained a tenth to several percent Th. Data for U are lacking, but a hundred to thousands of parts per million seems reasonable.

ing electrodes (cathode-ray tubes) that eventually indirectly lead to the discovery of radioactivity. Experiments involving the luminescence of materials when exposed to cathode rays, and the ability of these rays to penetrate black paper, led to a series of early experiments with uranium salts. This resulted in the discovery by Henri Becquerel, presented in a paper in 1896, that uranium salts and uranium-bearing minerals produce radiation spontaneously and continuously (Faure, 1977).

Figure 6 shows the locations of previously known uranium and thorium occurrences in the Reading Prong. Table 1 is a key linking the locations shown on Figure 6 and samples described in this report. These and selected occurrences of enriched accessory and associated minerals, such as allanite-(Ce), molybdenite, monazite, and zircon, are described below.

OCCURRENCES[2] HOSTED BY GNEISS AND THE HARDYSTON FORMATION IN THE MAIN PORTION OF THE READING PRONG

Genth (1855) reported allanite from Berks and Northampton Counties, but did not note the possibility of their containing the then relatively newly discovered elements uranium and thorium. He reported that the allanite from Eckhardt's furnace, Berks County, which Gordon (1922, p. 158) equated with his "Pricetown" locality, was abundant and associated with quartz, zircon, mica, and titaniferous magnetite. Allanite from Bethlehem, Northampton County, was reported to occur in flat pieces up to one half inch (1 cm) thick that were covered with hydrated oxides of iron and cerium. Analyses for "oxyd [*sic*] of cerium, lanthana, oxyd of didymium" (later separated into chiefly Pr and Nd), and for major oxides, were given for both locations (Genth, 1855, p. 76).

Rogers (1858, p. 710) reported allanite in a "sienitic [*sic*]" gneiss with magnetite, epidote, brown garnet, black spinel, and tourmaline from South Mountain near Bethlehem, but did not mention that allanite is typically a thorium- and uranium-bearing mineral.

Genth again mentioned allanite in the Reading Prong in 1875, noting it in association with magnetite and zircon near Pricetown, Berks County (Genth, 1875, p. 79). From Northampton County, he noted allanite (1) with zircon 0.75 mile (1.2 km) north of Bethlehem (p. 76); (2) with black tourmaline (possibly schorl) (p. 97), titanite (p. 102), and zircon (p. 76 and 80) in Lower Saucon Township, 5 miles (8 km) east of Bethlehem; and (3) as a "large mass" of about 100 pounds (45 kg) just south of Lehigh University, Bethlehem (p. 80).

D'Invilliers (1883, p. 74–75) reported molybdenite, siderite, and garnet in a light-colored feldspathic rock at Valentine Hartman's iron prospect on the hill just south of Peter Fies Tavern.[3] This may be the same as the Zion's Church (=Spies Church) locality he mentioned in his mineral list (p. 399). D'Invilliers (p. 76 and Fig. 5) also noted molybdenite in his description of the "Ohlinger Dam quarry" on the south side of the Antietam reservoir[4] (see RP2 and RP56, Appendix 2, this report).

Allanite in association with magnetite and zircon was reported from the Haines, Rhoades, and Schroeder farms, Pricetown area, Ruscombmanor Township (d'Invilliers, 1883, p. 61 and 394). These were apparently near Schittler's ore bank[5] (p. 273) where ". . . beautiful chocolate brown, lustrous and opaque crystals of zircon, sometimes an inch in length, but rarely perfectly terminated . . ." are found. Zircon crystals in magnetite are reported to have been found in the hornblende-feldspar gneiss outlier just north of Barnhart's Dam, Muhlenberg Township[6] (p. 273).

Eyerman (1911, p. 10 and 23) mentioned an allanite locality at Weber's, Lower Saucon, Northampton County, 6 miles (10 km) from Easton, as having long been exhausted. Molybdenite in serpentine was reported from "Williams' Delaware quarry" (believed to be the same location as sample RP39 of the present study) and at Wagener's Chestnut Hill quarry, Easton (p. 21). He also mentioned that he found both torbernite and autunite at the Trexler mica mine, Stony Creek, Berks County (p. 20).

Gordon (1922, p. 152) (Figure 6, occurrence 2) also mentioned a Trexler mica mine 0.75 mile (1.2 km) northeast of McKnight's Gap and about a quarter of a mile (0.4 km) south of a school, Alsace Township, Berks County. This location, given in Kemp's system of ninths as Reading 5557, was reported by

[2] "Occurrences," as used in this annotated literature survey, includes a variety of reports of U and Th, many of which were not relocated. Their environmental and economic significance varies from negligible to important. The locations of those believed to be of consequence are shown in Figure 6 and, except for occurrence 2 (lost) and occurrence 11 (a single boulder), they were restudied in Phases II and III of this report.

[3] This location has an approximate latitude and longitude of 40°22'19"N/75°51'18"W.

[4] This location has an approximate latitude and longitude of 40°21'22"N/75°52'10"W.

[5] The possible location has a latitude and longitude of approximately 40°25'30"N/75°47'39"W.

[6] The possible location has a latitude and longitude of approximately 40°22'19"N/75°54'28"W.

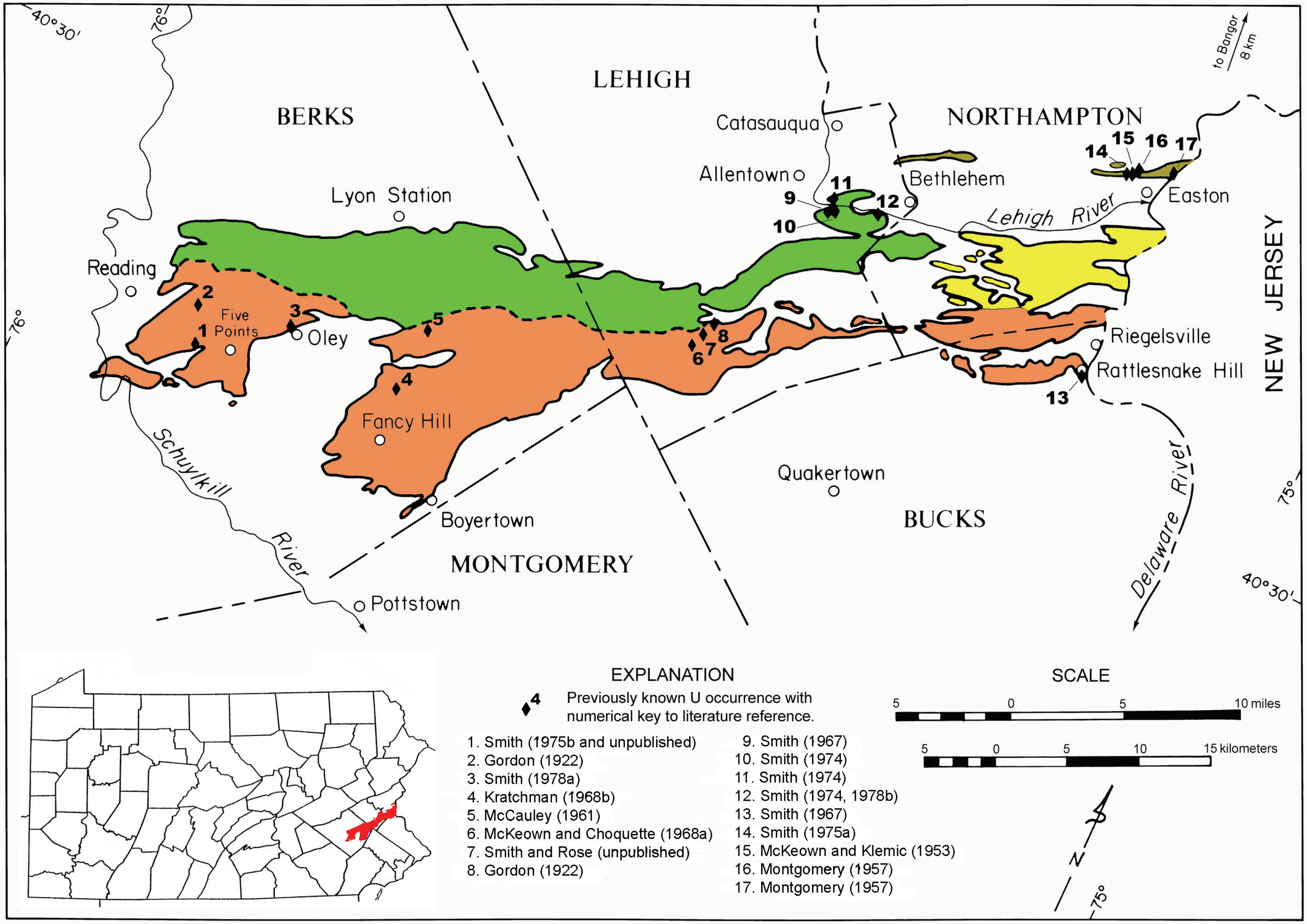


Figure 6. Location map showing the previously known uranium occurrences in the Reading Prong section. See Figure 3 for explanation of colors and Table 1 for names of occurrences.

Table 1. *Relationship of Occurrences Shown in Figure 6 to Sample Numbers for the Present Study*

Number used in Figure 6	Common name of uranium occurrence	Reference cited in Figure 6	Sample numbers for present study
1	Antietam reservoir	Smith (1975b)	RP2, RP56
2	Trexler mica mine	Gordon (1922)	Unable to relocate mine
3	Moxon borrow pit	Smith (1978a)	RP59
4	Pennsylvania Uranium Mining Corp.	Kratchman (1968b)	RP1
5	Rohrbach prospect	McCauley (1961)	RP32, RP33
6	Hoch-Frederick granite quarry	McKeown and Choquette (1968a)	RP28
7	Red feldspar layer, Northeast Extension, Pa. Turnpike	Smith and Rose (unpublished)	RP10
8	Vera Cruz granite quarry	Gordon (1922)	RP49
9	Allanite No. 15, Constitution Drive	Smith (1967)	RP20
10	Hardyston Formation fossil placer, Constitution Drive	Smith (1974)	RP5
11	Hardyston Formation fossil placer, Camp Mizpah	Smith (1974)	None, because original boulder was float
12	Chevkinite pegmatite dike	Smith (1974, 1978b)	RP55
13	Pa. Route 611	Smith (1967)	RP3
14	Quarry L	Smith (1975a)	RP57, RP60
15	Schweyer quarry	McKeown and Klemic (1953)	RP38
16	Easton reservoir site	Montgomery (1957)	RP21
17	C. K. Williams quarry	Montgomery (1957)	RP4, RP39

E. T. Wherry (Gordon, l922) to yield large masses of allanite, zircon, autunite, and torbernite.

Miller and others (1941, p. 446–470) noted the following new information on two minerals in Lehigh County: (1) molybdenite in dense gneiss in an abandoned quarry south of the Reading Railroad about 0.75 mile (1.2 km) east of Vera Cruz (see RP49 and Figure 6, occurrence 9), in a basic gneiss with secondary quartz and epidote on the lower slope of South Mountain south of Farmington, and in gneiss with hematite iron ore just west of Old Zionsville; and (2) uraninite reported by E. T. Wherry as small grains at the above-mentioned Vera Cruz molybdenite locality.

McKeown and Choquette (1968a) examined Henry Martin's Keystone quarry, 0.5 mile (0.8 km) east-northeast of Old Zionsville (Figure 6, occurrence 6), and reported gneissic granite, with a foliation dipping 45° northwest, exposed in a quarry about 200 feet (60 m) in diameter. A contact with "Pochuck(?) gneiss" (presumably amphibolite) strikes east-northeast and dips 45° northwest. The pulverized rock is used for chicken grits and a soil dressing. Henry Martin reported "high K_2O and 16 trace elements." The average radioactivity observed by McKeown and Choquette was 0.1 mR/hr (milli-Roentgen per hour) with a range from 0.07 to 0.2 mR/hr (see RP28, Appendix 2). Probable accessory allanite(?) and zircon were reported.

McKeown and Choquette (1968b) also examined the J. F. Rohrbach magnetite-ilmenite prospect about 4 miles (6 km) northeast of Lobachsville, northeast of Pikesville, Berks County. They noted a 300-foot- (90-m-) long by 20- to 40-foot- (6- to 12-m-) wide open cut and a caved and filled shaft from which a few tons of ore had been recently shipped (see RP32, Appendix 2). They quoted Rohrbach as reporting a north-northwest-trending ore body that was 500 feet (150 m) wide and 0.5 mile (0.8 km) long. Rohrbach also reported 25 percent TiO_2 and 1.69 percent CeO_2 in a magnetic concentrate.

On a visit by Kratchman (1968a) on November 5, 1955, Rohrbach reported an assay of 0.13 percent U_3O_8. Kratchman observed an 8-foot by 2-foot by 5-foot (2.4-m by 0.6-m by 1.5-m) zone with an average radioactivity of 0.10 mR/hr and a maximum of 0.40 mR/hr versus a background of 0.05 mR/hr (see RP33, Appendix 2).

On November 5, 1955, Kratchman (1968b) also visited the L. E. Brush, Jr., No. 1 prospect of the Pennsylvania Uranium Corp. (Figure 6, occurrence 4).[7] Kratchman gave the location as "left on dirt road at Earlville Junior High School."[8] Granite intruded by pegmatite was reported to yield an average of 0.04 mR/hr and a maximum of 0.10 mR/hr versus a background of 0.04 mR/hr.

McCauley (1961) described the Rohrbach prospect (McCauley Prospect 43). He noted both radioactive pegmatite pods and bands of titaniferous magnetite conformable with the enclosing gneissic foliation of N40°E, 75°S. McCauley reported an owner-supplied analysis showing up to 0.213 percent U_3O_8, as well as the presence of Th. Weathering is deep, but he observed (1) microcline gneiss; (2) hornblende gneiss; (3) magnetite-ilmenite ore; and (4) quartz-microcline pegmatite containing yellow secondary uranium minerals. His Figure 12 (p. 52) remains the best cross section of the occurrence (see RP32, RP33, and RP62 of the present study).

Smith (1967), in a mineralogic study of the allanite-epidote solid-solution series, analyzed several samples from the Reading Prong. La, Ce, Pr, Nd, Y, Th, and Ca were determined by X-ray fluorescence. The localities are summarized in Table 2 and the analyses in Table 3, both modified from Smith (1967). Compared to published analyses (Frondel, 1964), the allanites from the Reading Prong were reported to be relatively enriched in La and Ce and deficient in Nd.

Aaron (1969) described the petrography of the monazite-bearing Cambrian-age Hardyston Formation of Northampton County in the Nazareth and nearby quadrangles. Monazite in the Hardyston is reported to comprise about 10 to 50 percent of the detrital heavy-mineral fraction in arkose and arkosic sandstone, and trace amounts in orthoquartzite. Of the accessory minerals, it is second in abundance only to magnetite and limonite. Aaron (1969, p. 25) described the monazite as ". . . colorless to pale yellow, angular to subround, subequant to slightly elongate, sand- and silt-sized grains. Subhedral and euhedral detrital grains are not at all uncommon." Based solely on studies of the lowest foot (0.3 m) of the Hardyston, Smith (1974) speculated that Aaron's monazite might be thorite or uranoan thorite. Aaron

[7] Kratchman gave Brush's address at that time as 35 East Sixth Street, Reading, Pa.

[8] The Pennsylvania Uranium Mining Corp. shaft at Shanesville (see RP1) fits Kratchman's description.

Table 2. *Host-Rock Description and Location of Allanite-(Ce) Samples from the Reading Prong and Related Areas*[1]

Sample number	Host-rock description	Location
1	Sheared, hornblende-bearing granite containing 1- to 5-mm allanite-(Ce) grains	Roadcut 2.5 km east of Emmaus, Lehigh County[2]
6	Hornblende-bearing granite containing 1- to 5-mm allanite-(Ce) grains	Boulders 1.7 km northwest of Limeport, Lehigh County (see RP35)[2]
8	Loose, rough crystal (Lafayette College collection)	"J. Weber's, Lower Saucon," Northampton County
10	Magnetite-bearing pegmatite containing 5- to 25-mm grains of allanite-(Ce) (Lafayette College collection)	Roadcut 7.8 km west of the Downingtown interchange, Pa. Turnpike, Chester County
11	Pegmatite containing 5- to 25-mm platy crystals of allanite-(Ce) (Lafayette College collection)	Limecrest quarry near Newton, N.J.
14	Leucogranite containing sparse 0.1- to 1-mm grains of allanite-(Ce) and traces of "xenotime"[3]	Roadcut of Pa. 309 through South Mountain, Lehigh County (see RP46)
15	Pegmatite containing 5- to 25-mm grains of allanite-(Ce) and trace pyrite	Small quarry 1.2 km northeast of Farmington, Lehigh County (see RP20)

[1] From Smith, 1967.
[2] The localities for samples 1 and 6 were furnished by Dr. Allen V. Heyl of the U.S. Geological Survey.
[3] The "xenotime" occurs as grayish-white, strongly zoned ditetragonal prisms with a good prismatic cleavage. The crystals are biaxial positive with 1.93>1.74. An X-ray diffraction powder photograph suggests that the crystals could be a mixture of xenotime and zircon.

Table 3. *X-Ray Fluorescence Analyses, in Weight Percent, of Allanite-(Ce) Samples from the Reading Prong and Related Areas*[1]

Oxide	No. 1	No. 6	No. 8	No. 10	No. 11	No. 14	No. 15
La_2O_3	5.0	7.2	0.4	5.4	6.0	4.2	6.4
Ce_2O_3	10.0	11.4	2.9	12.2	12.0	9.2	11.3
Pr_6O_{11}	1.4	2.1	<0.1	1.6	.6	1.2	2.0
Nd_2O_3	2.8	2.7	1.0	3.3	2.9	2.5	3.1
Y_2O_3	.4	1.0	.3	.1	.1	3.7	.3
ThO_2	1.1	.8	3.6	.1	1.2	4.8	.9
CaO	10.7	8.6	17.6	7.1	10.4	6.9	9.8
Sum	31.4	33.8	25.8	29.8	33.2	32.5	33.8

[1]From Smith, 1967.

(personal communication, 1974) noted that his identifications were by thin section only and that it was conceivable that the monazite might be another mineral species.[9]

Smith (1974) reported that the basal Hardyston Formation conglomeratic sandstone in an abandoned building-stone quarry along River Road (Figure 6, occurrence 12), 1 mile (1.6 km) west of the Hill to Hill Bridge, Bethlehem, was radioactive. This zone is just above the "pinite" layer, a zircon-bearing serpentine-like rock composed of very fine-grained muscovite and quartz. The pinite layer was described by Miller and others (1941, p. 460) and Virgin (1955) as a sheared contact between the base of the Cambrian Hardyston Formation and the top of the Precambrian granitic gneiss.

An approximately 100-pound (45-kg) mass of radioactive float from Camp Mizpah (Figure 6, occurrence 11), Dutch Hill, Allentown East 7.5-minute quadrangle, was reported by Smith (1974) to contain translucent, orange-brown thorite in an apparent fossil placer, which also contained rutile, brookite, and zircon, from the base of the Hardyston Formation. Semiquantitative emission spectrographic analyses of this atypically rich boulder indicated about 1 ppm (part[s] per million) Ag, 500 ppm La, 10 ppm Mo, 100 ppm Nb, 200 ppm Ni, 7 ppm W, 300 ppm Y, 1,000 ppm Zr, and 380 ppm U_3O_8 (A. W. Rose, personal communication, 1973).

W. L. Chenoweth (personal communication to S. I. Root, Pennsylvania Geological Survey, 1975) provided analyses of some samples collected by the senior author. Chenoweth reported that a sample of basal Hardyston Formation from Constitution Drive (Figure 6, occurrence 10), Lehigh County, (40°36'00"N/75°26'19"W) contained 29 ppm U_3O_8, 0.04 percent ThO_2, 0.14 percent P_2O_5; and approximately 300 ppm La, 20 ppm Sn, 1,000 ppm Y, and 2,500 ppm Zr (see RP5). A composite of chips from a chevkinite-bearing Precambrian pegmatite dike, Bethlehem, Lehigh County (40°36'00"N/75°22'27"W) was reported to contain 1 ppm U_3O_8, 20 ppm ThO_2, and approximately 1,000 ppm Ba, 100 ppm Sr, and 200 ppm Zr (see sample RP55, Appendix 2, from the same dike).

Geyer and others (1976, p. 175–181) described an allanite and a thorite occurrence found by Smith (1967) along the south side of Constitution Drive (Figure 6, occurrence 9), about 870 feet (265 m) and 1,200 feet (365 m), respectively, east-northeast of the Allentown-Salisbury Township boundary, Lehigh County. The allanite occurs in a granitic pegmatite with titanite as well as trace bastnaesite and zircon (see RP20 and Smith, 1978b). The thorite occurs in a fossil placer (Figure 6, occurrence 10) at the base of the Hardyston Formation. The lowest foot (0.3 m) of the Hardyston is reported to be a hard, black rock enriched in magnetite, thorite and zircon (see RP5). Two autoradiographs indicate discrete radioactive particles in a relatively non-radioactive matrix.

Grauch and Zarinski (1976) prepared a summary of non-sedimentary uranium occurrences in Pennsylvania, based in part on information provided by the Pennsylvania Geological Survey. An 8-m- (26-ft-) long channel sample through weathered allanite-bearing gneiss across the northeast end of the Rohrbach prospect open pit (see RP33) was collected by R. I. Grauch and the senior author. Grauch and Zarinski reported

[9] Although seldom identified in hand specimen during the present study, monazite was found to be a common detrital mineral in heavy mineral samples panned from Antietam Creek, West Branch Perkiomen Creek, and an unnamed tributary to Cooks Creek in the western, central, and eastern portions of the study area, respectively.

gamma-ray spectrometer analysis of this sample indicating 12.6 ppm U, 85.3 ppm Th, and 4.6 percent K.

Smith (1978a) reported a series of shear zones mineralized with uranium near the headwaters of Monocacy Creek (Figure 6, occurrence 3), 0.6 mile (1 km) west of Oley, Berks County (Figure 7). Somewhat weathered, pegmatitic albite gneiss with intense N50°E±10°-trending shear zones was channel-sampled perpendicular to shearing (Table 4). The 100-foot (30-m) channel sample from the Moxen borrow pit, excluding a 5-foot (1.5-m) covered interval and a 9-foot (2.8-m) barren hornblende-biotite gneiss zone, contained 67 ppm U_3O_8 by fluorimetric analyses. Enrichments in Nb and Y were notable. Radioactivity along the channel site was typically 0.2±0.1 "mR/hr" with the higher readings being associated with more closely spaced shears.

Five traverses with a gamma-ray spectrometer provided evidence for three or more N20°E-N25°E-trending zones enriched in uranium. Continuity of anomalies between traverses was not proven, but the hypothesized linearity suggests subvertical shear zones. Variation of U counts along traverse A–A' is shown in Figure 7. (See also RP36 and RP59 from this area).

Smith (1978b, p. 69–76) presented a detailed summary of his studies on chevkinite (a rare-earth

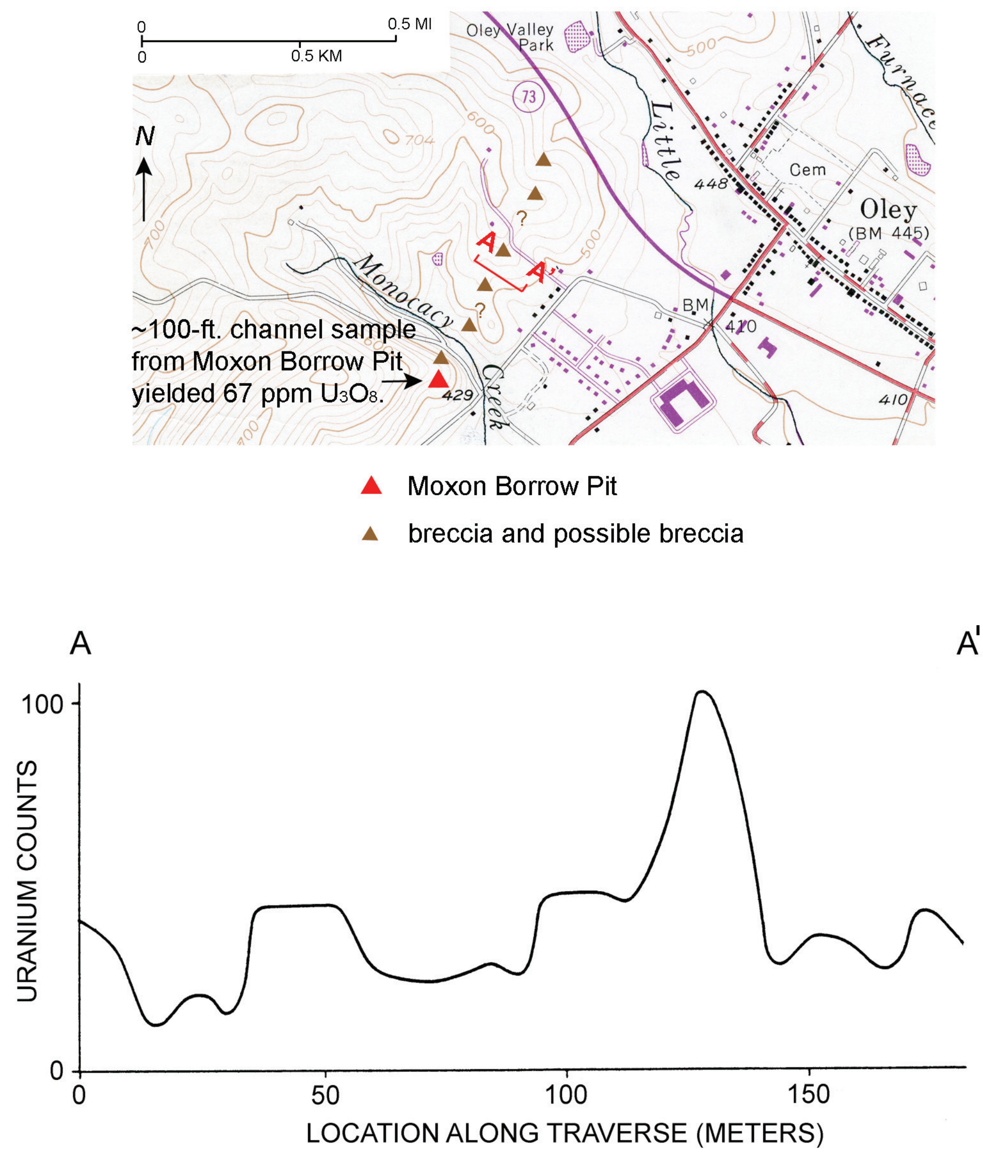


Figure 7. Location map and radiometric traverse of mineralized shear zones near the headwaters of Monocacy Creek, Berks County (modified from Smith, 1978a).

Table 4. *Analyses of Four Samples from the Oley Area, Berks County*[1]

Element or oxide[2]	Sample 1[3]	Sample 2[3]	Sample 3[3]	Sample 4[3]
Fe (percent)	1.5	2	1	10
La (ppm)	70	70	50	500
Nb (ppm)	20	300	200	500
Ti (ppm)	200	700	500	2,000
Y (ppm)	20	70	50	1,000
Zr (ppm)	20	300	<20	200
U_3O_8 (ppm)	67	520	230	1,100

[1] From Smith, 1978a.
[2] Except for the fluorimetric uranium assays, the analyses are semiquantitative via emission spectroscopy.
[3] Sample 1, 100-ft (30-m) channel from Moxon borrow pit collected with the assistance of Pennsylvania Geological Survey geologist Viktoras Skema; sample 2, float from area of highest counts on traverse D; sample 3, grab sample from 3- to 6-ft- (~1- to 2-m-) wide zone in Moyer borrow pit; sample 4, float from stone pile in Moyer field.

iron titanium silicate with minor thorium) from a pegmatite dike south of Bethlehem (see RP55, Appendix 2) in the Reading Prong. The pure chevkinite was found, by a variety of methods, to contain 0.071 percent U_3O_8 and 1.41 percent ThO_2. The remainder of the analysis yielded the following percentages: 18.2 SiO_2, 1.0 Al_2O_3, 5.02 FeO, 7.02 Fe_2O_3, 0.21 MgO, 2.65 CaO, 0.00 K_2O, 0.00 Na_2O, 0.26 MnO, 18.3 TiO_2, 0.05 P_2O_5, 0.32 H_2O^+, 10.9 La_2O_3, 21.5 Ce_2O_3, 2.11 Pr_6O_{11}, 7.08 Nd_2O_3, 0.92 Sm_2O_3, 0.025 Eu_2O_3, 0.9 Gd_2O_3, 0.053 Tb_2O_3, 0.23 Dy_2O_3, 0.02 Ho_2O_3, 0.04 Er_2O_3, 0.025 Tm_2O_3, 0.055 Yb_2O_3, 0.01 Lu_2O_3, 0.778 Y_2O_3, 0.03 Sc_2O_3, 0.0002 Rb, 0.064 SrO, 0.83 Nb_2O_5, 0.075 Ta_2O_5, and 0.071 PbO, totaling 100.227 percent.

Based on the uranium, thorium, and lead contents, the age of the chevkinite was estimated as 916 ± 45 Ma. The chevkinite-bearing pegmatite consists of albite, perthitic microcline, quartz, and hornblende in 2- to 3-cm- (0.8- to 1.1-in-) sized crystals, as well as trace zircon, pyrite, and molybdenite (ratio of polymorphs: 2H1:3R::10:1). The dike cuts hornblende-biotite gneiss.

Smith (1978b, p. 54–56) compiled data on bastnaesite (Ce,La,CO_3F) from two localities in the Reading Prong. At the Constitution Drive locality (40°35'58"N/75°26'22"W), bastnaesite occurs intimately associated with titanite as yellowish-gray to tan masses in a slightly Th-enriched, allanite-bearing granite (see RP20, Appendix 2). At the South Mountain locality (40°36'05"N/75°22'28"W), bastnaesite occurs as a "limonite"-like coating mixed with ilmenite in quartz on chevkinite. The chevkinite occurs in a pegmatite dike (RP55) cutting amphibolite and an iron-sulfide-bearing granodiorite.

Mwakio Tole (1979) and Rose and others (1980, p. A–45), reported uranium analyses of 10 zircon samples provided by the senior author and D. T. Hoff of the State Museum of Pennsylvania. The results are summarized in Table 5.

SKARN- AND GNEISS-HOSTED OCCURRENCES IN THE CHESTNUT HILL AREA

Wells and others (1933) reported the first verified occurrence of thorianite in the United States in serpentine from the Sherrer (C. K. Williams) quarry, Easton, Northampton County. According to G. W. Gehman, zircon and, rarely, molybdenite occur in actual contact with thorianite in places (Wells and others, 1933, p. 49). An average of two analyses of a thorianite concentrate yielded 4.44 percent UO_2, 33.15 percent UO_3, 38.47 percent ThO_2, 5.21 percent PbO, and 2.49 percent rare earths. Based on their preferred analyses for U, Th, and Pb, they estimated an age of 810 Ma.

Wells and others (1933) also reported lemon-yellow coatings of radial groups of flattened, blade-like crystals of carnotite in fractures in serpentine. They described the carnotite as biaxial negative, 2V equal to approximately 50°, $\alpha = 1.75$, $\beta = 1.92$, and $\gamma = 1.96 \pm 0.001$. They reported the presence of vanadium based on a momentary blood-red color when concentrated HCl was applied. Probable autunite was reported, based on a chemical test for phosphate. This test, however, might have had interference from arsenate.

Miller and others (1939, p. 435–463) noted new information on the following: (1) molybdenite (an ac-

Table 5. *Analyses of Zircon Separates from the Reading Prong and Other Areas in Pennsylvania and New Jersey*[1]

(Error range equals one standard deviation.)

Sample	Host	Location	Uranium, ppm (fission track)	Uranium, ppm (delayed neutron activation)
Zr11	Rare earth pegmatite with Th and U	Charlotte Mine, Cranberry Lake, N.J.	2,401±45	2,468±104
Zr12	Chevkinite-bearing pegmatite	Bethlehem Pegmatite, Northampton County, RP55[2]	834±27	388±29
Zr13	Phlogopitic serpentine	C. K. Williams quarry, Northampton County, RP39	4,893±170	—
Zr14	"Pinite" (muscovite) between base of Hardyston and Precambrian rock	Lehigh River Pumping Station, Bethlehem	325±23 551±31	—
Zr15	Serpentinite in State Line District	Rock Springs Church, Fulton Twp., Lancaster County	105±9	—
Zr16	Phlogopitic serpentine	Quarry L, Northampton County, RP60	2,747±48	3,045±206
Zr17	Magnetite	Pricetown, Berks County	419±13	—
Zr20	Pegmatitic soda gneiss of Losee(?) Fm.	South side of I-78, east side of Jugtown Mountain, near Bloomsburg, N.J.	165	—
Zr21	Allanite-magnetite-hornblende in Honeybrook Upland	North side of Pa. Turnpike, 4.7 mi. west of Downingtown Interchange, Chester County	350	—
Zr23	Apatite-bearing pegmatite in amphibolitic-facies basement	Bottom of General Crushed Stone Co., Glen Mills quarry, Delaware County	3,100	—

[1] From Tole, 1979.
[2] The bulk dike, RP55, contains 70 ppm Zr and 0.5 ppm U based on the present study. The pure chevkinite contains 0.071 percent U_3O_8.

cessory mineral at many uranium occurrences in the Reading Prong) in Byram gneiss float about 1-1/2 miles (2.4 km) east of Hellertown, as well as on Chestnut Hill; (2) uranophane as the yellow encrustations on serpentine from the C. K. Williams quarry; (3) "autunite" from the C. K. Williams quarry; and (4) thorianite from the C. K. Williams quarry, another quarry along Bushkill Creek (Schweyer's[?]), and the excavation for the Chestnut Hill reservoir. Miller and others credited the discoveries of 2, 3, and 4 to George W. Gehman.

Stewart (1951) revisited the Chestnut Hill localities examined by F. A. McKeown and H. A. Arndt in 1948 (unpublished[?]). An outcrop about 145 feet (45 m) south of the C. K. Williams quarry was reported to have an area of 25 by 100 feet (8 by 30 m) with a field equivalent uranium content of 0.02 to 0.05 percent. A sample of quartz and lime silicate minerals from this area yielded 0.09 percent uranium and 0.30 percent thorium.[10]

The roadcut of former Pa. Route 115 (Knox Avenue) on Chestnut Hill (Figure 6, occurrence 15; Figure 8) exposed weathered granite that yielded McKeown and Klemic (1953) 0.009 and 0.012 percent equivalent uranium in the laboratory and 0.004 and 0.008 percent U by chemical analyses (see sample RP41, Appendix 2, collected in this area). McKeown and Klemic also conducted a reconnaissance for uranium and thorium minerals in the Chestnut Hill area, Northampton County, and the Marble

[10] Coarse-grained thorite was noted during the present study in the sheared zone on the south rim of the quarry. See also RP4 from the landslide area of the quarry.

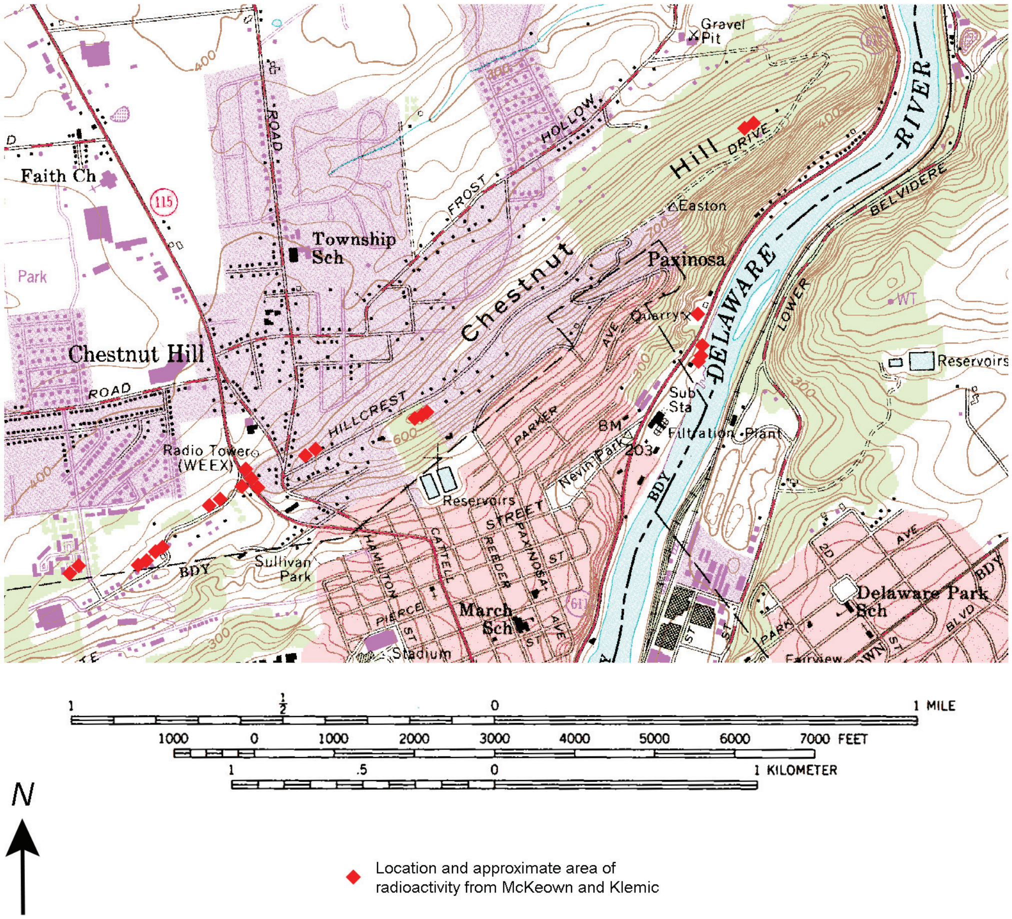


Figure 8. Location map showing previously known radioactive anomalies in the Chestnut Hill area of the Reading Prong, Northampton County (modified from McKeown and Klemic, 1953).

Mountain continuation to the northeast in New Jersey. They reported discontinuous anomalies slightly above 0.04 mR/hr for 1.5 miles (2.4 km) along the crest of Chestnut Hill southwestward from the C. K. Williams quarry (Figure 8). They also noted an anomaly along former Pa. Route 115 (Knox Avenue) (see RP41, Appendix 2) where pegmatite has injected the gneiss-marble contact. Thorite associated with specular hematite in pegmatite was noted from the southern part of the C. K. Williams quarry. They quoted Professor C. K. Cabeen of Lafayette College as saying that uranium and thorium mineral specimens were collected from the north face of the C. K. Williams quarry. A phlogopitic zone along the west face of the quarry was also reported to be radioactive (see RP39, Appendix 2).

Pegmatite from 4,000 feet (1,200 m) southwest of former Pa. Route 115 (Knox Avenue) on Chestnut Hill yielded 0.004 percent equivalent uranium; pegmatite from 340 feet (100 m) north of a burned-down hotel on Chestnut Hill yielded 0.015 percent; and pegmatite from Saint Anthonys Nose, 1 mile (1.6 km) north of Easton yielded 0.03 percent equivalent uranium (McKeown and Klemic, 1953). Samples from the Durham Furnace magnetite mines, to the south of Easton, were reported to be even leaner.

Montgomery (1957) described three occurrences of highly thorian uraninite near Easton, Northampton County. Each occurred in serpentinized dolomitic limestones which were, at that time, lumped together as the Franklin Formation. Uraninite from the C. K. Williams quarry (Figure 6, occurrence 17) typically occurs in grayish-green serpentine with grayish patches of fibrous tremolite pseudomorphic after coarsely prismatic diopside (Montgomery, 1957, p. 810). Montgomery noted that G. W. Gehman found most of the uraninite and zircon in a narrow shootlike zone near the north end of the quarry. The zircon occurred as euhedral, dark-brown to creamy-gray crystals, some larger than 1 cm (0.4 in.). The uraninite grains tended to be rounded, and the majority were partly altered to early wölsendorfite and thorogummite and later boltwoodite, uranophane, and various carnotite-like and autunite-group unidentified minerals.

Uraninite from the Royal Green Marble quarry, about 2 miles (3.2 km) north of Phillipsburg, N.J., occurs as jet-black (submetallic) grains with small pyrite cubes and coarse molybdenite scales in apple-green serpentine (Montgomery, 1957). The larger uraninite grains have a cubic or a cuboctahedral habit. Zircon, sphalerite and galena occur in minor amounts. E. S. Larson, Jr., of Harvard University, reported an approximate date of 850 Ma to Montgomery (1957) for this zircon.

Uraninite from the College Hill reservoir site (Figure 6, occurrence 16), Chestnut Hill, occurs in coarsely prismatic tremolite that has been partly altered to serpentine and talc, and in a similarly altered phlogopitic dolomite (Montgomery, 1957). The uraninite occurs as 0.2- to 1-cm (0.1- to 0.4-in.) cubes and cuboctahedrons.

Montgomery (1957, p. 817) reported that X-ray fluorescence analyses of highly thorian uraninite from the Easton area yielded U:Th ratios of 86:14, 76:24, 72:28, and 71:29 for the C. K. Williams quarry; 66:34 for the Royal Green Marble quarry; and 59:41 and 57:43 for the College Hill reservoir site.

Based on a detailed paragenetic study, Montgomery (1957, Table 1) concluded that the Th-, U-, and Zr-bearing minerals for all occurrences were derived from a granite-pegmatite magma through (1) contact metamorphism; (2) deformation and rare-element-bearing hydrothermal solutions from the crystallizing magma; and (3) extensive serpentinization.

Montgomery (1969) noted that both highly uranoan thorianite and highly thorian uraninite occur in the serpentine near Easton. In addition to mineralogic descriptions of thorianite, wölsendorfite, boltwoodite, thorogummite, betauranophane, weeksite, molybdenite, and zircon from these localities, Montgomery also reported the optical identification of allanite as small black grains in a microcline-rich pegmatite just south of the C. K. Williams quarry, and thorite from the northernmost part of the quarry. The thorite occurred as resinous brownish-black grains in coarsely prismatic, pale-green diopside-tremolite rock.

Smith (1975a) described a fourth uranium-thorium occurrence in contact-metamorphic serpentine in the Easton area. This occurrence is in an abandoned serpentine-talc quarry, Quarry L (Figure 6, occurrence 14), on the west side of Bushkill Gap through Chestnut Hill (40°42"00"N/75°13'59"W). Compositional bedding trends N85°E, 42°S, with the uranium-rich beds being phlogopitic. A 36-inch (1-m) channel sample of a phlogopitic bed yielded 0.1 percent U_3O_8 in a commercial assay.[11] This radioactive zone continues for at least 15 feet (4.6 m) along the quarry face, and for at least an additional 12 inches (30 cm) into the quarry floor. Serpentine, phlogopite, tremolite, talc, thorian uraninite, thorogummite, and traces of zircon, chalcopyrite, galena, and pyrite have been identified. Smith (1977, p. 11–16) described three sites that have trace sphalerite and galena on Chestnut Hill, Easton: the C. K. Williams quarry, Quarry L, and Schweyer's quarry. Each is in phlogopitic and tremolitic serpentine. Detailed locations and mineral lists are given for each. Quarry L was estimated to contain up to 1,000 kg (2,200 lb) each of U and Th. A 3-foot- (1-m-) long channel sample was reported by the former U.S. Energy Research and Development Administration (ERDA) to contain 0.1 percent U_3O_8 or 0.085 percent U, and a 48-inch (1.2-m) sample collected with R. I. Grauch contained 0.05 percent eU, 0.039 percent eTh, and 1.9 percent K (analyzed by the USGS). The quarry was sketched in Figure 1 of Smith (1977).

Smith (1977) also observed (1) brick-red thorite(?) in a small pit about 775 feet (235 m) east of the east end of the road in Hackett Park at the west end and just south of the crest of Chestnut Hill; (2) felsic gneiss with a 0.07 "mR/hr" background just west of where a power line crosses the same hill (see RP42); and (3) a small abandoned quarry in talc schist about 75 feet (23 m) east of the power line, close to the plant of Pfizer Inc., on the southwest side of Bushkill Gap, with up to 0.15 "mR/hr."[12]

Smith (1978b, p. 174–178) compiled data on metanovacekite, a magnesium uranyl arsenate hydrate found at the C. K. Williams quarry, from his own observations as well as those of G. A. Desborough, A. V. Heyl, W. Sharp, B. E. Smith, and R. Wilcox of the USGS and A. Montgomery of Lafayette College. This is probably the mineral listed as autunite by

[11] A split of this sample, collected by R. C. Smith, II, on October 3, 1974, was reanalyzed by the USGS as sample RP60 during the present study. This analysis, by delayed neutron activation, indicated 247 ppm U and 228 ppm Th. Another split of this sample, shipped to the former Energy Research and Development Administration (ERDA), now the U.S. Department of Energy, on August 6, 1975, yielded 360 ppm U_3O_8 (305 ppm U), 31 ppm As, and 400 ppm Zn (W. L. Chenoweth, personal communication, February 11, 1976).

[12] During the present study, normal background in the Reading Prong was found to be 0.02 ± 0.01 "mR/hr." Note that the Geiger counter was used in this study with the beta shield open, thereby yielding readings that are not truly milliroentgens per hour, hence the use of quotations marks around "mR/hr."

some of the earlier mineralogists. The metanovacekite was reported to have occurred in a sheared and slickensided pale-green serpentine with very abundant phlogopite flakes, calcite, fibrous tremolite, and talc in the northern half of the quarry, away from other known occurrences of uranium and thorium minerals.

Grauch and Ludwig (1979) provided additional analyses and an age estimate of uranium-thorium mineralization in serpentinized dolomitic marble at Quarry L. They reported that a nearly 4-foot (1.2-m, erroneously reported as "3.5-m") sample collected by R. C. Smith, II, and R. I. Grauch contained 503 ppm eU, 390 ppm eTh, and 1.5 percent K.[13] Grauch and Ludwig noted that Grauch and Smith collected cubic uraninite crystals having small octahedral faces from the sampled layer. One such crystal yielded Grauch and Ludwig a unit cell of 5.527Å, suggesting thorium or some other element in partial substitution for uranium.

Grauch and Ludwig reaffirmed a strong stratigraphic (compositional) control on the distribution of uraninite in this quarry and suggested the possibility of a synsedimentary origin.

A split of the channel sample collected by Grauch and Smith (sample 675–72, a split of sample RP57, Appendix 2) yielded a $^{207}Pb/^{206}Pb$ age of 948 ± 5 Ma. Grauch and Ludwig (1979, p. 16) noted that "the near concordance of the U-Pb age estimates suggests that there has been no intense thermal event at Quarry L since about 948 million years ago." Their complete analyses yielded 1,050 ppm U and 547 ppm Th with U/Th$=$1.9. Their $^{206}Pb/^{238}U$ ratio yielded an age estimate of 920 ± 10 Ma and their $^{207}Pb/^{235}U$ yielded 928 ± 10 Ma. However, their $^{207}Pb/^{206}Pb$ derived estimate of 948 ± 5 Ma for Quarry L is a preferred date for uranium mineralization in the Reading Prong of Pennsylvania.

PHASE I: CARBORNE SCINTILLOMETER GAMMA-RAY ANOMALY SURVEY

METHODS

The principal means of reconnaissance for uranium and thorium in the Reading Prong was by a carborne gamma-ray survey.[14] The method employed was to traverse all accessible roads, public and private, that cross the crystalline terrane, as shown by Gray and others (1960). Traverses were driven at a constant speed of either 20 miles per hour (32 km/h) or 10 miles per hour (16 km/h), depending on the condition of the road. The weather and approximate soil moisture were recorded each day.[15] The distance of each traverse, estimated to the nearest 0.01 mile, was recorded using the odometer of the vehicle. Prominent landmarks, such as road intersections, were chosen as the beginning and end points of each traverse. The direction of travel was noted. For some prominent anomalies, the traverse was repeated in the opposite direction on the opposite side of the road, or at 10 miles per hour (16 km/h), to improve resolution. Notations were also made to indicate the pavement type, road name, county, municipality, and quadrangle map (Figure 9).

The equipment used for this survey consisted of a Mount Sopris Model SC–132A Portable Scintillation Counter containing a 1.5- x 1.5-inch (38- x 38-mm), NaI crystal (Figure 10). The scintillometer was connected to a portable chart recorder that produced a continuous record of gamma-radiation levels as the vehicle was driven along a traverse. Although not a part of the data-recording procedure, an auxiliary meter, visible to the driver and equipped with an audible alarm adjustable for various threshold levels, was used for general reconnaissance. The equipment was mounted in a Jeep CJ–5 four-wheel-drive vehicle, with the scintillation counter resting in a cardboard box on the floor behind the right front seat, 28.5 inches (74 cm) above the road surface. Maintaining this configuration kept day-to-day variations caused by shielding effects of the vehicle to a minimum and provided a stable, secure location for the scintillometer. Vehicle shielding reduced the count rate by close to 50 percent.

In addition to the authors, traverses were run by four other staff members of the Pennsylvania Geological Survey. Thirty-six days, spread over 14 months,

[13] A split of this sample, collected by Grauch and Smith on May 22, 1975, was reanalyzed by the USGS as RP57 during the present study by delayed neutron activation analyses and found to contain 1,130 ppm U and ≤250 ppm Th.

[14] Potassium-40 atoms, as well as uranium and thorium progeny, emit gamma rays. However, potassium emits only a relatively small amount of the radiation in the Reading Prong, and the anticipated range in K_2O in a granitic gneiss terrane is only from about 2 to 8 percent. U and Th range from a few ppm in normal rocks up to thousands of ppm in rocks enriched in those elements.

[15] Ward (1981, p. 844–845) presented a summary of meteorological effects on gamma-ray surveys. In general, excess soil moisture attenuates gamma radiation. In this study, meteorological effects were minimized by not collecting data within a day after heavy rains or over potentially frozen ground.

Pennsylvania Geological Survey

RADIOMETRIC ROAD LOG

Mt. Sopris SC-132 Carborne Scintillometer

Date: 6/18/79 *Time:* 10:05

Weather: Hazy, temp ~25°C

Soil Moisture: Moderate

County: Berks

Township: Alsace

7-1/2' Quadrangle: Fleetwood

Traverse No.: 1-2 *Direction:* SE

Road Name: Mexico Road

Pavement: *Macadam* X *Concrete*___ *Gravel*___

Other:

Starting Point: Antietam Road

Ending Point: Basket Road

Speed (mph): 20

Odometer at start: 54,784.95 *miles*

Odometer at end: 786.30 *miles*

Comments:

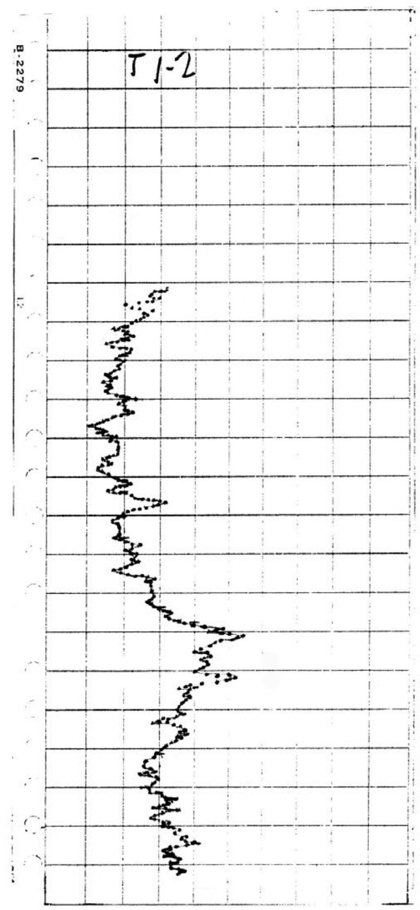


Figure 9. Example of road log for radiometric survey (left), and typical gamma-radiation strip chart (right).

Figure 10. Photograph of the Mount Sopris Model SC–132A scintillation counter and chart recorder.

were spent driving 990 traverses for a total of 869 miles (1,398 km). The procedure was begun on March 14, 1979, the one-hundredth anniversary of the birth of Albert Einstein.

Each traverse produced a strip chart, such as that reproduced in Figure 9, indicating the gamma-radiation level recorded along the course of the traverse. Wherever possible, the charts were prepared using a full-scale setting of 200 counts/sec, a 1-second time constant, and a chart speed of approximately 1 inch (2.5 cm) per minute. The data were transferred to 7.5-minute topographic maps (Figure 11), and the count rates were classified into five major categories, using a break at every 20 counts/sec from 40 counts/sec to 100 counts/sec for convenience. This range covered most count rates encountered in the project area.

As a test of the procedure, three traverses were selected for replication to test precision. At least one of the three was run each day. The three were T1–2, Mexico Road from Antietam Road to Basket Road, Alsace Twp., Berks County (see samples RP9 and RP63); T396–395, Mine Road from the road at Pine Waters to Long Lane, Pike Twp., Berks County (see RP32 and RP33); and T588–589, Constitution Drive from the intersection with an unnamed dead-end road adjacent to the railroad tracks in the city of Allentown to River Road, Salisbury Twp., Lehigh County (see RP5 and RP20). Anomalies appeared to be reproducible from one day to another, suggesting that statistical and meteorological effects were acceptably small.

ANOMALY LOCATIONS

The significant anomalies are summarized in Appendix 1 and shown on Plate 1. On Plate 1, the anomalies are divided into three groups, those with count rates between 60 and 80 counts/sec in vehicle (slight anomaly), those between 80 and 100 counts/sec (moderate anomaly), and those with count rates greater than 100 counts/sec (strong anomaly). Count rates below 60 counts/sec were considered to be background, with 40 counts/sec being a "typical" background reading. It should be noted that readings can be affected by roadside geometry. An incline upward to the side of the road can increase the count rate; a downward slope can reduce the count rate. Appendix 1 lists the latitude and longitude of each anomaly with a count rate of greater than 80 counts/sec, and those greater than 100 counts/sec are designated with an asterisk. The traverse distance over which the anomaly was detected is also indicated. The anomalies greater than or equal to 80 counts/sec had a total length of 24 miles (38 km), or 2.7 percent of the total distance traversed. Of that length, 14 miles (22 km), or 1.5 percent, had in-vehicle count rates between 80 and 100 counts/sec, and 10 miles (15 km), or 1.2 per-

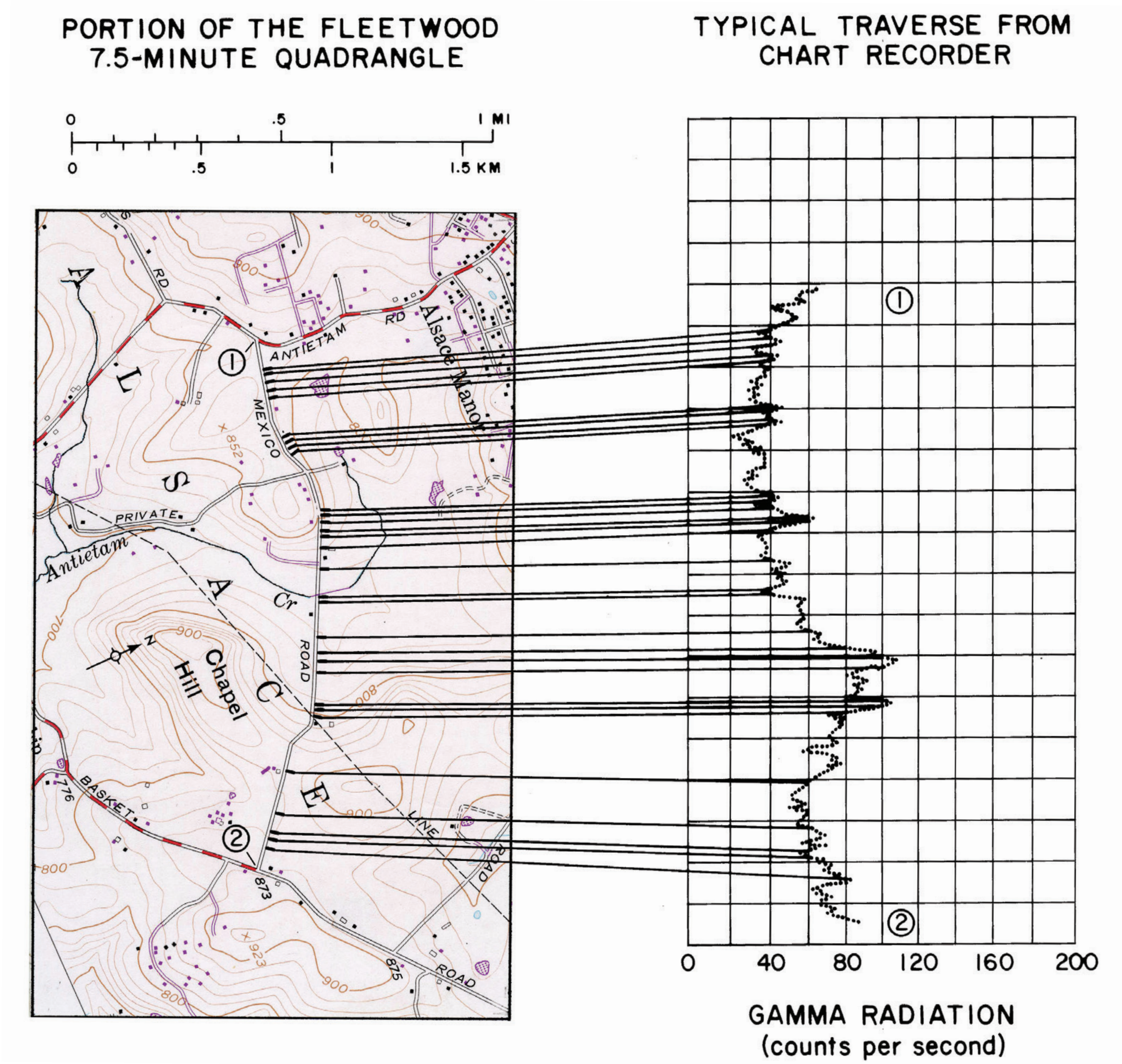


Figure 11. Illustration showing the results of transferring chart recorder data to 7.5-minute quadrangle maps.

cent, had count rates exceeding 100 counts/sec. It is likely that similar proportions of the Reading Prong would yield a moderate to high gamma flux.

EFFICACY OF METHOD

Because of the high level of absorption of gamma rays in the energy range of interest by 0.6 to 1.5 feet (0.2 to 0.45 m) of rock (Ward, 1981) and the steel shell of the vehicle, the survey at first may appear to have only detected near-surface (<1.5 ft or 0.5 m) occurrences of U, Th, and their decay products. However, due to the extreme mobility of radon-222 (ancestor of the intense gamma emitter bismuth-214, the principal indicator of uranium) and other isotopes in the decay series, it may be possible to indirectly detect uranium at depths more than an order of magnitude greater than would be predicted by the absorption of gamma rays emitted from the original locus of mineralization. Thus, under favorable circumstances, the survey might be able to detect uranium occurrences down to the water table, typically at depths on the order of 50 feet (15 m) in the Reading Prong. The mobility of the uranyl ion (UO_2^{2+}) and immobility of Th (in resistant zircon, etc.), as well as other geochemical effects (Rose and others, 1979), have probably significantly increased the effectiveness of carborne gamma traverses. Detection of several anomalies also appears to have resulted from radioactive boulder trains being transected by a hill-circling road network at the break in slope. Transported boulders concentrated on the upslope side of the road by natural and artificial means have, in some cases, led to the discovery of radioactive outcrops much farther uphill.

PHASE II: ANOMALY ROCK SAMPLING AND ANALYSES

The goal of the rock-sampling program was to obtain, for analysis, representative samples of the enriched rocks associated with the stronger gamma-ray anomalies and the previously known occurrences. This was done in order to classify, evaluate, and interpret the occurrences. A minimum radioactivity threshold for sampling was established that eliminated essentially all of the rocks that are not mineralized in U and Th and that comprise more than 90 percent of the portion of the Reading Prong that is exposed at the surface.

SITE SELECTION AND LOCATION

Approximately 75 of the gamma-ray anomalies detected by the carborne survey were selected for field study. Thirty six of these gamma-ray anomaly sites that registered greater than 80 counts/sec in the vehicle were chosen in the field for rock sampling as described below. Most of the approximately 40 rejected sites failed to meet the established general guideline of 10 boulder-sized rocks having a radioactivity on contact of greater than or equal to 0.07 "mR/hr."[16] This empirical sampling cutoff constitutes the difference between what is referred to herein as an "anomaly" and an "occurrence."[17] A few anomalous sites were rejected, in part, because of culture and accessibility; for example, some were entirely in lawn. Such sites were given only a cursory examination by walking along the edge of the road with a scintillometer and examining a few pieces of float. In addition to the 36 sampled sites that were discovered during the carborne survey (indicated in Appendix 2), 19 samples were collected from previously known uranium/thorium occurrences and five from other known Fe, As, Mo, and Ti metallic occurrences. (Several of the previously known sites were "rediscovered" by the carborne gamma-ray survey but are not included in the 36-sample new-site total.) Four follow-up rock samples (RP62 to RP65), collected during the detailed studies of selected sites (see Phase III), are included here because they were similarly sampled and analyzed.

The 64 rock-sampling sites are summarized in Appendix 2 and shown on Plate 1. Reference to Appendix 2 throughout the following discussion will aid the reader. This appendix lists all samples in numerical order, giving the sample name, location, type, field description of rock type and degree of weathering, size, radioactivity, and amount of uranium for each sample. Throughout the text, "RP" numbers will be used to denote both samples and the localities from which those samples were collected.

SAMPLING METHODS

Because the typical anomaly appeared to be derived from a boulder train on a wooded slope, most samples consisted of a composite of float boulders. Having established the approximate area of anomalous rock with a scintillometer, at least the first ten boulders encountered across the anomaly with a radioactivity of greater than 0.07 "mR/hr" with a Geiger counter, or greater than 200 counts/sec with a scintillometer, were selected. The average radioactivity of each boulder was measured, and each of the ten boulders was broken with a sledgehammer to obtain about 300 g (10 oz) from the boulder core to be combined into a composite sample. Most such composite samples weighed 3 ± 0.5 kg (6.5 ± 1 lb) (Appendix 2). A few exceptions were made so as to include samples of leaner rocks that contained visible allanite-(Ce) or highly enriched rocks where only two large boulders were observed (RP23). At RP14, thirty-five boulders were broken and composited because of the unusually coarse grain size of the pegmatite.

For 23 samples collected from outcrop (RP2, 3, 5, 10, 15, 16, 25, 28, 37, 38, 39, 43, 44, 47, 50, 53, 55, 57, 59, 60, 61, 63, and 65), channel samples were cut perpendicular to the apparent trend of mineralization. These samples consisted of a continuous series of approximately similar-sized chips or chunks, together with all the crumbs that could be caught,

[16] Data were recorded with the probe window open on the Geiger Muller tube.

[17] The 36 anomalies that generally met this criterion were sampled and later found to have a median U content of 68 ppm, a mean of 140 ppm, and a standard deviation of 248 ppm.

obtained after removing and discarding the outer centimeter or two of weathered and potentially leached rock. Channel lengths ranged from 20 cm to 20 m, with the median being 0.8 m (Appendix 2). They tended to weigh a few kilograms more than the float-boulder composite samples.

At six anomalies and occurrences where neither float boulders nor outcrops are present (RP1, 7, 13, 32 [crushed "ore" pile], 41, and 45), a channel sample was cut across the apparent trend of radioactivity in the stony and sandy C–zone subsoil. (As shown later, weathering has apparently removed plagioclase [Na_2O+CaO] relative to potassium feldspar [K_2O] and, therefore, probably much of the uranium. These samples are not included in the classification of the fresh samples.) The median channel length in stony soil was 3.3 m.

SAMPLE PREPARATION

The 65 samples, typically weighing 3 ± 0.5 kg each, were crushed to <1 cm by means of two passes through a jaw crusher. After homogenization by rolling, one 2-kg split was shipped to the USGS for further grain-size reduction and trace-element analyses, and one 500-g split was pulverized to about -100 mesh with a ceramic plate grinder for further preparation and analyses by the Pennsylvania Geological Survey as described below.

From the 500-g split, four splits of 4 to 6 g each were prepared for in-house analyses, and the remaining approximately 480 g of approximately -100 mesh material was held in reserve. The one 4- to 6-g split actually used for analysis was hand-ground in an agate mortar and pestle to 100 percent passing a 100-mesh nylon sieve. Because preliminary X-ray diffractometer scans indicated that this size was still too coarse for reproducible semiquantitative results, each sample was further hand-ground in an agate mortar and pestle for an additional 15 to 20 minutes, yielding a fraction largely passing 200 mesh. Semiquantitative X-ray diffractometer estimates of the mineralogy and quantitative atomic absorption determinations of major, minor, and selected trace elements were performed on this reground material, as described in Appendix 3.

TRACE-ELEMENT ANALYSES AND GEOCHEMISTRY

Trace-element analyses of the rock samples were obtained to determine which anomalies resulted from a significant amount of uranium and to focus attention on low-thorium occurrences. They were also used to identify associated-element enrichments that might be useful as an aid in locating uranium enrichments, in interpreting their genesis, or that might have inherent economic value themselves.

Elements and Methods

Quantitative uranium and thorium analyses were provided by the USGS Branch of Analytical Laboratories, Lakewood, Colo. Both were determined by a delayed neutron activation analysis procedure (Millard and Keaten, 1982). An apparent interference to the thorium determination from uranium prevented an accurate estimation of thorium in samples with a high U/Th ratio. This interference is not a serious drawback to the present study, even though it focused on occurrences having a high U/Th ratio. In most samples in which this interference occurred, the net result was a reported Th content of less than 20 percent of the U content. Large (10-g) samples of powdered rock were irradiated to reduce sampling errors. Potential neutron moderation by carbon in the skarn samples was not considered. Data for U, Th, and other trace elements are reported in Table 6.

Quantitative flame-emission analyses for Ba, Rb, and Sr were performed by the authors on samples fused in lithium metaborate and dissolved in dilute nitric acid, as described in Appendix 3. The data are included in Table 7.

Semiquantitative trace-element analyses for B, Ba, Be, Co, Cr, Cu, Ga, Mo, Nb, Ni, Pb, Sc, Sn, Sr, V, Y, Zr (Table 8), and the lanthanides La, Ce, Pr, Nd, Sm, Eu, Gd, Dy, Ho, Yb, and Lu (Table 9), were provided by the USGS. N. M. Conklin analyzed RP1 through RP60 via a semiquantitative 6-step emission spectrographic procedure that yields results as the midpoints of a geometric series (Myers and others, 1961). For typical elements, this method produces a semiquantitative estimate that is within plus or minus one step (1/3 order of magnitude) of a quantitative emission spectrographic estimate 68 percent of the time, and within plus or minus two steps 95 percent of the time.

Semiquantitative data for a similar suite of trace elements in RP61 through RP65 were obtained by P. Briggs of the USGS using an inductively coupled plasma (ICP) spectroscopic determination of HF–aqua regia–$HClO_4$ digestions (Tables 8 and 9). Because the acid digestion probably did not attack refractory minerals such as zircon, no data are available for Zr. Additionally, reported values for such elements as Y and lanthanides, which are typically enriched in zircon, are probably significantly low. Data are listed as if quantitative but, based on follow-up analyses, they

Table 6. *Quantitative Analyses for U and Th, With Other Criteria for Evaluating the Significance of Occurrences Examined in Phase II*[1]

Sample	Type	Name	Mo (ppm)[2]	U (ppm)	Th (ppm)[3]	U/Th	U/Th >2	U>200 ppm
RP1	Soil	Pennsylvania Uranium Mining Corp. dumps	N	541.0	16,900	0.032	—	—
RP2	Mo-bearing quartz monzonite	Antietam reservoir	10	30.8	83	.371	—	—
RP3	"Byram" granitic rock	Pa. Route 611 roadcut	N	18.1	178	.102	—	—
RP4	B-bearing alaskitic quartz monzonite	C. K. Williams quarry	N	55.4	1,740	.032	—	—
RP5	Hardyston Formation basal conglomerate	Constitution Dr.	N	30.5	243	.126	—	—
RP6	Mo-bearing quartz monzonite	Limeport Rd. anomaly	7	1,120.0	230	4.870	*	*
RP7	Soil	Shenkel Hill Rd. anomaly	N	62.3	374	.167	—	—
RP8	Allanite-bearing pegmatite	Water St. anomaly	N	13.5	528	.026	—	—
RP9	"Byram" granitic rock	Mexico Rd. anomaly	N	63.5	125	.508	—	—
RP10	Mo-bearing quartz monzonite	Red feldspar layer anomaly	30	231.0	67	3.448	*	*
RP11	"Byram" granitic rock	Oley Rd. anomaly	N	160.0	27	5.926	*	—
RP12	do.	M. Moore property	N	30.7	73	.419	—	—
RP13	Weathered	Hartman Rd. anomaly	N	18.3	239	.077	—	—
RP14	Allanite-bearing pegmatite	Dogwood Lane anomaly	N	34.6	986	.035	—	—
RP15	B-bearing alaskitic quartz monzonite	Bushkill Dr. anomaly	N	69.6	138	.504	—	—
RP16	"Byram" granitic rock	Forgedale Route anomaly	N	130.0	331	.393	—	—
RP17	do.	Hay Rd. anomaly	N	81.0	123	.659	—	—
RP18	do.	Cherry St. west	N	17.5	111	.158	—	—
RP19	do.	Harlem anomaly	N	26.2	63	.417	—	—
RP20	do.	Constitution Dr. U allanite quarry	N	2.9	161	.018	—	—
RP21	B-bearing alaskitic quartz monzonite	Easton upper reservoir N bank	N	166.0	30	5.533	*	—
RP22	do.	Hillside Ave. anomaly	N	125.0	247	.506	—	—
RP23	Mo-bearing quartz monzonite	Heller's 2 boulders	70	960.0	240	4.000	*	*
RP24	"Byram" granitic rock[4]	Coutumas tract	N	91.7	169	.543	—	—
RP25	"Byram" granitic rock	Reichard tract	N	3.5	31	.112	—	—
RP26	do.	Bonaskiewich's rock	N	21.8	45	.483	—	—
RP27	"Byram" granitic rock[4]	Leister stone fence	N	45.0	291	.155	—	—
RP28	"Byram" granitic rock	Hock-Frederick granite quarry	N	7.1	21	4.624	*	—
RP29	"Byram" granitic rock[4]	Martin's Lane anomaly	N	127.0	427	.297	—	—
RP30	"Byram" granitic rock	Mountain Rd. anomaly	N	121.0	181	.669	—	—
RP31	Mo-bearing granodiorite[5]	Jobst magnetite mine	150	58.3	12	4.858	*	—
RP32	Fe-Ti ore	Rohrbach prospect crushed Fe-Ti ore	N	8.6	17	.509	—	—
RP33	Mo-bearing granodiorite	Rohrbach prospect U ore boulders	15	1,210.0	220	5.500	*	*
RP34	Hardyston Formation basal conglomerate	South Mountain Park	N	65.4	2,130	.031	—	—
RP35	"Byram" granitic rock	Larue Diehl Ranch	N	8.5	89	.095	—	—
RP36	do.	S. Deturk borrow pit trail	N	85.2	166	.513	—	—
RP37	Mo-bearing quartz monzonite	SW crest Chapel Hill	N	271.0	63	4.302	*	*
RP38	Skarn[6]	Ledge N Schweyer's quarry	N	24.9	243	.102	—	—
RP39	Skarn	Northern C. K. Williams quarry	30	1,080.0	200	5.400	*	*

Table 6. *(Continued)*

Sample	Type	Name	Mo (ppm)[2]	U (ppm)	Th (ppm)[3]	U/Th	U/Th >2	U>200 ppm
RP40	"Byram" granitic rock	Boone Club open pit	N	30.3	286	0.106	—	—
RP41	Soil	Knox Ave. anomaly	N	216.0	239	.904	—	*
RP42	B-bearing alaskitic quartz monzonite	Hackett Park ridge NE	N	6.6	152	.043	—	—
RP43	do.	E Lafayette St. talc quarry	N	30.2	269	.112	—	—
RP44	Skarn	W Lafayette St. talc quarry	N	63.0	81	.774	—	—
RP45	Soil	Pa. Route 309 saprolite gulley	N	16.1	56	.290	—	—
RP46	"Byram" granitic rock	Pa. Route 309 parent gneiss	N	22.0	36	.608	—	—
RP47	Hardyston Formation basal conglomerate	Pa. Route 309 basal Hardyston Fm.	N	23.0	323	.071	—	—
RP48	Mo-bearing quartz monzonite	Sunrise Lane anomaly	L	90.5	155	.584	—	—
RP49	Mo-bearing granodiorite	Vera Cruz granite quarry	N	29.2	400	.073	—	—
RP50	Allanite-bearing pegmatite	NE Ext. Pa. Turnpike pegmatitic zone	L	99.1	952	.104	—	—
RP51	"Byram" granitic rock	Bella Vista orchard ledges	N	11.7	132	.089	—	—
RP52	do.	Swoveberg Hill	N	85.1	16	5.319	*	—
RP53	Mo-bearing granodiorite	Dillinger Station railroad tunnel	15	116.0	356	.326	—	—
RP54	Fe ore	Olafsen's mine	L	2.0	2	.929	—	—
RP55	Mo-bearing quartz monzonite	Bethlehem pegmatite	L	0.5	5	.103	—	—
RP56	do.	Antietam reservoir S molybdenite pod	700	89.3	18	4.961	*	—
RP57	Skarn	Quarry L, channel B	L	1,130.0	250	4.520	*	*
RP59	"Byram" granitic rock	Moxon quarry face composite	N	57.5	241	.239	—	—
RP60	Skarn	Quarry L, channel A	N	247.0	288	.858	—	*
RP61	"Byram" granitic rock	Forgedale Route anomaly	N	51.4	229	.224	—	—
RP62	do.	Leake-Rohrbach prospect	N	149.0	237	.629	—	—
RP63	Mo-bearing quartz monzonite	Chapel Hill, NW outlier	2	154.0	34	4.529	*	—
RP64	do.	Korn-Stelts anomaly	19	718.0	320	2.244	*	*
RP65	"Byram" granitic rock	Swoveberg Hill	N	9,610.0	2,600	3.696	*	*

[1] U and Th determined by delayed neutron activation analysis. Mo for RP1 through RP60 by semiquantitative emission spectroscopy and for RP61 through RP65 by inductively coupled plasma determination of acid digestions.

[2] N, not detected; L, detected but below limit of determination.

[3] The following Th assays are maximum values: RP6, 10, 11, 21, 23, 28, 31, 33, 37, 39, 52, 54, 56, 57, 63, 64, and 65. The detection limit for Th is directly proportional to the U/Th ratio.

[4] Aberrant "Byram" samples (see text).

[5] Vein not included in statistical calculations.

[6] Hybrid skarn-granite, included in statistical calculations as a skarn.

Table 7. *Results of Flame-Emission Analyses for Ba, Rb, and Sr*

Sample	Ba (ppm)	Rb (ppm)	Sr (ppm)
RP1	1,050	245	170
RP2	330	110	190
RP3	1,225	165	70
RP4	595	130	265
RP5	550	285	60
RP6	560	195	155
RP7	445	250	90
RP8	725	210	225
RP9	140	310	10
RP10	600	125	70
RP11	130	225	75
RP12	290	245	80
RP13	200	50	85
RP14	810	160	225
RP15	525	130	80
RP16	490	185	100
RP17	180	245	100
RP18	435	165	70
RP19	155	320	70
RP20	1,000	145	495
RP21	460	235	35
RP22	350	235	60
RP23	630	190	160
RP24	600	345	105
RP25	370	100	60
RP26	190	225	60
RP27	425	270	175
RP28	120	285	60
RP29	510	155	90
RP30	205	135	105
RP31	1,615	250	120
RP32	575	300	320
RP33	260	80	260
RP34	100	30	15
RP35	880	195	215
RP36	280	180	70
RP37	80	130	30
RP38	570	300	250
RP39	630	320	160
RP40	225	240	10
RP41	380	165	70
RP42	295	250	90
RP43	400	325	60
RP44	1,370	140	465
RP45	130	275	10
RP46	150	200	80
RP47	190	235	15
RP48	240	190	105

Table 7. *(Continued)*

Sample	Ba (ppm)	Rb (ppm)	Sr (ppm)
RP49	305	50	120
RP50	320	100	100
RP51	345	180	70
RP52	230	135	80
RP53	180	25	110
RP54	445	325	75
RP55	890	60	240
RP56	155	85	90
RP57	580	295	15
RP59	180	195	80
RP60	240	190	15
RP61	260	140	55
RP62	130	150	65
RP63	50	110	30
RP64	590	140	80
RP65	190	110	55

are probably not as accurate as those for RP1 through RP60. Additional comments on the trace-element analyses appear as footnotes to the tables.

Trace Elements

For purposes of establishing the typical trace-element contents of the various host rocks to U-Th mineralization in the Reading Prong, samples RP1 to RP65 have been divided into four general rock types: granitic, skarn, basal Hardyston, and miscellaneous. The 47 "granitic"[18] samples are RP2, 3, 4, 6, 8, 9, 10, 11, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 33, 35, 36, 37, 40, 42, 46, 48, 49, 50, 51, 52, 53, 54, 56, 59, 61, 62, 63, 64, and 65. These 47 granitic samples are further subdivided on the basis of mineralogy and key elements. The skarn samples, all collected along an east-west strike with each other on Chestnut Hill, north of Easton, are RP38, 39, 43, 44, 56, and 60. The basal Hardyston samples are RP5, 34, and 47. The miscellaneous samples include a heterogeneous collection of ores, veins, stony soils, and so on, that does not constitute a statistically meaningful population.

Median trace-element data for the Reading Prong granitic rocks, skarns, and basal Hardyston samples are presented in Table 10, and the corresponding data

[18] "Granitic" as used herein refers to crystalline quartzo-feldspathic rocks of both metamorphic and igneous origin. No particular texture is implied.

Table 8. *Trace-Element Data*[1]

(Quantities are in parts per million)

Sample	B	Ba	Be	Co	Cr	Cu	Ga	Mo[2]	Nb	Ni	Pb	Sc	Sn	Sr	V	Y	Zr
RP1	N[3]	700	3	7	N	7	20	N	30	7	700	10	N	150	30	700	150
RP2	N	300	1	30	70	300	15	10	N	150	10	15	N	300	70	30	150
RP3	L[4]	1,500	3	N	1.5	3	15	N	70	3	30	7	N	150	20	300	20
RP4	70	500	1	3	1	70	7	N	70	3	30	7	N	150	20	300	20
RP5	N	200	N	15	70	30	30	N	30	15	15	7	N	30	300	70	2,000
RP6	N	700	N	3	1	3	15	7	N	N	150	N	N	300	15	150	100
RP7	N	700	1.5	3	2	15	15	N	20	2	30	7	N	150	15	100	150
RP8	N	500	1.5	7	N	2	30	N	50	N	30	N	N	200	N	500	2,000
RP9	N	150	N	N	N	N	15	N	N	N	30	N	N	100	N	30	150
RP10	N	1,000	1	N	N	3	15	30	N	N	30	N	N	200	7	30	70
RP11	N	150	1	N	N	N	15	N	50	N	20	N	N	150	N	30	50
RP12	N	500	N	N	1	1.5	15	N	20	L	15	N	N	150	L	15	100
RP13	N	200	1	5	15	7	15	N	15	7	15	N	N	150	30	70	200
RP14	L	700	2	5	N	5	15	N	15	3	30	N	N	150	30	300	5,000
RP15	30	700	N	N	N	3	15	N	N	N	10	N	N	150	N	30	150
RP16	N	700	1.5	N	N	7	15	N	N	N	30	N	N	150	7	50	150
RP17	N	300	1	N	N	N	15	N	10	N	30	N	N	150	7	15	150
RP18	N	700	1.5	N	N	15	15	N	15	2	10	N	N	150	7	20	150
RP19	N	200	1	N	N	7	15	N	L	L	30	N	N	70	N	10	70
RP20	N	1,500	1	N	N	7	15	N	30	L	N	N	N	700	N	150	30
RP21	20	1,500	N	N	N	7	15	N	70	N	30	N	N	70	7	150	700
RP22	30	700	1	N	N	1.5	15	N	N	N	50	N	N	50	N	30	700
RP23	N	700	1	N	N	15	15	70	30	N	150	N	15	200	30	300	300
RP24	N	1,000	1	N	N	3	15	N	10	N	30	N	N	150	15	50	200
RP25	N	700	N	N	N	7	15	N	N	N	N	N	N	50	N	10	150
RP26	N	300	2	N	N	3	30	N	50	N	30	N	L	150	N	30	300
RP27	N	700	1.5	3	1.5	3	15	N	N	3	30	L	N	300	30	30	100
RP28	N	150	1.5	N	N	2	15	N	70	N	30	N	N	70	N	70	150
RP29	N	700	1	N	1.5	3	30	N	N	3	30	N	N	150	15	70	70
RP30	L	300	1.5	N	1	15	15	N	10	N	30	N	N	200	7	30	300
RP31	N	500	3	30	150	30	15	150	N	30	15	30	N	50	150	70	30
RP32	N	150	N	70	50	70	15	N	N	30	N	30	N	100	700	20	150
RP33	N	300	1.5	3	N	3	15	15	N	N	150	N	N	300	20	15	700
RP34	200	70	N	7	30	15	15	N	150	N	30	7	30	30	70	150	1,000
RP35	N	700	N	N	N	3	15	N	N	N	N	5	N	300	7	70	300
RP36	N	300	N	N	N	N	20	N	50	N	30	N	N	100	N	30	100
RP37	N	70	1.5	N	N	N	15	N	10	N	30	N	N	70	N	70	150
RP38	30	300	5	N	2	1.5	20	N	100	N	N	30	30	30	15	700	15
RP39	70	200	N	N	30	50	10	30	N	7	100	N	N	70	30	30	30

Table 8. *(Continued)*

Sample	B	Ba	Be	Co	Cr	Cu	Ga	Mo[2]	Nb	Ni	Pb	Sc	Sn	Sr	V	Y	Zr
RP40	N	300	N	N	N	3	15	N	N	N	30	N	N	150	N	50	100
RP41	30	300	L	L	3	15	15	N	100	L	70	L	N	30	15	70	300
RP42	100	300	L	N	1	1	20	N	N	N	L	7	N	150	N	70	15
RP43	30	70	1.5	L	15	5	15	N	10	7	15	L	N	30	70	15	70
RP44	30	150	N	N	1	7	N	N	N	L	30	N	N	70	N	20	N
RP45	L	150	N	L	L	1.5	30	N	70	L	20	N	15	50	N	70	300
RP46	L	150	1.5	N	L	1.5	15	N	70	N	15	N	N	150	N	70	150
RP47	150	70	1.5	7	70	3	N	N	70	5	15	15	30	30	150	700	1,000
RP48	L	200	L	N	L	1.5	15	L	N	N	30	N	N	150	L	15	100
RP49	L	150	2	N	L	15	15	N	N	N	30	N	N	150	7	10	150
RP50	L	200	10	7	3	7	15	L	200	L	30	30	30	70	15	500	2,000
RP51	L	300	N	N	L	5	15	N	N	N	20	N	N	100	N	15	30
RP52	L	300	1.5	N	L	3	15	N	15	N	30	N	N	150	N	30	300
RP53	L	150	L	7	10	30	10	15	N	15	30	L	N	150	50	10	300
RP54	L	150	N	70	30	700	N	L	N	150	N	10	N	20	150	30	30
RP55	L	1,000	L	N	70	15	15	L	N	7	N	L	N	300	L	30	70
RP56	L	150	1.5	30	30	500	10	700	15	150	50	L	N	70	50	30	70
RP57	30	150	N	7	15	15	15	L	L	7	70	N	N	15	30	15	50
RP59	L	150	N	N	7	7	15	N	10	L	30	N	N	70	L	20	70
RP60	30	150	N	5	10	3	15	N	15	7	30	N	N	5	15	10	20
RP61	—[5]	340	2	N	11	6	20	N	11	N	20	N	N	6	4	49	—
RP62	—	190	2	N	6	2	20	N	N	N	77	N	N	78	5	27	—
RP63	—	88	3	N	2	2	23	2	4	N	42	N	N	52	N	17	—
RP64	—	750	2	2	3	6	18	19	68	6	95	4	13	110	—	6	—
RP65	—	250	3	N	1	10	18	N	36	4	1,200	N	N	61	N	640	—

[1] Data for RP1 through RP60 were determined using semiquantitative emission spectroscopy. Data for RP61 through RP65 were determined using inductively coupled plasma (ICP) analysis of acid digestions. Detection limits are different by each method. B and Zr were not determined by ICP. Ag was detected using ICP as follows: RP63, 2 ppm; P was detected using ICP as follows: RP61, 0.01 percent; RP62, 0.02; RP63, <0.005; RP64, 0.03; RP65, 0.02; Li was detected using ICP as follows: RP61, 5 ppm; RP62, 7; RP63, 11; RP64, 2; RP65, 6.
[2] Reanalysis using optical spectroscopy verified the following Mo values: RP2, 17 ppm; RP6, 13 ppm; RP10, 40 ppm. Mo for RP21 through RP65 was unverified.
[3] N, not detected.
[4] L, detected but below limit of determination.
[5] —, not analyzed.

Table 9. *Semiquantitative Lanthanide (Rare-Earth) Analyses of Rock Samples*[1]

(Quantities are in parts per million)

Sample[2]	Type[3]	La	Ce	Pr	Nd	Sm	Gd	Dy	Ho	Yb	Lu
RP1	M	700	1,500	150	700	150	300	150	30	30	N[4]
RP2	G	70	150	N	N	N	—[5]	—	—	3	—
RP3	G	150	300	N	150	N	N	N	N	7	N
RP4	G	N	N	—	—	—	30	L[6]	N	20	N
RP5	H	150	300	N	150	N	N	N	N	N	N
RP6	G	2,000	3,000	300	1,500	150	70	N	N	7	N
RP7	M	300	700	N	300	N	N	N	N	15	N
RP8	G	7,000	7,000	1,000	5,000	500	300	150	30	50	N
RP9	G	30	N	N	N	N	—	—	—	3	—
RP10	G	150	300	N	100	N	—	—	—	3	—
RP11	G	70	150	N	70	N	—	—	—	5	—
RP12	G	70	150	N	70	N	—	—	—	1.5	—
RP13	M	150	300	N	150	N	N	N	N	5	N
RP14	G	7,000	7,000	1,500	3,000	500	150	70	N	30	N
RP15	G	70	100	N	N	N	—	—	—	3	—
RP16	G	300	500	N	200	N	—	—	—	5	—
RP17	G	30	N	N	N	N	—	—	—	2	—
RP18	G	30	N	N	N	N	—	—	—	3	—
RP19	G	N	N	—	—	—	—	—	—	1	—
RP20	G	1,500	3,000	150	700	100	70	50	N	15	N
RP21	G	70	N	N	N	N	N	N	N	15	N
RP22	G	150	150	N	70	N	—	—	—	7	—
RP23	G	700	700	L	300	L	70	70	N	30	L
RP24	G	70	100	N	N	N	—	—	—	50	—
RP25	G	30	N	N	N	N	—	—	—	1	—
RP26	G	150	150	N	70	N	—	—	—	7	—
RP27	G	150	200	N	150	N	—	—	—	3	—
RP28	G	30	N	N	N	N	N	N	N	15	N
RP29	G	500	700	L	300	L	N	N	N	7	N
RP30	G	N	N	—	—	—	—	—	—	7	—
RP31	M	100	150	N	150	N	N	N	N	3	N
RP32	M	N	N	—	—	—	—	—	—	2	—
RP33	G	300	300	N	150	N	—	—	—	3	—
RP34	H	300	700	L	300	N	50	50	N	15	N
RP35	G	700	700	L	300	N	N	N	N	5	N
RP36	G	50	100	N	70	N	—	—	—	3	—
RP37	G	70	100	N	100	N	N	N	N	7	N
RP38	S	50	N	N	100	N	70	100	30	70	20
RP39	S	N	N	—	—	—	—	—	—	2	—
RP40	G	150	150	N	150	N	—	—	—	3	—
RP41	M	N	N	—	—	—	—	—	—	10	—

Table 9. *(Continued)*

Sample[2]	Type[3]	La	Ce	Pr	Nd	Sm	Gd	Dy	Ho	Yb	Lu
RP42	G	700	1,000	150	500	100	N	N	N	5	N
RP43	S	N	N	—	—	—	—	—	—	2	—
RP44	S	L	L	N	N	N	—	—	—	3	—
RP45	M	150	L	N	150	N	N	N	N	7	N
RP46	G	150	L	N	70	N	N	N	N	15	N
RP47	H	300	700	L	300	N	N	70	20	30	N
RP48	G	150	L	N	150	N	—	—	—	L	—
RP49	G	150	L	N	70	N	—	—	—	L	—
RP50	G	3,000	3,000	300	1,500	200	L	70	L	70	N
RP51	G	100	L	N	N	N	—	—	—	1	—
RP52	G	150	200	N	150	N	—	—	—	3	—
RP53	G	70	L	N	N	N	—	—	—	1	—
RP54	G	N	N	—	—	—	—	—	—	N	—
RP55	M	70	L	N	70	N	—	—	—	2	—
RP56	G	N	N	—	—	—	—	—	—	3	—
RP57	S	N	N	—	—	—	—	—	—	1.5	—
RP59	G	70	L	N	70	N	—	—	—	1.5	—
RP60	S	N	N	—	—	—	—	—	—	N	—
RP61	G	90	180	20	73	10	10	15	N	5	—
RP62	G	75	140	20	64	10	10	13	N	3	—
RP63	G	11	14	N	10	N	N	7	N	2	—
RP64	G	230	510	40	120	20	20	34	5	15	—
RP65	G	160	320	40	150	50	50	140	28	130	—

[1] Analyses performed by Branch of Analytical Laboratories, USGS. Data collected using emission spectroscopy (RP1 through 60) and inductively coupled plasma (RP61 through 65). Detection limits are different for each of the two semiquantitative methods.

[2] For RP1 through RP60, Pr, Nd, Sm, and Eu were analyzed only when La or Ce were found. No Eu was detected in any sample. Gd, Dy, Ho, and Lu were analyzed only in samples in which Y>50 ppm. Tb, Er, and Tm were sought in RP1 through RP60 only in samples in which Y>50 ppm, but no Tb, Er, or Tm was detected in the samples checked. For those three elements in RP61 through RP65, 30 ppm Tb was detected in RP65, 5 ppm Er in RP61, 12 ppm Er in RP64, and 110 ppm Er in RP65.

[3] G, granite; S, skarn; H, basal Hardyston; M, miscellaneous.

[4] N, not detected.

[5] Dash, not analyzed.

[6] L, detected, but below limit of determination.

for lanthanides in Table 11. Both tables include comparative crustal-abundance data from the compilation by Turekian (1977). Selected data are discussed by element, below. The lanthanide elements are discussed as a group.

Barium

The median Ba content of Reading Prong granitic rocks is 305 ppm, well below Turekian's (1977) average values for high-Ca granite (420 ppm) and low-Ca granite (840 ppm), as well as syenite (1,600 ppm) and shale (580 ppm). The skarns are somewhat enriched in Ba, perhaps occurring as hypogene sulfates associated with trace Pb and Zn (Smith, 1977). Orange barite, for example, was verified in the C. K. Williams quarry not far from RP39.

Individual Ba contents of ≥1200 ppm are deemed worthy of note in the study area: RP3, with 1,225 ppm Ba, occurs within a few meters of hypogene

Table 10. *Medians of Trace-Element Contents for Reading Prong Mineralized Rock Types With Some Comparative Data from Turekian (1977)*

(Quantities are in parts per million)

Rock Type	B	Ba	Be	Co	Cr	Cu	Ga	Mo	Nb	Ni	Pb	Rb	Sc	Sn	Sr	V	Y	Zr	U	Th	U/Th
Reading Prong 47 granitic	N[1]	305	1	N	L[2]	3	15	N	10	N	30	165	N	N	80	4	30	150	81	161	[3]0.48
Reading Prong 6 skarn	30	575	N	N	12.5	6	12.5	N	5	7	30	297.5	N	N	110	22.5	17.5	25	155	246.5	[3].82
Reading Prong 3 basal Hardyston	150	190	N	7	70	15	15	N	70	5	15	235	7	30	15	150	150	1,000	30.5	323	[3].07
Granites[4]																					
High Ca	9	420	2	7	22	30	17	1.0	20	15	15	110	14	1.5	440	88	44	140	2.3	8.9	[5].26
Low Ca	10	840	3	1	4	10	17	1.3	21	4.5	19	170	7	3.0	100	44	41	175	4.7	20	[5].24
All sandstones[4]	35	A[6]	B[7]	.33	35	C[8]	12	.2	D[9]	2	7	60	1	B[7]	20	20	10	220	1.7	5.5	[5].31

[1] N, not detected.
[2] L, detected, but below limit of determination.
[3] Median ratios of Reading Prong samples.
[4] From Turekian (1977).
[5] Ratios of means of world samples.
[6] A, value is between 10 and 99.
[7] B, value is between 0.1 and 0.9.
[8] C, value is between 1 and 9.
[9] D, value is between 0.01 and 0.09.

Table 11. *Median Lanthanide Contents of Reading Prong Mineralized Rock Types With Some Comparative Data From Turekian (1977)*

(Quantities are in parts per million)

Rock type	La	Ce	Pr	Nd	Sm	Eu	Gd	Dy	Ho	Yb	Lu
Reading Prong 47 granitic	100	150	N[1]	70	N	N	N	N	N	5	N
Reading Prong 6 skarn	N	N	N	N	N	N	N	N	N	2	N
Reading Prong 3 basal Hardyston	300	700	L[2]	300	N	N	N	50	N	15	N
Granites[3]											
High Ca	84	100	17	55	8.5	1.7	6.7	8.0	2.2	4.0	1.1
Low Ca	55	57	7.2	33	7.1	1.1	7.1	5.0	1.2	4.0	1.2
All sandstones[3]	7.2	15	2.1	8.8	1.9	.51	1.8	1.4	.35	.85	.063

[1] N, not detected.
[2] L, detected, but below limit of determination.
[3] From Turekian (1977).

fluorite; RP31, with 1,615 ppm Ba, is a somewhat veinlike material from an iron-mine dump that is highly enriched in Mo; and RP44, with 1,370 ppm Ba, is a skarn in which trace galena was observed.

Boron

The median B content of Reading Prong granitic rocks is below the detection limit of approximately 20 ppm established by Myers and others (1961). B is enriched in the skarn samples (Table 10), which were all collected from Chestnut Hill, as well as all granitic rock samples from that area (see "Petrology and Mineralogy"). This B in Chestnut Hill granitic and skarn samples may have been introduced as fluids from late pegmatites, but, as discussed under "Deposit Types," these rocks differ in other ways from the U-mineralized rocks observed in the main portion of the Reading Prong. As expected, B is especially enriched in the basal Hardyston samples. At least some of the B in the Hardyston occurs as schorl, $NaFe_3^{2+}Al_6(BO_3)_3Si_6O_{18}(OH)_4$, the common species of tourmaline. Because of the low abundance of B in granitic rocks from other than Chestnut Hill, the possibility exists that most of the Reading Prong granites have not resulted from partial melting of shale, inasmuch as Turekian (1977) reported a worldwide average content of 100 ppm B for shale. Low B in these granites also tends to somewhat reduce the possible role of late magmatic differentiation.

Copper

The median Cu contents of granitic rocks and skarns from the Reading Prong are low. Individual values of Cu $\geq$70 ppm are deemed worthy of note: RP2, having 300 ppm Cu, contains disseminated chalcopyrite, molybdenite, and pyrrhotite; RP4, containing 70 ppm Cu, occurs within meters of float containing several percent Cu as chalcopyrite associated with actinolite in hand-sample-sized specimens, and molybdenite occurs elsewhere at the locality; RP32, containing 70 ppm Cu, is from an ilmenite-concentrate stockpile, and trace molybdenite occurs elsewhere at the locality; RP54, containing 700 ppm Cu, is from an arsenic-rich assemblage that contains chalcopyrite, pyrrhotite, and very rare molybdenite; and RP56, containing 500 ppm Cu, is from the same general area as RP2 and also contains molybdenite, pyrrhotite, and pyrite. Cu appears to have good potential as a pathfinder element for Mo occurrences in a variety of host rocks in the Reading Prong. Because of the association of pyrrhotite, a good host for Co and Ni, with chalcopyrite in the Reading Prong granitic rocks, Cu also shows a correlation with those elements. In the Reading Prong skarn samples, Cu shows a strong correlation with B and Pb as well as Mo.

Lanthanides

The lanthanide elements La, Ce, and Yb were sought in every sample. For RP1 through RP60, Pr, Nd, Sm, and Eu were sought only when La or Ce was found (detection limits approximately 20 and 70 ppm, respectively), and Gd, Tb, Dy, Ho, Er, Tm, and Lu only when Y was >50 ppm. Tb, Er, and Tm were not detected in samples RP1 through RP60. For samples RP61 through RP65, lanthanides were analyzed by ICP (inductively coupled plasma); however, results would be low because of the incomplete digestion of zircon. Tb and Er were, however, detected in RP65.

For granitic rocks, the median lanthanide composition is La, 100 ppm; Ce, 150; Nd, 70; and Yb, 5. These amounts are high relative to the data for low-Ca granite in general (Turekian, 1977), but these data for the Reading Prong obviously have been strongly biased by sampling rocks enriched in U and/or Th. The bias results from the well-known enrichment of Th and U in accessory rare-earth minerals. For Pr, Sm, Eu, Gd, Dy, Ho, and Lu, the medians are below the detection limits.

Individual samples in the reading Prong with the total concentration of La plus Ce exceeding 3,000 ppm in granitic rocks are worthy of note: RP6, which contains 2,000 ppm La and 3,000 Ce, is a U occurrence that was deemed worthy of follow-up study in Phase III, whereas RP8 with 7,000 La and 7,000 Ce, RP14 with 7,000 La and 7,000 Ce, RP20 with 1,500 La and 3,000 Ce, and RP50 with 3,000 La and 3,000 Ce are low-U, allanite-rich pegmatites. As such, their lanthanide distribution pattern is selectively enriched in the lighter lanthanides, as well as the even-atomic-number lanthanides (Ce, Nd, Sm, Gd, Dy, Er, and Yb) (Rankama and Sahama, 1950) (Figure 12A). A similar lanthanide enrichment pattern is reported for a chevkinite concentrate from site RP55 (Figure 12B).

Sample RP38, a titanite-bearing skarn, has a lanthanide distribution pattern that is enriched in those elements with an intermediate atomic number. This type of pattern can be seen more clearly in the lanthanide distribution for RP67, a pure titanite concentrate from RP38. The geochemistry of the pure titanite from RP38 and other samples is discussed in detail in Appendix 4. The intermediate-atomic-number lanthanides in the titanites are potentially of greater economic value than the lighter ones in allanite-(Ce).

Sample RP65, an extremely U-rich and high U/Th granitic sample having accessory magnetite, has a rather uniform apparent lanthanide distribution pattern (Figure 12C). Because of its U enrichment, the occurrence is discussed further in "Phase III" of this report.

In the Reading Prong granitic rock, the lighter lanthanides tend to show a strong correlation with each other as well as with MnO and Zr. This latter probably reflects substitution of lanthanides into zircon. The heavier lanthanides may show the expected correlation with Y, but this is artificially reinforced by the fact that these lanthanides were only determined when Y was ≥50 ppm.

In general, the correlation of U with lanthanides is weak, so the latter are not good pathfinder elements for most U occurrences in the Reading Prong.

Lead

The median Pb content of both granitic rocks and skarns in the Reading Prong is 30 ppm. This at first appears to be somewhat high compared with a world average of 19 ppm for a low-Ca granite (Turekian, 1977). The correlation coefficient of Pb with U for 46 Reading Prong granitic rocks is 0.93, suggesting that much of the lead in the higher U, higher Pb samples could be radiogenic[19] (Figure 13), as does a Th-Pb correlation of 0.75. Calculations of the radiogenic lead that would accumulate in a one-billion-year-old Grenvillian-age granite with the observed U and Th contents suggest that this is reasonable. In skarns, Pb also shows a strong correlation coefficient with U but not with Th. Thus, Pb appears to be a useful pathfinder for uranium in granitic rocks of the Reading Prong. A strong correlation of Pb with Cu in the skarn host, however, suggests that some of the Pb in this host may be of nonradiogenic, hypogene origin.

Molybdenum

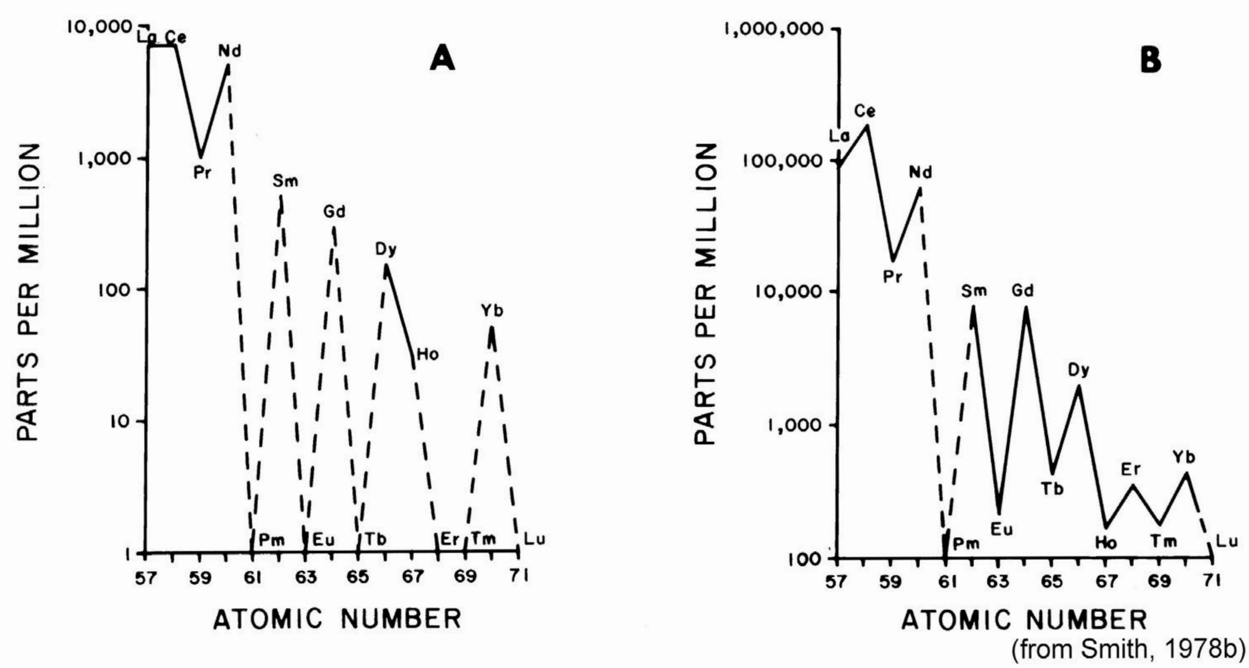
The median Mo contents of Reading Prong granitic rocks and skarns are below the detection limit of approximately 5 ppm for the method used for RP1 through RP60 (Myers and others, 1961). At least a trace of visible molybdenite was found in both granitic and skarn occurrences having ≥7 ppm, except RP23. Mo tends to be enriched in samples with high U/Th ratios, and its detection tends somewhat to support an igneous source for these granitic rocks (Chappell and White, 1974). An igneous source is also supported by a strong correlation of Mo with Cu in granitic samples.

Occurrences RP2, from the same outcrop as RP56, and RP31 warrant further investigation for Mo. Smith (1978b, p. 194–197) described other Mo occurrences within 2 km of RP2 and reported 0.15 percent Mo in a composite rock sample.

Nickel

The median Ni content of Reading Prong granitic rocks is below the detection limit of 3 ppm established by Myers and others (1961). Individual Ni contents of ≥150 ppm are worth noting in the Reading Prong: RP2, RP54, and RP56 each have 150 ppm Ni, which is associated with pyrrhotite and small amounts of chalcopyrite and molybdenite. The apparent correlation coefficient with Co is strong, but

[19] When RP65 is included in the calculation for r, the extremely high concentrations of U and Pb in this sample overwhelm the formula and yield a correlation coefficient of 1.00.



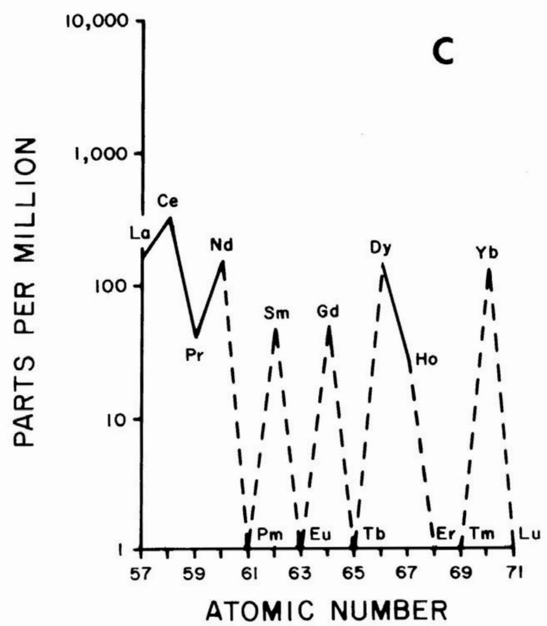


Figure 12. Lanthanide distributions. A. Low-U allanite-rich pegmatite (RP8), showing enrichment in light rare-earth elements (even atomic numbers); B. chevkinite concentrate from the same dike as RP55, based on Smith (1978b); and C. relatively unfractionated bulk rock sample (RP65).

only 16 samples have both Co and Ni contents above the detection limit.

Niobium

The median Nb content of Reading Prong granitic rocks is 10 ppm; in skarns, 5 ppm; and in the basal Hardyston Formation, 70 ppm. Individual Nb contents ≥100 ppm are worthy of note in the project area: RP34, with 150 ppm Nb, is a basal Hardyston sample; RP38, with 100 ppm Nb, is a skarn sample with Nb-Ta-Sn-bearing titanite (see Appendix 4); RP41, with 100 ppm Nb, is a stony soil from Chestnut Hill; and RP50, with 200 ppm Nb, is an allanite-rich pegmatite. Although the small volumes of these rocks do not encourage economic exploitation, analyses of these samples for the geochemically similar element Ta should be considered.

Rubidium

The median Rb content of the Reading Prong granitic rocks is 165 ppm, in good agreement with Turekian's (1977) average of 170 ppm for low-Ca

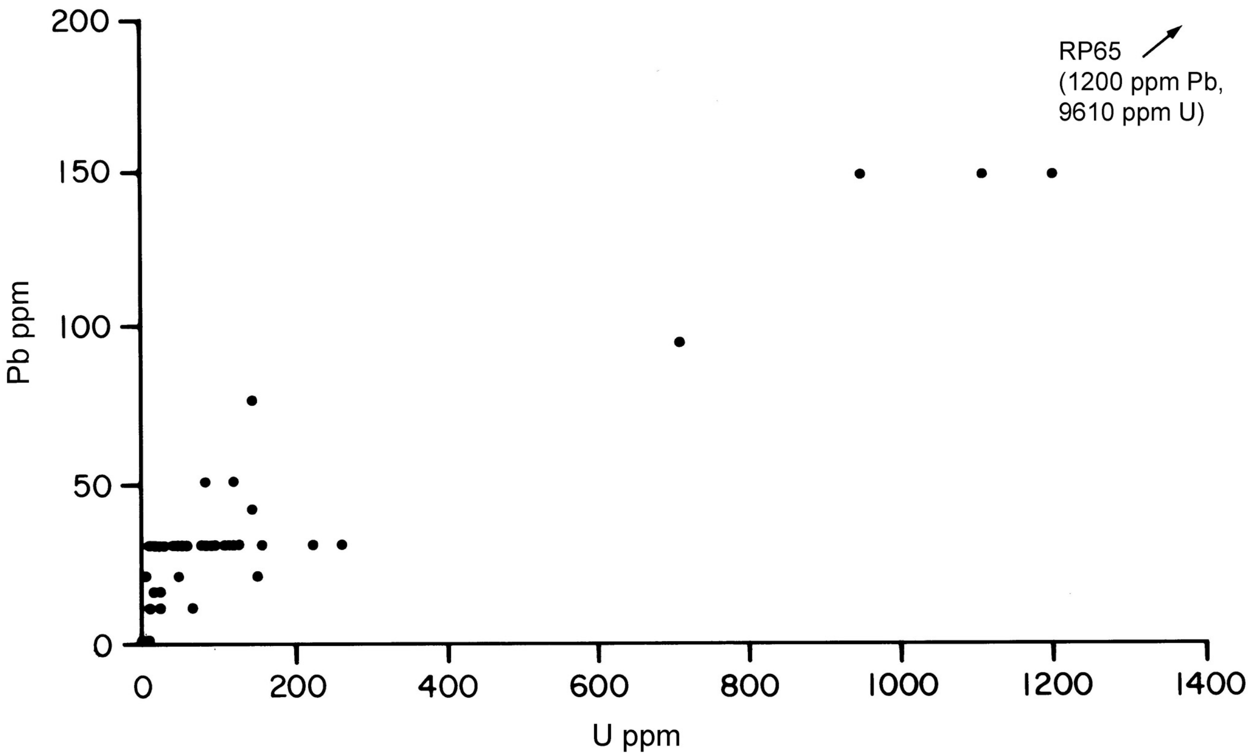


Figure 13. Plot of Pb vs. U for 47 Reading Prong granitic samples, showing the apparent correlation of the elements. This suggests that much of the Pb could be radiogenic. U analyses are quantitative and Pb analyses are semiquantitative.

granite. The median-K/median-Rb ratio of Reading Prong granitic rocks is 43,900/165, or 266, a normal value for crustal rock. A plot of Rb vs. K_2O for the granitic rocks shows a moderately strong positive correlation.

Strontium

The median Sr content of Reading Prong granitic rocks is 80 ppm, in good agreement with Turekian's (1977) average of 100 ppm for low-Ca granite.

Thorium

The median Th content of the sampled granitic rocks is 161 ppm versus Turekian's (1977) world average for low-Ca granite of 20 ppm. This is obviously a result of the sampling program being biased toward radioactive rocks.

The median Th content of the sample skarns is 246 ppm. Keeping in mind that there are only six skarn samples, Th has an apparent strong negative correlation coefficient with CaO, Ce, Ba, and Sr, and an apparent positive correlation with Ti. The latter may be in part due to Th enrichment in titanite (see RP65 through RP67, titanite concentrates from skarns, in Appendix 4).

The median Th content of the three basal Hardyston samples is 323 ppm, consistent with the accumulation of resistant, insoluble Th minerals in placers.

Tin

The median Sn content of Reading Prong granitic rocks and skarns is below the detection limit of approximately 10 ppm established by Myers and others (1961). Two out of three basal Hardyston samples contain 30 ppm Sn. Other samples with 30 ppm Sn include RP38, a titanite-bearing hybrid skarn with 0.25 percent Sn in the pure titanite (RP67), and RP50, an allanite-rich pegmatite.

Uranium

The median U content of the sampled radioactive granitic rocks is 81 ppm versus Turekian's (1977) world average for low-Ca granite of 4.7 ppm and the present typical ore grade cutoff of 1,000 ppm. The median U/Th ratio for the Reading Prong granitic rocks sampled is 0.48, but this value may be somewhat low due to preferential leaching of U. As noted above under "Lead," there appears to be a positive correlation coefficient of U with Pb in Reading Prong granitic rocks. The U-Th correlation in these rocks is 0.74, but this could, in part, be an artifact of the detection limit for Th increasing with increasing U in high-U samples.

The median U content of the skarn samples is 155 ppm and the apparent median U/Th ratio is 0.82. The U-Pb correlation coefficient for the skarn samples is significantly positive, but that for U-Th is much less so.

The median U content of the three sampled basal Hardyston samples is 30.5 ppm, and the median U/Th ratio is 0.07. This relatively low U content was expected because of the mobility of U and the fact that these samples represent an insoluble resistate fraction in which Th is likely to be retained.

Figure 14, a plot of U versus U/Th for Reading Prong granitic rocks, shows how these samples can be divided on the basis of U/Th ratios. Those samples that indicate high-U, low-Th occurrences are identified in the plot, and most are further examined in Phase III.

Vanadium

The median V content of Reading Prong granitic rocks is 4 ppm. This is low compared to Turekian's (1977) reported average of 44 ppm for low-Ca granite. A strong correlation coefficient of V with MgO suggests that the low V in the Reading Prong granitic samples reflects their very felsic nature and the paucity of V collectors such as magnetite and ilmenite in the mineralized rocks.

V contents ≥300 ppm are deemed worthy of note in the Reading Prong: RP5, with 300 ppm V, is

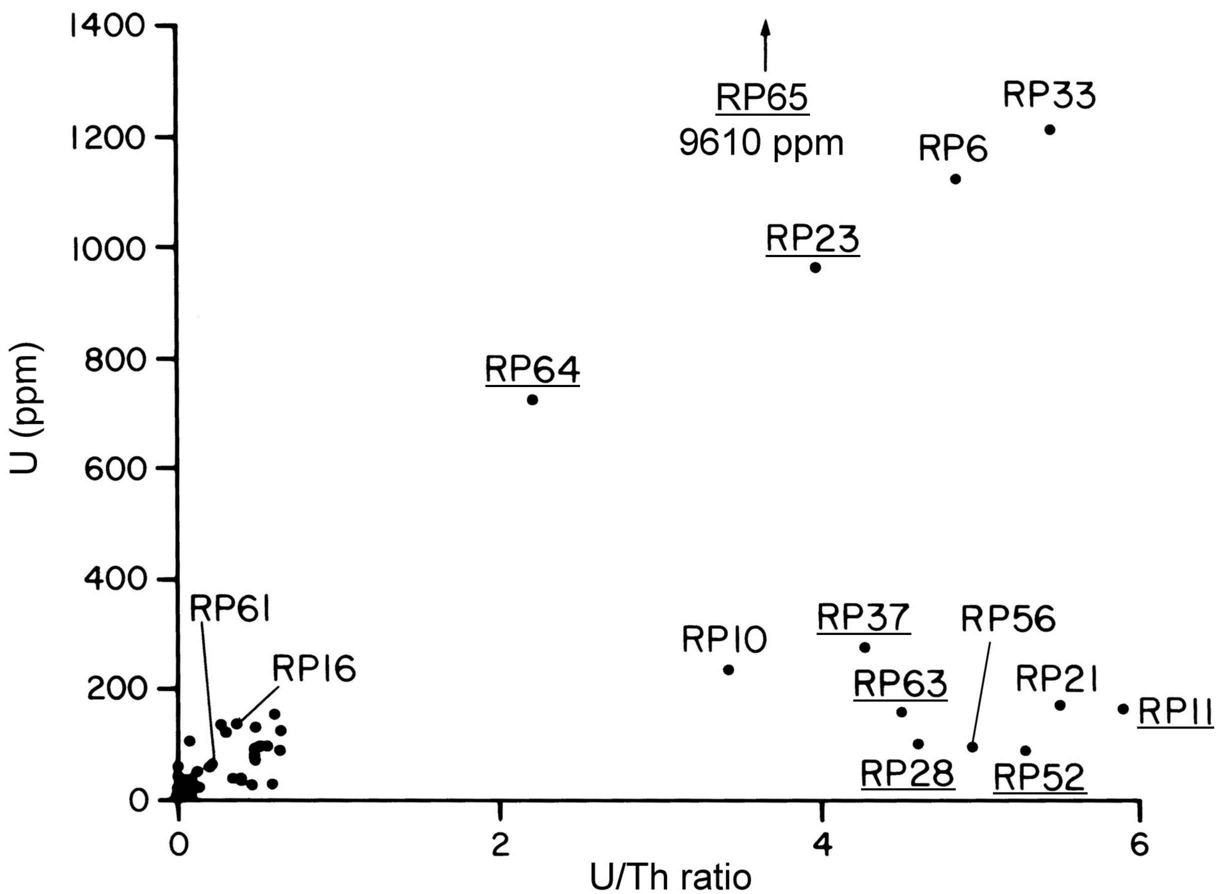


Figure 14. Plot of U vs. U/Th for 47 granitic rock samples from the Reading Prong based on quantitative delayed-neutron activation analysis. The high U/Th occurrences that are underscored are described in detail in Phase III, as are RP16 and RP61. RP33 (Rohrbach prospect) was described by McCauley (1961).

an ilmenite-rich basal Cambrian fossil placer, and RP32, with 700 ppm V, is an ilmenite-magnetite-rich stockpile. Presumably, the V in both samples is enriched in the opaque oxides.

Zirconium

The median Zr content of Reading Prong granitic rocks is 150 ppm, that of skarns, 25 ppm; and that of basal Hardyston samples, 1,000 ppm. Inasmuch as the average low-Ca granite of Turekian (1977) contains 175 ppm Zr, the content in Reading Prong granites is surprisingly low, considering the sampling bias toward the radioactive units and the typical enrichment of U and Th in zircon. Because of zircon's chemical and physical resistance, it is naturally concentrated in the residual minerals in the basal Hardyston Formation. The similar immobility of zircon during metamorphism may be useful in further subdivision of the granitic gneiss populations based on their content of Zr.

Zr contents ≥2,000 ppm are worthy of note in the Reading Prong: RP5, with 2,000 ppm, is a basal Hardyston fossil placer, and RP8, with 2,000 ppm Zr, is an allanite-bearing pegmatite with minor zircon, as are RP14 with 5,000 ppm Zr and RP50 with 2,000 ppm Zr.

PETROLOGY AND MINERALOGY

Representative splits of the 65 samples collected during the gamma-ray anomaly rock-sampling program were quantitatively analyzed for major and minor elements, and semiquantitative estimates were made of the mineralogy. In addition, a typical sample from each rock-sampling site was examined in thin section. These data were obtained to characterize the major radioactive rock types in the Reading Prong and especially to subdivide the granitic rocks into meaningful populations related to their uranium content. The quantitative data also provide some insight into the genesis of radioactive rocks in the Pennsylvania portion of the Reading Prong. The results of these petrographic and mineralogic studies were among the criteria used to select preferred sites for detailed descriptions in Phase III.

Major and Minor Elements and Methods

The elements Si, Ti, Al, Fe, Mn, Mg, and Ca were determined by atomic-absorption analysis of lithium-metaborate fusions, as described in Appendix 3, using the procedure of Medlin and others (1969). The alkali elements Na and K were determined by flame emission of similarly prepared samples. The concentrations of the major and minor elements in the individual rock samples are reported as oxides in Table 12.

K_2O–Na_2O–CaO

A plot of K_2O–Na_2O–CaO (Figure 15) for 47 granitic, 5 skarn, and 3 basal Hardyston samples[20] illustrates the major divisions and characteristics of the radioactive rock populations. The basal Hardyston samples were leached of essentially all Na_2O and CaO by intense weathering during the time represented by the unconformity that separates underlying Precambrian rock from the Hardyston Formation. The serpentine skarns from Chestnut Hill, on the other hand, are all rich in K_2O and/or CaO but nearly devoid of Na_2O. The granitic rock field contains a central rather dense cluster of samples and a more diffuse rim. This granitic field is subdivided further on the basis of mineralogy (see the section "Subdivision of the 47 'Granitic' Rock Samples").

Medians

Median major- and minor-element data for the Reading Prong granitic rocks, skarns, and basal Hardyston samples plotted in Figure 15 are presented in Table 13.

In general, the median Reading Prong mineralized granitic rock is remarkably similar to Turekian's average low-Ca granite. This similarity suggests that the Reading Prong granitic rocks are not particularly unusual and that one need not call upon exotic processes to explain their formation. The median Na_2O for Reading Prong granitic rocks is slightly lower than Turekian's (1977) world average. This low Na may be in part due to the fact that the atomic absorption procedure used in this study (Medlin and others, 1969) minimizes Na contamination from glassware and other sources, or, more likely, reflects the S-type character (Chappell and White, 1974) of the Reading Prong granitic rocks. Ratios of Al_2O_3/K_2O+Na_2O+CaO for the Reading Prong granitic rocks are high, also suggesting an S-type character.

A significant positive correlation coefficient of 0.81 between total Fe as "Fe_2O_3" and TiO_2 reflects the role of opaque oxides such as ilmenite. A correlation coefficient of 0.81 between Na_2O and Al_2O_3 reflects the significant role of albite as a carrier of

[20]These populations are defined on pages 44–58. They exclude ores, veins, soils, and mineral concentrates.

Table 12. *Quantitative Major- and Minor-Element Analyses by Atomic Absorption and Flame Emission*

(Quantities are percent oxides)

Sample	SiO_2	TiO_2	Al_2O_3	"Fe_2O_3"	MnO	MgO	CaO	Na_2O	K_2O	Total
RP1	60.8	0.40	12.68	11.80	0.252	0.75	1.39	1.64	5.28	94.99
RP2	67.5	.38	11.35	4.87	.057	1.73	1.84	2.50	3.23	93.46
RP3	72.5	.20	13.41	1.76	.017	.56	.50	3.38	5.29	97.62
RP4	72.2	.41	9.18	1.45	.045	1.17	3.86	1.72	5.21	95.24
RP5[1]	47.0	4.00	5.33	35.95	.037	.68	.10	.07	3.12	96.29
RP6	72.3	.29	13.10	1.82	.025	.52	1.22	3.08	5.18	97.54
RP7	70.0	.27	15.07	2.82	.028	.25	.27	1.63	6.06	96.40
RP8	64.3	.98	11.80	8.70	.107	.40	2.59	2.37	4.52	95.77
RP9	77.3	.10	13.00	1.47	.022	.10	.61	2.85	6.28	101.73
RP10	72.3	.13	13.77	1.71	.017	.20	.57	3.84	6.11	98.65
RP11	77.2	.13	13.80	1.12	.015	.12	.66	3.52	5.28	101.84
RP12	75.1	.10	13.39	1.07	.009	.11	.43	3.01	6.17	99.39
RP13	74.5	.50	11.57	3.09	.062	.50	.86	3.93	2.02	97.03
RP14	69.0	.52	8.08	10.60	.155	.44	1.48	.65	2.81	93.74
RP15	73.9	.13	12.12	3.19	.022	.25	.58	2.54	6.29	99.02
RP16	74.2	.21	14.02	2.71	.023	.14	1.10	3.41	5.29	101.10
RP17	72.3	.13	15.38	1.24	.026	.17	1.23	3.13	5.38	98.99
RP18	75.4	.15	13.10	1.36	.017	.13	.47	3.01	5.21	98.85
RP19	74.5	.12	13.66	.72	.013	.16	.61	2.66	6.25	98.69
RP20	71.5	.27	12.87	2.37	.030	.27	1.38	3.05	5.95	97.69
RP21[1]	76.8	.16	11.50	2.34	.017	.15	.11	1.77	6.70	99.55
RP22	75.1	.14	11.66	3.07	.029	.13	.33	2.41	5.62	98.49
RP23	72.7	.37	12.77	2.42	.034	.21	1.05	3.13	6.17	98.85
RP24	73.3	.17	13.42	1.04	.014	.10	.68	2.10	7.79	98.61
RP25	78.1	.12	12.85	1.92	.007	.12	.16	2.98	5.99	102.25
RP26	71.0	.09	11.60	1.97	.013	.10	.72	2.94	5.02	93.45
RP27	75.0	.19	13.41	2.43	.034	.48	1.39	3.29	4.23	100.45
RP28	73.3	.11	13.35	1.62	.019	.11	.84	2.99	5.36	97.70
RP29	74.7	.44	13.42	5.84	.024	.31	.85	3.86	3.60	103.04
RP30	78.5	.05	12.90	.64	.011	.12	.88	3.22	4.75	101.07
RP31	44.5	.77	12.16	18.86	.087	9.70	4.57	3.77	2.09	96.51
RP32[1]	34.9	12.40	9.18	29.40	.328	6.80	4.74	1.08	1.38	100.21
RP33	77.2	.20	12.75	1.21	.017	.44	1.77	3.54	2.14	99.27
RP34[1]	74.5	2.81	5.85	11.85	.030	.62	.02	.06	1.91	97.65
RP35	71.1	.37	13.48	3.96	.029	.31	1.28	2.74	5.08	98.35
RP36	72.1	.21	13.32	1.90	.005	.14	.29	3.29	5.75	97.00
RP37	74.5	.11	12.70	1.77	.028	.09	1.02	3.24	4.71	98.17
RP38	64.3	.28	12.68	3.97	.387	1.57	4.93	3.03	5.31	96.46
RP39	43.4	.15	4.75	1.08	.044	32.20	6.16	.09	3.12	90.99
RP40	70.6	.18	13.15	2.19	.012	.35	.27	2.97	5.95	95.67
RP41	74.7	.20	12.55	5.08	.039	.36	.35	.20	5.02	98.50
RP42	70.9	.00	15.00	.44	.027	.15	.52	3.78	6.53	97.35
RP43	49.8	.24	5.20	1.80	.075	29.15	5.67	.10	3.31	95.34
RP44[1]	22.0	.05	1.12	2.36	.238	33.80	20.30	.03	.32	80.22
RP45	78.8	.13	12.66	2.28	.006	.32	.02	.12	5.72	100.06
RP46	75.7	.15	12.18	1.64	.013	.28	.60	2.19	5.35	98.10
RP47[1]	55.1	7.10	7.51	24.70	.062	.91	.0	.07	2.73	98.20

Table 12. *(Continued)*

Sample	SiO_2	TiO_2	Al_2O_3	"Fe_2O_3"	MnO	MgO	CaO	Na_2O	K_2O	Total
RP48	72.6	.21	13.48	1.83	.017	.26	.94	2.91	6.18	98.43
RP49	74.0	.27	13.98	3.79	.048	.29	2.23	3.92	2.51	101.04
RP50	73.2	.91	5.69	10.81	.124	.84	1.33	1.07	1.83	95.80
RP51	76.2	.20	14.25	1.94	.031	.11	.73	3.18	5.95	102.59
RP52	76.8	.18	11.52	2.69	.019	.12	.80	2.32	4.58	99.03
RP53	77.2	.30	10.11	2.78	.049	.82	1.97	2.57	1.32	97.12
RP54[1]	33.4	.33	4.42	47.00	1.500	4.30	3.28	.61	.70	95.54
RP55	70.9	.07	14.42	2.22	.032	.16	.72	4.24	4.60	97.36
RP56	73.3	.20	8.82	5.34	.028	.87	1.75	2.19	2.31	94.81
RP57	38.3	.36	5.08	2.67	.108	34.85	.39	.09	2.48	84.33
RP59	76.3	.15	13.01	2.27	.025	.19	.25	3.54	4.89	100.63
RP60	40.8	.54	4.94	2.81	.081	37.05	.52	.02	1.00	87.76
RP61	74.6	.33	13.00	2.18	.022	.27	.63	3.27	5.39	99.69
RP62	72.6	.18	13.25	1.11	.026	.18	.76	2.70	6.05	96.86
RP63	74.2	.06	13.65	1.21	.030	.11	1.47	3.42	4.85	99.00
RP64	69.6	.52	13.10	2.96	.052	.16	.87	2.72	5.68	95.66
RP65	75.7	.13	11.10	3.30	.035	.11	1.00	2.28	4.19	97.84

[1]The following determinations were estimated by extrapolation beyond the normal working range of the analytical curves:
RP5: TiO_2, "Fe_2O_3"
RP21: K_2O
RP32: TiO_2, "Fe_2O_3"
RP34: CaO
RP44: CaO
RP47: TiO_2, CaO
RP54: "Fe_2O_3," MnO

soda. A correlation coefficient of 0.88 between total Fe as "Fe_2O_3" and MnO reflects the general substitution of Mn for Fe^{2+} in mafic silicates. The correlation coefficient of 0.02 between total Fe as "Fe_2O_3" and U is considered to be highly insignificant.

The low median SiO_2 data for the six Reading Prong skarns reflect their carbonate-bearing nature. This is also reflected in the low analytical totals, as no analysis was performed for carbonate. The median CaO/median MgO ratio of 0.16 suggests that the parent carbonate rock was probably dolomitic, and the modest K_2O content indicates that it might have been argillaceous. The low totals also reflect the hydrous nature of major minerals such as serpentine and phlogopite.

In addition to the intense weathering noted above (see the section "K_2O–Na_2O–CaO"), the median data for the basal Hardyston samples indicate an extreme enrichment in titanium and iron. Most Hardyston samples appear nonmagnetic to a strong hand magnet; therefore the Ti is believed to be present mainly as ilmenite. The excess Fe probably occurs as hematite.

Mineralogic Estimates and Methods

Semiquantitative estimates of the percentages of the chlorite, mica, potassium feldspar, plagioclase feldspar, and amphibole groups, as well as quartz, were made for samples RP1 through RP65 by an X-ray diffraction procedure. These minerals are expected to be the major and minor constituents of the granitic rocks. Pressed pellets of the samples were scanned over selected 2-theta ranges and the peak areas compared with those of a set of standards composed of pure minerals mixed in proportions so as to approximate the Reading Prong "granitic" modal data of Drake (1969). The semiquantitative X-ray diffraction procedure is described in detail in Appendix 3. X-ray diffraction data for the major and minor minerals of the individual samples appear in Table 14.

In addition to the major and minor minerals that are listed in Table 14, many other minerals were observed in trace amounts in samples from the Reading Prong and were identified using 114.6-mm-diameter X-ray powder cameras. Those minerals and the sam-

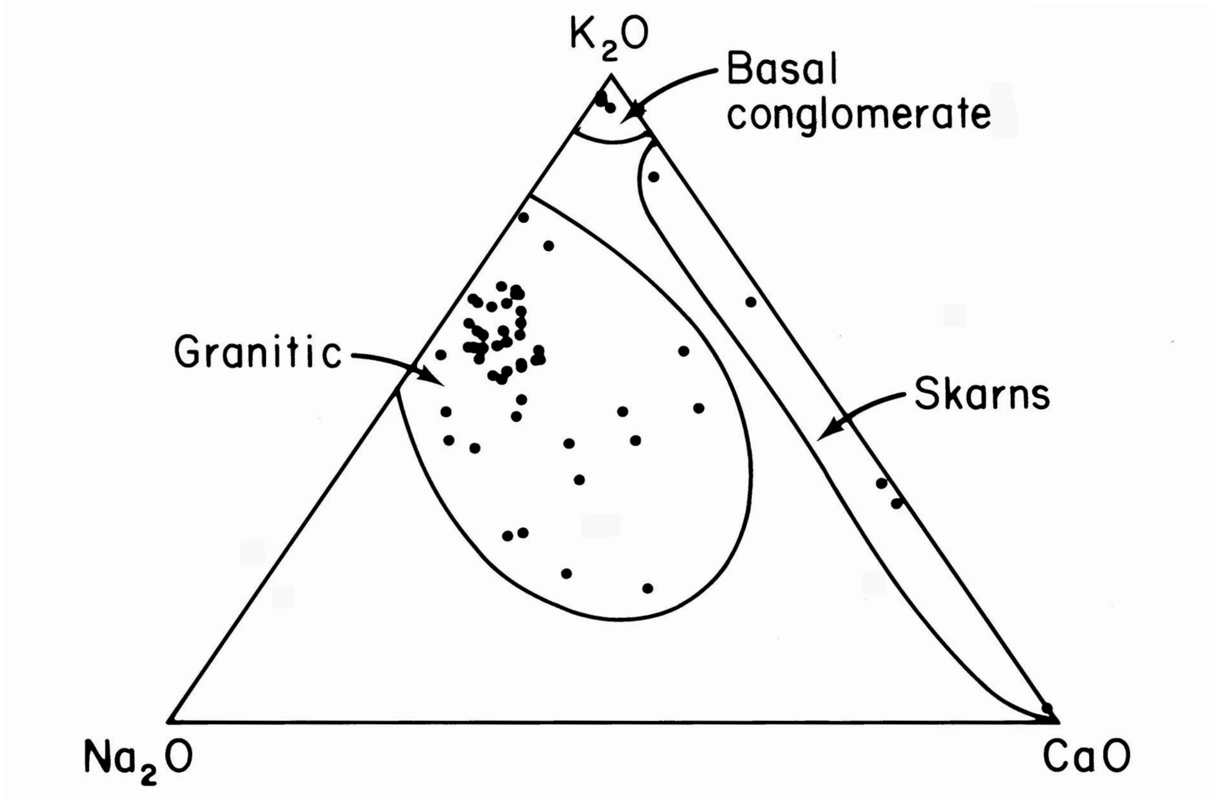


Figure 15. Plot of K_2O–Na_2O–CaO for 47 granitic, 5 skarn, and 3 basal Hardyston Formation samples, excluding ores, veins, soils, RP38, and mineral concentrates.

ples in which they were observed are listed in Appendix 5.

Although the care exercised in the execution of the X-ray procedure was "quantitative," the results are only semiquantitative, as indicated by the totals. The total of the median concentrations of each of the minerals for the 47 granitic samples (Table 15) is only 78.1 percent. Based on the approximate percentages of potassium feldspar and albite expected from the percentages of K_2O and Na_2O, respectively, as determined by flame emission, the reported contents of these minerals are believed to be significantly low. These low contents might be due to the highly crystalline nature of the "pure" minerals available to pre-

Table 13. *Medians of Major and Minor Oxides for Reading Prong "Granitic" Rocks*

(Quantities are in percent)

Unit	SiO_2	TiO_2	Al_2O_3	"Fe_2O_3"	MnO	MgO	CaO	Na_2O	K_2O	Na_2O/K_2O
47 (all) "granitic" rocks	73.9	0.18	13.10	1.97	0.025	0.18	0.84	2.99	5.29	0.56
5 B-bearing alaskitic quartz monzonites	73.9	.14	11.66	2.34	.027	.15	.52	2.41	6.29	.4
4 Mo-bearing granodiorites[1]	75.6	.28	12.46	3.28	.048	.63	2.10	3.66	2.12	1.72
10 Mo-bearing quartz monzonites	72.4	.20	13.10	2.02	.029	.20	1.04	3.10	5.02	.66
3 allanite-bearing pegmatites	69.0	.52	8.08	10.60	.124	.44	1.48	1.07	4.52	.24
26 "Byram" quartz monzonites	74.6	.16	13.28	1.91	.019	.14	.70	3.01	5.36	.56

[1]Includes sample RP31 from Jobst magnetite mine.

Table 14. *Semiquantitative Estimates of Some Major and Minor Minerals in Samples RP1 Through RP65, and Names of Significant Accessory Minerals*

(Quantities are in percent)

	Semiquantitative X-ray diffraction							Accessory minerals	
Sample	Chlorite	Mica	Amphibole	Quartz	K-feldspar[1]	Albite[2]	Total	Greater	Lesser
RP1	0.7	0.0	3.6	15.9	23.7	7.0	50.9	Thorite	
RP2	3.2	1.2	2.0	34.4	11.9	16.2	68.9	Molybdenite	Pyrite
RP3	2.0	1.0	.0	36.5	20.7	19.5	79.7	Thorite	
RP4	1.2	2.0	.0	49.7	23.9	11.2	88.0	Thorite	
RP5	.2	3.6	.0	14.3	6.7	.6	25.4	Zircon	Thorite
RP6	2.6	1.5	1.3	35.4	24.5	14.8	80.1	Yellow U sec.[3]	Uraninite
RP7	1.0	1.0	.0	40.9	25.5	7.1	75.5		
RP8	.1	.0	3.7	23.0	16.0	10.5	53.3	Allanite-(Ce)	Zircon
RP9	.2	.5	.0	39.3	27.3	12.8	80.1		
RP10	.0	.0	.0	33.9	23.7	16.1	73.7	Yellow U sec.[3]	Pyrite
RP11	.4	.5	.0	40.3	18.2	17.2	76.6		
RP12	.0	1.0	.0	39.2	20.7	13.7	74.6		
RP13	.6	.1	1.8	37.7	5.7	19.5	65.4		
RP14	.6	2.0	.0	40.1	7.6	2.8	53.1	Allanite-(Ce)	Zircon
RP15	.3	2.2	.0	43.3	26.8	14.1	86.7	Pyrite	
RP16	.5	.9	.0	31.0	21.1	16.4	69.9	Allanite-(Ce)	Pyrite
RP17	.6	.5	.0	36.9	28.3	24.3	90.6	Allanite-(Ce)	
RP18	.2	1.3	.0	36.0	20.0	16.2	73.7		
RP19	.0	1.6	.0	41.3	27.7	12.7	83.3		
RP20	.9	.6	1.3	37.3	39.5	20.9	100.5	Allanite-(Ce)	
RP21	.0	1.3	.0	43.8	32.3	11.3	88.7	Thorite	
RP22	.0	1.2	.0	42.2	25.7	13.7	82.8	Yellow U sec.[3]	Thorite
RP23	.2	.3	.5	35.4	32.0	14.8	83.2	Titanite	Thorite
RP24	.0	.3	.0	40.8	32.8	9.6	83.5	Thorite	Allanite-(Ce)
RP25	.0	.7	.0	41.8	31.8	17.3	91.6		
RP26	.5	1.0	.0	39.5	27.0	17.2	85.2		
RP27	.7	2.9	.0	41.8	16.5	21.2	83.1	Allanite-(Ce)	
RP28	.7	1.2	.0	43.2	24.7	13.7	83.5		
RP29	.3	1.5	.0	30.1	13.9	23.6	69.4	Thorite	Zircon
RP30	.3	.4	.0	44.3	32.6	17.2	94.8	Thorite	Molybdenite
RP31	12.0	22.0	30.9	3.2	7.3	40.1	115.5	Molybdenite	Pyrite
RP32	.6	4.3	30.9	1.8	5.4	2.3	45.3		
RP33	.8	1.4	.0	43.9	9.2	23.9	79.2	Yellow U sec.[3]	Molybdenite
RP34	.2	3.4	.0	54.2	2.0	.5	60.3	Thorite	Zircon
RP35	.6	.4	.7	34.2	19.9	12.6	68.4	Allanite-(Ce)	Zircon

Table 14. *(Continued)*

	Semiquantitative X-ray diffraction							Accessory minerals	
Sample	Chlorite	Mica	Amphibole	Quartz	K-feldspar[1]	Albite[2]	Total	Greater	Lesser
RP36	0.0	0.3	0.0	31.6	24.5	16.7	73.1	Zircon	
RP37	.6	.4	.0	38.2	16.5	16.5	72.2	Zircon	Thorite
RP38	.0	.4	1.2	24.8	27.5	15.6	69.5	Titanite	Thorite
RP39	[4].0	30.0	6.3	3.2	7.5	.0	47.0	Molybdenite	Pyrite
RP40	.9	.2	.0	41.3	16.3	12.4	71.1	Thorite	
RP41	4.7	2.2	.0	50.8	18.7	1.3	77.7		
RP42	.1	.6	.0	25.0	25.4	20.5	71.6	Allanite-(Ce)	
RP43	[4].0	31.0	27.6	.0	11.9	.9	71.4		
RP44	[4]1.0	1.4	.0	.0	5.3	.3	8.0	Pyrite	
RP45	5.1	2.7	.0	60.0	14.3	1.0	83.1		
RP46	.4	1.2	.0	49.8	23.0	9.4	83.8	Allanite-(Ce)	
RP47	.2	9.5	.0	19.0	2.0	1.0	31.7	Thorite	Zircon
RP48	.8	.3	.0	38.3	25.4	15.0	79.8	Allanite-(Ce)	Molybdenite
RP49	.6	2.8	.0	30.8	10.8	23.5	68.5	Uraninite	Molybdenite
RP50	.2	7.3	6.6	38.4	2.0	5.5	60.0	Allanite-(Ce)	Thorite
RP51	.2	.3	.0	36.7	30.8	17.7	85.7	Thorite	Allanite-(Ce)
RP52	.2	.6	.0	50.6	22.5	13.7	87.6	Uraninite	yellow U sec.
RP53	1.2	1.2	.0	49.5	6.0	14.1	72.0	Molybdenite	Pyrite
RP54	1.7	3.8	6.7	1.0	2.0	1.7	16.9		
RP55	.0	.2	1.1	35.1	19.1	30.7	86.2	Molybdenite	Zircon
RP56	3.6	.7	.0	49.8	8.6	13.7	76.4	Molybdenite	Pyrite
RP57	[4]3.0	14.4	.0	.8	2.0	.8	21.0		
RP59	.3	.2	.0	34.2	23.3	21.2	79.2		
RP60	[4]7.0	3.5	.0	.0	2.0	.2	12.7		
RP61	.2	2.1	.0	41.6	20.0	18.1	82.0	Thorite	
RP62	.4	.6	.0	36.9	33.8	17.5	89.2	Zircon	
RP63	.9	.0	.0	41.6	14.1	17.3	73.9	Yellow U sec.[3]	Thorite
RP64	.0	.4	.0	33.1	22.0	12.3	67.8	Titanite	Zircon
RP65	.6	.5	.0	37.7	19.7	12.7	71.2	Uraninite	Yellow U sec.
RP66	—	—	—	—	—	—	—	Titanite	Zircon
RP67	—	—	—	—	—	—	—	Titanite	
RP68	—	—	—	—	—	—	—	Titanite	Molybdenite

[1]K-feldspar values <4 percent recorded as 2 percent.
[2]Albite values <1 percent estimated from chemical analyses.
[3]Yellow U sec., yellow uranium secondary mineral.
[4]These values were estimated from 14Å peak height.

Table 15. *Medians of Semiquantitative Estimates of Mineralogy for Reading Prong "Granitic" Samples*

(Quantities are in percent)

Unit	Chlorite	Mica	Amphibole	Quartz	K-feldspar	Albite
47 "granitic" rocks	0.4	0.7	0.0	38.4	22.5	16.1
5 B-bearing alaskitic quartz monzonites	.1	1.3	.0	43.3	25.7	13.7
4 Mo-bearing granodiorites[1]	1.0	2.1	.0	37.4	8.2	23.7
10 Mo-bearing quartz monzonites	.7	.4	.0	35.4	20.6	15.6
3 allanite-bearing pegmatites	.2	2.0	3.7	38.4	7.6	5.5
26 "Byram" quartz monzonites	.4	.6	.0	39.2	23.2	17.0

[1]Includes sample RP31 from Jobst magnetite mine.

pare the standards. Comparison of the calculated mineralogic percentages derived from the K_2O and Na_2O data with the X-ray-derived estimated mineralogic percentages for the 47 granitic samples yields a mean correction factor for potassium feldspar of 1.57 and for albite of 1.83.[21] Because the variability of the correction factors from sample to sample is believed to be moderately large, only the raw data are reported in Table 14.

Significant positive correlation coefficients between feldspar as estimated by X-ray and alkalis were found. An Na_2O-albite correlation coefficient of 0.85 would probably be even stronger if the ratio of albite, which is sodium rich, to anorthite, which is calcium rich, was constant. A K_2O to K-feldspar correlation coefficient of 0.84 reflects the positive role of microcline and orthoclase and the paucity of micas in Reading Prong granitic rocks.

DEPOSIT TYPES

Subdivision of the 47 "Granitic" Rock Samples

Petrographic examination of thin sections, together with the major, minor, and trace-element data and X-ray mineralogy estimates, permitted subdivision of the 47 "granitic"[22] samples from the Phase II rock sampling into five somewhat arbitrary populations, with the two Mo-bearing ones differing only in K-feldspar/total feldspar. The criteria used to define the populations are rather heterogeneous and, as expected for a hybrid terrane, a few samples were somewhat arbitrarily categorized into one suite, or population. Nevertheless, it is believed that the defined suites can be meaningful with respect to U/Th mineralization and perhaps genesis as well. The classification criteria used to subdivide the quartzofeldspathic rocks include detectable B and/or tourmaline, detectable Mo and/or molybdenite, and major lanthanides and/or allanite-(Ce). The K-feldspar/total feldspar ratio was used to further subdivide the Mo-bearing suite. K_2O–Na_2O–CaO ratios derived from atomic absorption and flame emission were used as cross-checks in the classification of all populations. Textures, such as gneissic vs. granitic, were not utilized in this classification. This classification scheme, developed for the anomalously radioactive granitic rocks studied herein, is *not* being proposed for general use in the Reading Prong or elsewhere. Attempts to correlate U-rich areas with existing mapped geologic units were unsuccessful. Attempts to use the classification system of Streckeisen (1976) were also largely unsuccessful.

Table 16 presents the results of normative calculations for the median analytical values for all quartzofeldspathic samples and for each of the subdivisions.

Throughout the following discussions of each suite, samples and localities are referred to by RP number. Appendix 2 shows these in numerical order and includes locations and other pertinent information.

[21]These factors assume a potassium feldspar with 15 percent K_2O and a plagioclase with 10 percent Na_2O, and that these are the only significant alkali-bearing species.

[22]"Granitic" as used herein refers to crystalline quartzofeldspathic rocks of both metamorphic and igneous origin. No particular texture is implied.

Table 16. *CIPW Normative Calculations of Median Analytical Values*

(Quantities are in percent)

Unit	Quartz	Corundum	Orthoclase	Albite	Anorthite	Diopside	Hypersthene	Magnetite	Ilmenite	Total
47 "granitic" rocks	33.93	0.93	31.26	25.30	4.17	—[1]	1.02	1.42	0.34	98.37
5 B-bearing alaskitic quartz monzonites	34.14	—	37.17	20.39	2.43	0.13	1.09	1.69	.27	97.31
4 Mo-bearing granodiorites	40.31	.33	12.53	30.97	10.42	—	2.56	2.38	.53	100.03
10 Mo-bearing quartz monzonites	32.37	.68	29.67	26.23	5.16	—	1.06	1.46	.38	97.01
3 allanite-bearing pegmatites	40.68	—	26.71	9.05	3.90	2.96	3.32	7.68	.99	95.29
26 "Byram" quartz monzonites	34.61	1.26	31.68	25.46	3.47	—	.91	1.39	.30	99.08

[1] A dash represents an absence in the calculated results for that particular mineral.

B-Bearing Alaskitic Quartz Monzonite Suite (Moderately Potassic)

This suite includes samples RP4, 15, 21, 22, and 42, all from the Chestnut Hill outlier, Northampton County. It is characterized by the presence of schorl(?) tourmaline (Figure 16), $NaFe_3^{2+}Al_6(BO_3)_3Si_6O_{18}(OH)_4$, as well as the absence of amphibole and pyroxene. K-feldspar, quartz, and albite, in approximate decreasing order, are major minerals in each thin section.

The K-feldspar in RP4 is perthitic orthoclase(?), and that in RP15 is microcline. RP21, 22, and 42 contain microcline with slightly lesser amounts of perthitic orthoclase(?). The plagioclase in RP42, which is the least altered of the suite but also contains the greatest percentage of Na_2O, is estimated to have a probable composition of An_4Ab_{96} based on the Michel Levy optical petrographic method, and a CaO content of only 0.52 percent in the bulk rock.

The suite has a median mineralogy (by X-ray diffraction estimate) of chlorite, 0.1 percent; mica, 1.3; amphibole, 0.0; quartz, 43.3; K-feldspar, 25.7; and albite, 13.7 (Table 15).[23] Using the more reliable alkali data obtained by flame emission, the median calculated amount of albite is 24.1 percent, and that of K-feldspar is 37.5 percent, yielding an assumed K-feldspar/total feldspar ratio of 0.61. In the absence of quantitative modal mineralogy of unaltered representative samples, this ratio is used to classify the suite as quartz monzonite (Table 17).

This B-bearing suite has a median chemical composition, determined by atomic absorption, of SiO_2, 73.9 percent; TiO_2, 0.14; Al_2O_3, 11.66; "Fe_2O_3," 2.34; MnO, 0.027; MgO, 0.15; CaO, 0.52; Na_2O, 2.41; and K_2O, 6.29. These data are organized with data for other suites and all 47 "granitic" rock samples for comparison in Table 13. The alaskitic appearance of this suite appears to conflict with the typical iron contents, suggesting that perhaps much of the iron in this suite may be highly concentrated in oxide phases. RP15 and RP21 are particularly enriched in opaque oxides.

Except for RP4, which has late calcite in fractures, the suite has a rather compact field on a K_2O–Na_2O–CaO plot (Figure 17A). The Na_2O/K_2O ratio is lower than other Reading Prong suites; that is, the suite is moderately potassic.

Semiquantitative trace-element analyses indicate that each sample in this suite contains measurable B within an observed range of approximately 20 to 100 ppm and with a median of 30 ppm. No other anomalously radioactive sampled granite or gneiss from the

[23]K-feldspar and albite estimates by X-ray diffraction are significantly low as discussed earlier. The data reported here have not been corrected.

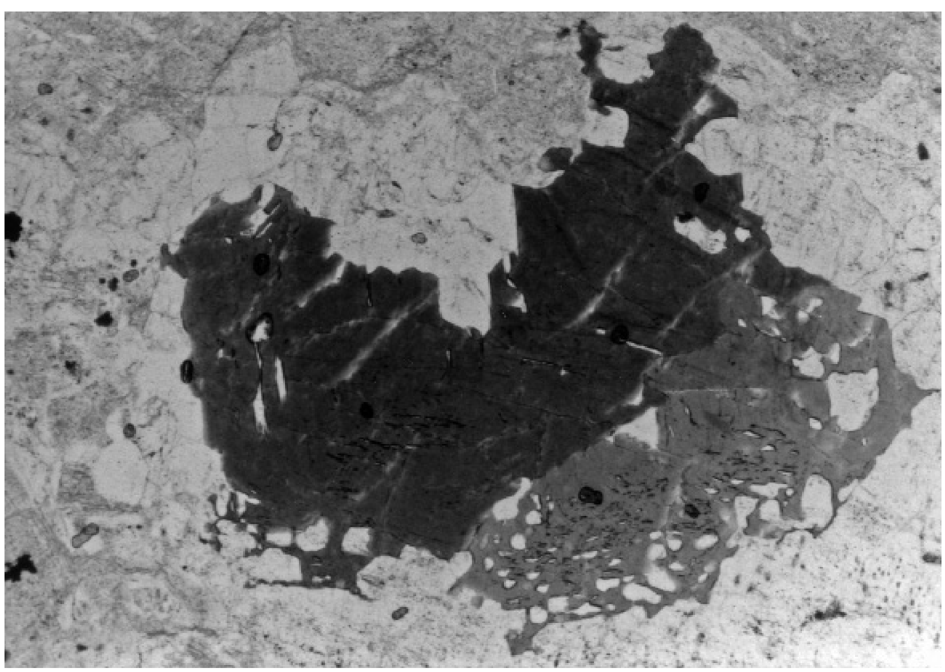


Figure 16. Photomicrograph (31x) of a thin section of sample RP15, from the Bushkill Drive anomaly, Northampton County, showing a large crystal of tourmaline (dark) in microcline.

Table 17. *Classification of B-Bearing Alaskitic Quartz Monzonite Suite Via Feldspar Concentrations Calculated From Flame-Emission Determinations of Percent K_2O and Percent Na_2O*[1]

Sample	K_2O	Calculated K-feldspar	Na_2O	Calculated Plagioclase	Percent K-feldspar / percent K-spar+plag.[2]	Classification
RP4	5.21	34.7	1.72	17.2	0.67	Quartz monzonite
RP15	6.29	26.8	2.54	25.4	.51	do.
RP21	6.70	44.7	1.77	17.7	.72	Granite
RP22	5.62	37.5	2.41	24.1	[3].61	Quartz monzonite
RP42	6.53	43.5	3.78	37.8	.53	do.

[1] Calculations made with the assumption that all potash is present as a K-feldspar containing 15 percent K_2O and that all soda is present as albite-oligoclase having 10 percent Na_2O.

[2] K-spar, K-feldspar; plag., plagioclase feldspar.

[3] The median value. Except for RP15, these K-feldspar/total-feldspar ratios agree well with those estimated from the X-ray data. The median derived from X-ray estimates is 0.65.

Reading Prong contains detectable B or tourmaline. Thus, the spatial association with the metasedimentary zinc-bearing marble, previously mapped as "Franklin" (in the same quarries as RP38, RP39, and others; see also Smith, 1977), sillimanite-bearing metagraywacke, and the Upper Proterozoic (Z-age) Chestnut Hill Formation of Drake (1984) may mean that this portion of the Musconetcong nappe core is distinct from the main mass of the Reading Prong. The median concentration of B and other trace elements for the various granitic suites is presented in Table 18. The median U of 70 ppm and median Th of 152 ppm should be noted. Figure 18 is a histogram of the U content of each of the suites. Sample RP21, with 166 ppm U, is the richest granitic sample of this suite.

Based on the report of Frazier (1882) of the B-bearing mineral manganaxinite at Camelhump, 7.1 miles (11.2 km) southwest along strike from Bushkill Gap, further discussed by Smith (1978b, p. 45–51), the Camelhump outlier is tentatively considered part of the Chestnut Hill province-nappe core. F. J. Markewicz (personal communication, June 13, 1984) reported similar tourmaline-bearing rocks at Marble Mountain, N.J., along the trend of the northwest portion of the Reading Prong, and boron minerals in the Franklin and Sterling Hill zinc ore bodies. Marble Mountain, in particular, is known to be mineralized with U and Th.

The rock comprising Saint Anthonys Nose, the east end of Chestnut Hill overlooking the Delaware River (Figures 19 and 20), contains quartz, K-feldspar, albite, schorl, and mica in approximate decreasing order of abundance. It is the most tourmaline-rich outcrop known in the Reading Prong of Pennsylvania, and possibly represents a late pegmatitic differentiate of this suite. It was not studied in detail because of its low radioactivity, but a heavy-mineral separate yielded major tourmaline, monazite as a common accessory, and several hexagonal prisms of molybdenite.

Molybdenite and thorite, $ThSiO_4$, may be somewhat characteristic of this suite of rocks and of Chestnut Hill in general. Other occurrences in Chestnut Hill where at least a trace of molybdenite was observed nearby include RP15, 38, and 39. Thorite has been observed in Chestnut Hill in RP4, RP21, RP38, in pits near RP42, in the southeasternmost outcrops overlooking the C. K. Williams quarry, and in Quarry L (Smith, 1977). Zoned zircons occur in RP15, 21, and 22. The thin section of RP42 contains a euhedral pleochroic grain of monazite.

Closely associated samples from Chestnut Hill include a titanite-bearing hybrid skarn (RP38) and titanite concentrates extracted from such skarns (RP66, 67, and 68), as well as serpentine-phlogopite skarns (see RP39, 43, 44, 57, and 60 in Appendix 2).

One sample from outside Chestnut Hill, RP24, also has some of the characteristics of the B-bearing alaskitic quartz monzonite suite. RP24 contains abundant titanite, based on relict leucoxene. Although it lacks B and tourmaline, it tends to resemble this suite from Chestnut Hill on a K_2O–Na_2O–CaO plot. Its intimate association with garnet-hornblende-diopside-epidote skarn (not shown on published maps) on the knoll just east of the RP24 sample site also resembles the situation at Chestnut Hill.

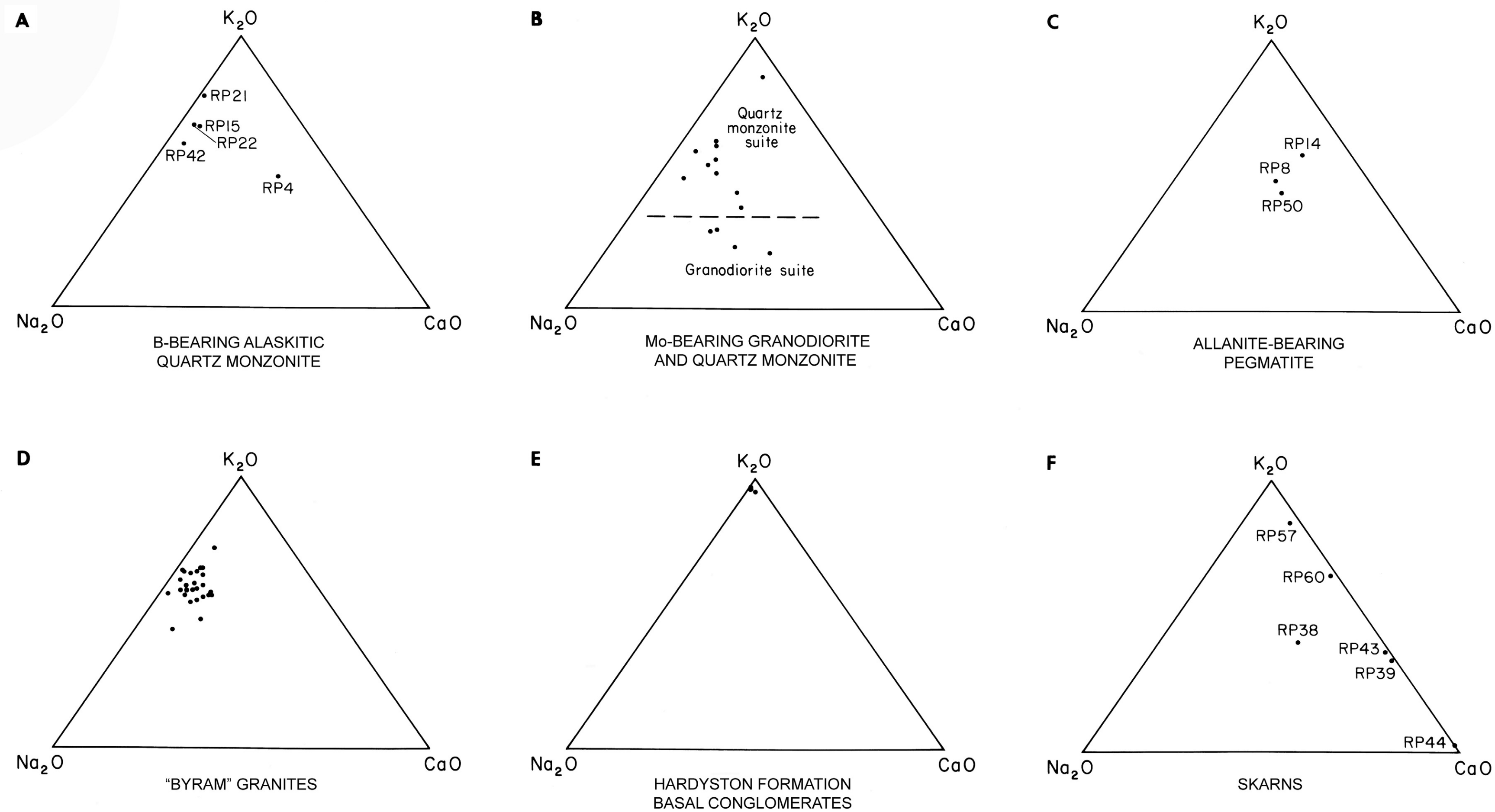


Figure 17. Plots of K_2O–Na_2O–CaO. A. Plot for the B-bearing alaskitic quartz monzonite suite, showing that it is moderately potassic. With the exception of RP4, with late calcite in fractures, the suite is low in calcium. B. Plot indicating the observed fields of the Mo-bearing granodiorite and Mo-bearing quartz monzonite suites. The granodiorite suite is distinctly low in K_2O relative to other suites in the Reading Prong. C. Plot for three allanite-bearing pegmatites. D. Plot for the "Byram" suite, as used herein, indicating the limited range of observed composition for mineralized samples of this low-calcium suite. E. Plot for basal Hardyston Formation samples, indicating the high concentration of K_2O relative to Na_2O and CaO. This is believed to be a result of leaching of the Reading Prong crystalline rocks that were the source of the heavy minerals in the sedimentary rock. F. Plot for the five skarn samples, reflecting the exceptionally low Na_2O content of this suite. Also shown is the hybrid sample RP38.

Table 18. *Medians of Trace-Element Concentrations for Reading Prong "Granitic" Rocks*

(Quantities are in parts per million)

Unit	B	Ba[1]	Be	Co	Cr	Cu	Ga	La	Mo	Nb	Ni	Pb	Rb[1]	Sc	Sn	Sr[1]	V	Y	Zr	U	Th	U/Th
47 "granitic" rocks	N[2]	305	1	N	L[3]	3	15	100	N	10	N	30	165	N	N	80	4	30	150	81	161	0.48
5 B-bearing alaskitic quartz monzonites	30	460	L	N	N	3	30	70	N	N	N	30	235	N	N	80	N	70	150	70	152	.50
4 Mo-bearing granodiorites[4]	N	282	2	5	5	22	15	125	15	N	8	30	65	N	N	120	35	12	225	87	288	2.59
10 Mo-bearing quartz monzonites	N	445	1	N	2	4	15	110	8	2	N	36	128	N	N	98	11	30	85	192	75	3.72
3 allanite-bearing pegmatites	L	725	2	7	N	5	15	7,000	N	50	L	30	160	N	N	225	15	500	2,000	70	952	.10
26 "Byram" quartz monzonites	N	245	1	N	N	3	15	82	N	10	N	30	190	N	N	72	N	30	100	54	146	.42

[1]Ba, Rb, and Sr determined by flame emission by Pennsylvania Geological Survey.
[2]N, not detected.
[3]L, detected but below limit of determination.
[4]Includes sample RP31 from Jobst magnetite mine.

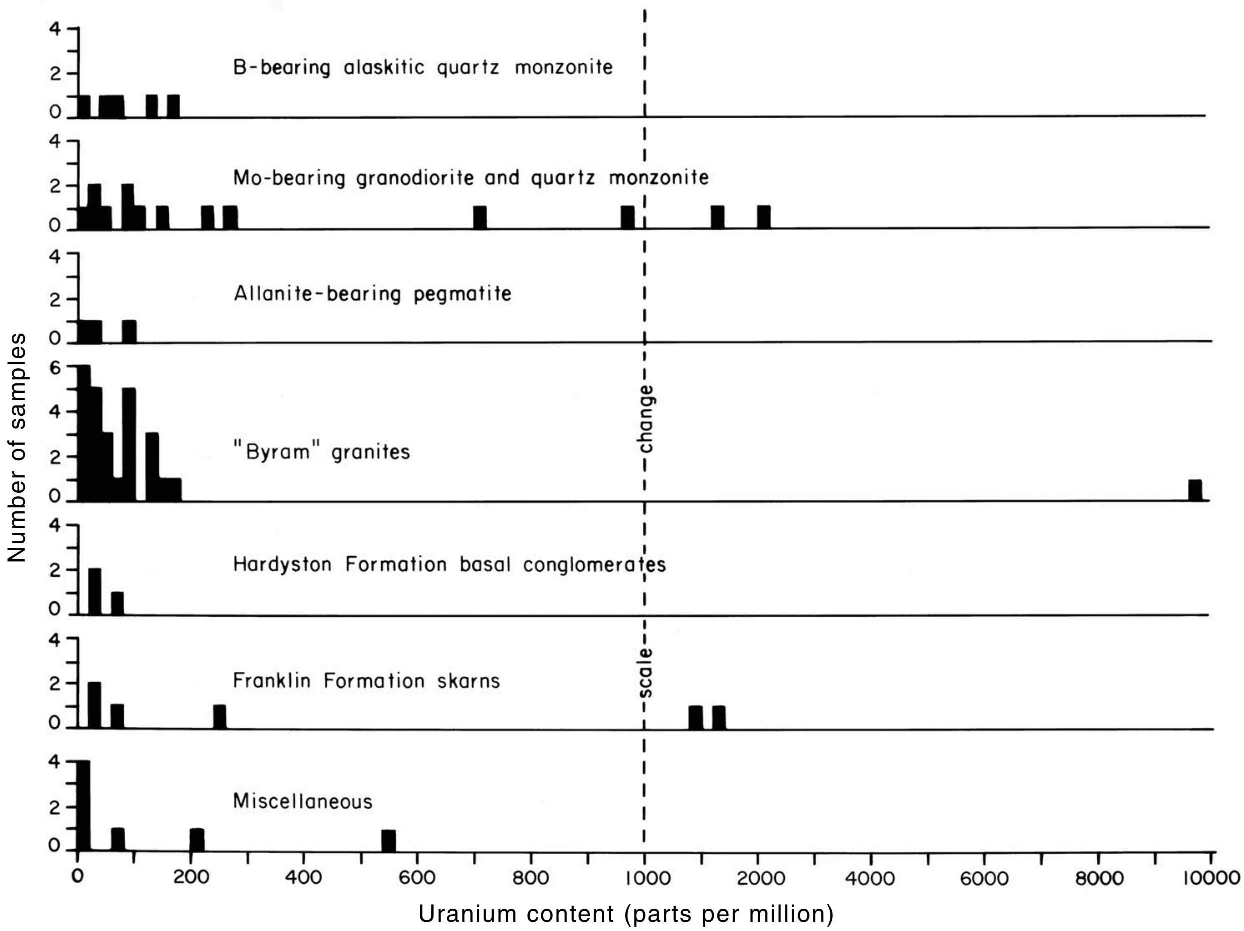


Figure 18. Histogram of the uranium content of each suite.

Mo-Bearing Granodiorite (Relatively Sodic) and Mo-Bearing Quartz Monzonite Suites (Intermediate Alkalis)

The Mo-bearing granodiorite suite includes samples RP31 (a vein contact not included among the 47 granitic samples for statistical calculations), 33, 49, and 53. The related Mo-bearing quartz monzonite suite includes samples RP2, 6, 10, 23, 37, 48, 55, 56, 63, and 64. All but one of these samples are from Lehigh and Berks Counties. (The exception, RP55, is an unusual small cross-cutting pegmatite dike that is 974.5±2.4 Ma, located in Northampton County 0.9 mile [1.4 km] east of Lehigh County.) Most of the samples are from the Applebutter nappe unit and southeastern portions of the adjacent Irish Mountain nappe unit (as defined on Figure 3). No samples of this suite were obtained from the Musconetcong unit or Chestnut Hill outlier.

Both of these suites are typically characterized by (1) trace to minor Mo in most of the semiquantitative trace-element analyses (Table 8);[24] (2) the presence of trace to minor molybdenite (Figure 21) at each locality, except RP23 (which is similar to RP64, from the adjoining property) and RP37 (which is similar to RP63, from a boulder 50 m to the north); and (3) ratios of calculated K-feldspar/total feldspar of 0.26 to 0.30 for the Mo-bearing granodiorite suite and 0.41 to 0.59 for the Mo-bearing quartz monzonite suite (Table 19). As discussed below, they differ slightly in other ways. Other interesting accessories in this latter suite include intensely pink garnet in RP37; probable monazite (optically positive, high relief, pale green, pebbly appearance) in RP2 and RP6; and an optically negative but similar appearing mineral in RP37. Zircon was observed in some thin sections in this suite. It is commonly zoned and partly metamict.

[24]Mo was not detected in RP37, but was found in RP63 from the same area. RP49 also lacks detectable Mo, but molybdenite-rich hand samples were found on the same dump.

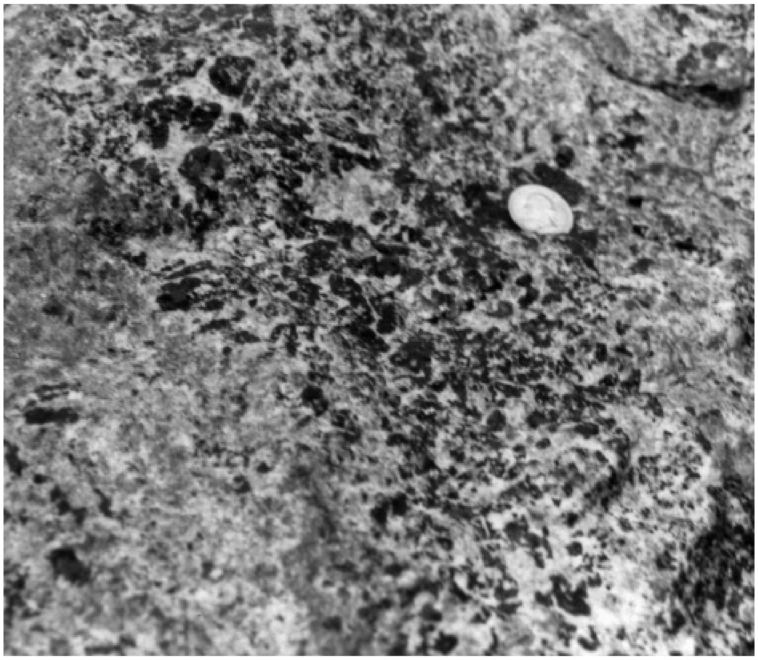


Figure 19. Tourmaline (black) in an unusually B-rich phase of the B-bearing alaskitic quartz monzonite suite. From a roadcut of Pa. Route 611 through the east end of Chestnut Hill, Northampton County. The outcrop is locally known as Saint Anthonys Nose. U.S. quarter for scale.

The Mo-bearing granodiorite suite lacks amphiboles, an exception being RP31, the vein sample. Pyroxenes are likewise absent, except for sample RP53, a composite of two rock types, one of which does contain pyroxene. Thin sections typically contain quartz and lesser, variable amounts of K-feldspar relative to altered plagioclase. Of the four thin sections from which the plagioclase composition could be estimated, three (two from different phases of RP53) have estimated compositions of An_{36-37}, and one has an approximate composition of An_{26}. Hand samples from each locality are gray in color. The zircons in most of the thin sections are strongly zoned. Sample RP49, which consists of two rock types, contains a grain of probable monazite in one thin section.

The Mo-bearing quartz monzonite suite also tends to lack amphiboles and, especially, pyroxenes. Only RP23, 48, 55, and 63 contain even trace amphibole (R. I. Grauch, personal communication, March 6, 1984).[25] The thin sections examined contain quartz and K-feldspar with what appear to be lesser amounts of plagioclase. This apparent low content of plagioclase could, however, be the result of partial sericitic alteration. The K-feldspar in most samples is perthitic. Samples of the Mo-bearing quartz monzonite suite are the most sheared and altered of the observed populations. Because

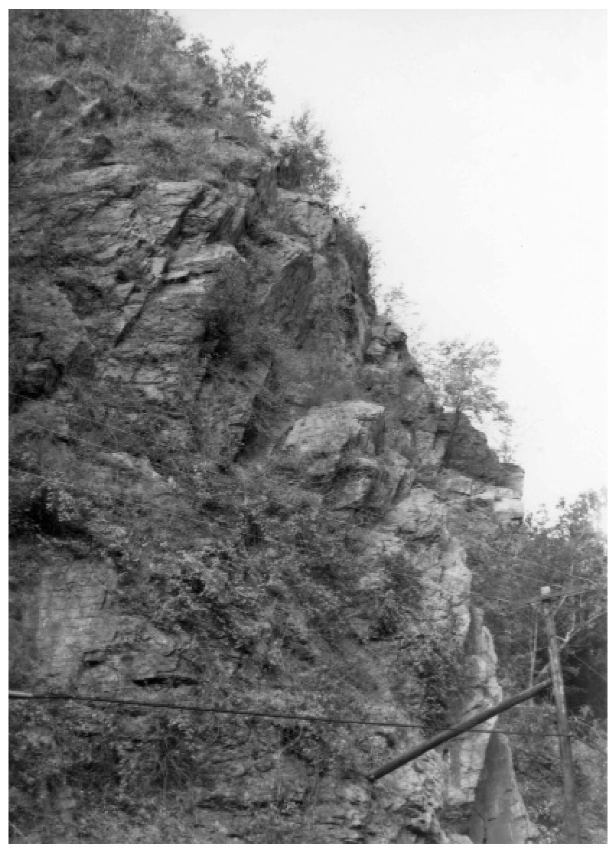


Figure 20. Photograph from the southeast of Saint Anthonys Nose on the east end of Chestnut Hill, Northampton County. The foreground consists of an unusually tourmaline-rich phase of the B-bearing alaskitic quartz monzonite suite.

[25] A "gray granite" in the same outcrop as RP55 also contains fresh green clinopyroxene cores with altered rims.

Figure 21. Photograph of a roadcut to the southeast of Antietam reservoir, Berks County. A geologist stands at a location where there is coarse-grained molybdenite along the contact between felsic gneiss (similar to samples RP2 and RP56) to the right and mafic gneiss to the left.

Table 19. *Classification of Mo-Bearing Granodiorite and Mo-Bearing Quartz Monzonite Suites via Feldspar Concentrations Calculated From Flame-Emission Determinations of Percent K_2O and Percent Na_2O*[1]

Sample	K_2O	Calculated K-feldspar	Na_2O	Calculated plagioclase	Percent K-feldspar / percent K-spar + plag.[2]
			Granodiorite		
RP31[3]	2.09	13.9	3.77	37.7	0.27
RP33	2.14	14.3	3.54	35.4	.29
RP49	2.51	16.7	3.92	39.2	.30
RP53	1.32	8.8	2.57	25.7	.26
			Quartz monzonite		
RP2	3.23	21.5	2.50	25.0	.46
RP6	5.18	34.5	3.08	30.8	.53
RP10	6.11	40.7	3.84	38.4	.51
RP23	6.17	41.1	3.13	31.3	.57
RP37	4.71	31.4	3.24	32.4	.49
RP48	6.18	41.2	2.91	29.1	.59
RP55	4.60	30.7	4.24	42.4	.42
RP56	2.31	15.4	2.19	21.9	.41
RP63	4.85	32.3	3.42	34.2	.49
RP64	5.68	37.9	2.72	27.2	.58

[1]Calculations were made assuming that all potash is present as K-feldspar containing 15 percent K_2O and that all soda is present as albite-oligoclase with 10 percent Na_2O.

[2]K-spar, K-feldspar; plag., plagioclase feldspar.

[3]A vein contact, rather than a granitic rock.

of alteration, the plagioclase composition was estimated for only one sample, RP63. It is estimated to have a plagioclase composition of An_{34}. Samples of RP63 and RP37 (from the same hill) also contain bright red hematite dust along selected plagioclase twin planes. The abundance of opaque oxides in most thin sections from this suite ranges from 10 small grains to approximately 0.5 percent.

The median mineralogy (X-ray estimates) of the Mo-bearing suites is summarized in Table 15, which includes data for other suites for comparison. Using the more reliable flame-emission-derived alkali data, the median percentages of feldspars calculated from alkali concentrations for the Mo-bearing granodiorite are 14.1 percent K-feldspar and 36.6 percent albite. These yield a K-feldspar/total feldspar ratio of 0.28 for the granodiorites. The comparable data for the Mo-bearing quartz monzonites are 33.4 percent K-feldspar, 31.0 percent albite, and a ratio of 0.52. These data constitute the basis for classifying the suites as granodiorite and quartz monzonite.

The major- and minor-oxide data of the suites are summarized in Table 13. The moderate enrichment of the granodiorite suite in total iron as "Fe_2O_3" and in CaO should be noted. The fields of the suites are shown on a K_2O–Na_2O–CaO plot (Figure 17). As expected, the granodiorite suite is distinctly low in K_2O relative to other suites from the Reading Prong.

Semiquantitative trace-element analyses indicate that nearly every sample in the Mo-bearing granodiorite suite contains detectable Mo, with a median of 15 ppm. The median for the Mo-bearing quartz monzonite suite is 8 ppm. No other sampled granite or gneiss from the main mass of the Reading Prong (excluding the Chestnut Hill outlier) contains detectable Mo or molybdenite. Xenotime may be a somewhat characteristic trace mineral of the Mo-bearing granodiorite and quartz monzonite suites.

For the Mo-bearing granodiorites, the median U is 86 ppm and for the Mo-bearing quartz monzonites, it is 192 ppm. Both suites contain samples that could be from significant uranium occurrences.

Samples RP52 and RP65, both from Swoveberg Hill in the southeast portion of the Reading Prong, show a possible relation to the Mo-bearing quartz monzonite suite but were not included in the median calculations. Mo was not detected in the trace-element analyses, but a trace of molybdenite was found in heavy-mineral separates of RP65. The ratios of calculated K-feldspar/total feldspar for RP52 and RP65, 0.57 and 0.55, respectively, fit the granodiorite classification as well as the "Byram" granitic suite (see below) to which they were assigned. Both samples could contain xenotime. The Swoveberg Hill occurrence is described further in Phase III.

Allanite-Bearing Pegmatite

This suite includes samples RP8, 14, and 50 from Berks, Bucks, and Lehigh Counties, respectively. Samples RP8 and 14 are from the Applebutter nappe as used herein, whereas RP50 is from the Irish Mountain nappe. The suite is characterized by minor to major amounts of coarse (>1 cm) allanite-(Ce) crystals in otherwise dissimilar quartz pegmatite granites. RP8 is a hedenbergite-microperthite-quartz-allanite pegmatite granite. The allanite-(Ce) crystals are partly zoned and have lighter colored rims (Figure 22). Titanite occurs as partial rims on opaque oxides (Figure 23). RP14 is a quartz–K-feldspar–allanite pegmatite with a cataclastic texture. The quartz exhibits pressure-solution suturing. The allanite-(Ce) in RP14 occurs as tabular crystals with olive to brown pleochroic cores and golden rims. Zircon occurs as euhedral grains in trains and clusters near allanite-(Ce). Several unidentified grains that are pleochroic from red-brown to brown and have high relief occur adjacent to allanite-(Ce). The optical properties of the red-brown grains and the relatively high bulk MnO content of 0.155 percent suggest a possible rare-earth piemontite or manganoan allanite. RP50 is a hornblende–quartz–K-feldspar pegmatite with altered allanite-(Ce). Zircon crystals occur in clusters.

What has here been grouped into a "suite" on the basis of grain size and allanite-(Ce) probably consists of only grossly similar differentiates of initially different parent compositions. Because of this and the small number of samples, the following combined median mineralogic and chemical data should be interpreted cautiously: chlorite, 0.2 percent; mica, 2.0; amphibole, 3.7; quartz, 38.4; K-feldspar, 7.6; albite, 5.5; and SiO_2, 69 percent; TiO_2, 0.52; Al_2O_3, 8.08; total Fe as "Fe_2O_3," 10.60; MnO, 0.124; MgO, 0.44; CaO, 1.48; Na_2O, 1.07; K_2O, 4.52. Note that the percentage of amphibole is notably high and that TiO_2, MnO, K_2O, and especially "Fe_2O_3" are high. The Na_2O/K_2O ratio is very low.

The three samples have a somewhat limited range on a K_2O–Na_2O–CaO plot (Figure 17C). The median amount of calculated K-feldspar (from percent K_2O) is 18.7 percent, and the median amount of calculated albite is 10.7 percent. These yield a K-feldspar/total feldspar ratio of 0.64, which gives the suite a quartz monzonite classification.

Semiquantitative trace-element analyses verify that each sample is high in lanthanides and zirconium. For RP8, 14, and 50, the total of La, Ce, Pr, and Nd equals 2.0 percent, 1.85 percent, and 0.78 percent, respectively. The estimate of about 30 ppm Ho in RP8 may be significant because of a market price of Ho metal of $1,600/kg (Hedrick, 1987).

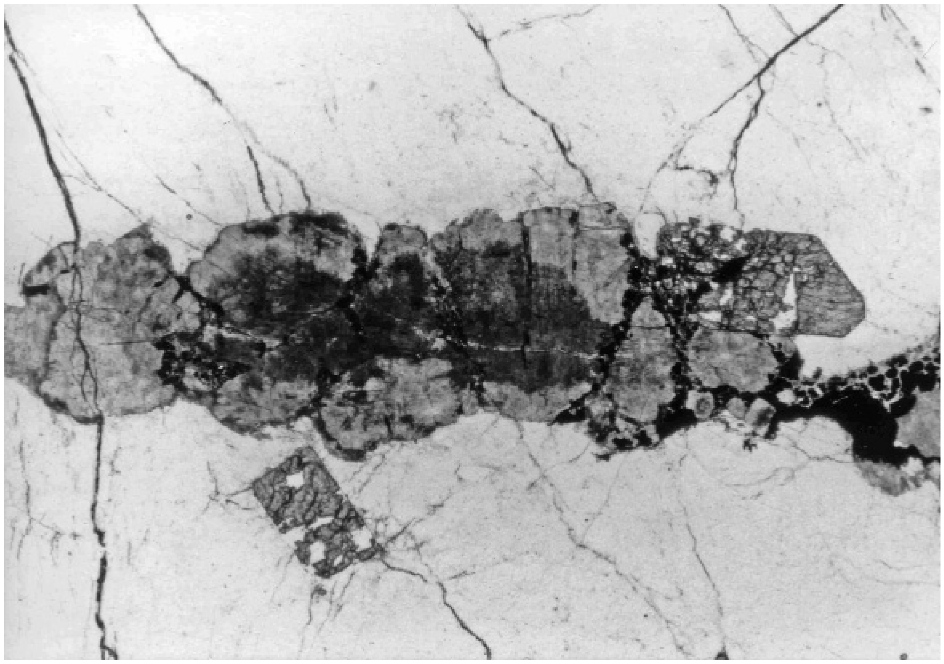


Figure 22. Photomicrograph (31x) of a thin section of sample RP14, from the Dogwood Lane anomaly, Bucks County, showing a large zoned allanite-(Ce) grain with a dark core and a lighter rim. Also visible are euhedral zircon crystals.

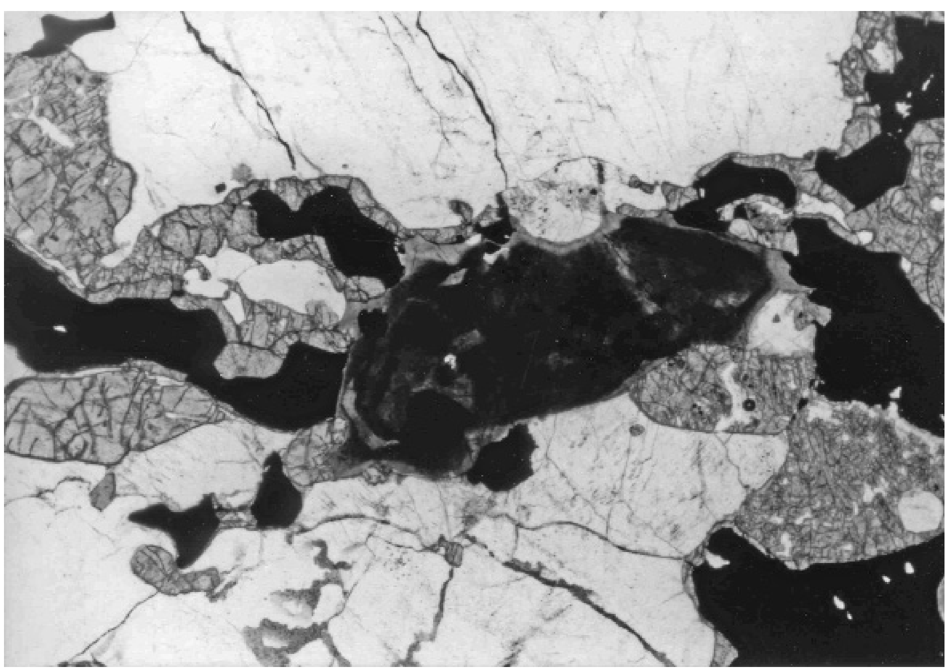


Figure 23. Photomicrograph (31x) of a thin section of sample RP8, from the Water Street anomaly, Berks County, showing a partial titanite rim on opaque Fe-Ti oxides adjacent to allanite-(Ce).

"Byram" Granitic Rocks

The "Byram" granitic suite includes all of the 47 grossly granitic samples minus the three populations defined on the basis of B, Mo, and allanite-(Ce). The 23 "Byram" samples are RP3, 9, 11, 12, 16, 17, 18, 19, 20, 25, 26, 28, 30, 35, 36, 40, 46, 51, 52, 59, 61, 62, and 65, and constitute what appears to be a moderately congruous population. Most of the samples are from the Applebutter nappe as used herein. Aberrant samples RP24 (potassic), RP27 (brecciated, sodic), and RP29 (magnetite-rich, sodic) are included with the "Byram" samples only for the lack of a better pigeonhole.

The "Byram" suite is characterized by typically pink- to salmon-colored, moderately coarse-grained granitic rocks that lack tourmaline or measurable B, are relatively low in CaO and, except for RP24, 27, and 29, have a limited range of K_2O–Na_2O–CaO contents (Figure 17D).

The suite has a median mineralogy, by X-ray diffraction estimate, of quartz, 39.2 percent; K-feldspar, 23.2; albite, 17.0; mica, 0.6; chlorite, 0.4; and amphibole, 0.0 (Table 15). Calculations based upon the flame-emission data indicate that the median sample could contain 33.9 percent K-feldspar and 27.4 percent albite if only alkalies are considered, yielding a K-feldspar/total feldspar ratio of 0.55. This suite is thus classified as quartz monzonite (Table 20) if only feldspars are considered.

The "Byram" mineralized suite, as defined above, has a median chemical composition of SiO_2, 74.6 percent; TiO_2, 0.16; Al_2O_3, 13.28; total Fe as "Fe_2O_3," 1.91; MnO, 0.019; MgO, 0.14; CaO, 0.70; Na_2O, 3.01; and K_2O, 5.36 by atomic absorption and flame emission (Table 13). This is somewhat different from the formal "Byram Intrusive Suite" of Drake (1984, Table 11).

Medians of the semiquantitative trace-element data for various populations are summarized in Table 10. The "Byram" group is not separated from the other granitic rocks in this table because, although the medians for Ba and Zr are lower and the median for Nb is higher than for other populations, the variation of these elements is too large to use these criteria to define populations.

Figure 24 is a histogram of the U/Th ratios observed for the 26 "Byram" samples, including the three deviates, RP24, 27, and 29. It shows two distinct populations. One, included in the U/Th range 0–1.0, is designated as "barren" and the second, included in the range 3.5–6.0, is designated as "mineralized." The mineralized samples are somewhat lower in Ba and higher in Nb than the barren samples, but the distinction is not consistently useful. The mineralized Byram occurrences, RP11, 28, 52, and 65, are described further in Phase III.

Hardyston Formation Basal Conglomerates

The basal portion of the Cambrian Hardyston Formation is represented by three samples, RP5 from Constitution Drive (Figure 25), RP34 from South Mountain Park, and RP47 from Pa. Route 309, 0.37 km east of Emaus Avenue, Allentown, all from Lehigh County. These three samples were collected from the Irish Mountain nappe as used herein.

The Hardyston is described as principally feldspathic sandstone, arkose, and orthoquartzite (Aaron, 1969), but the basal portion, represented here, generally is conglomeratic with abundant quartz pebbles and fossil placer concentrations.

RP5 has a particularly high concentration of opaque minerals, presumably ilmenite and magnetite. Hand samples are magnetic. The opaque minerals in RP5 constitute 70 percent of the minerals as estimated by point counting, much more than either of the other two samples. RP5 is also distinct in having a higher concentration of feldspar and a lower concentration of quartz than the other two samples, according to both point counting and X-ray diffraction.

RP34 is distinguished by purplish quartz cobbles up to 10 cm in diameter and thorite grains up to 5 mm in diameter. It has a radioactivity measured at the outcrop of 0.90 "mR/hr," as opposed to 0.12 "mR/hr" for RP5 and 47. RP34 is the only one of the Hardyston samples in which thorite was observed in thin section. It occurs as red grains surrounded by anastomosing fractures, and possibly as associated veinlets of dark-red material. Thorite constituted 2 percent of the points counted, whereas analyses of the bulk sample yielded 0.2 percent Th.

According to both X-ray diffraction and point counting, RP34 has the greatest concentration of quartz of the three samples, and much less feldspar than RP5. It also has the smallest concentration of opaque minerals, only 15.5 percent. Hand samples are very weakly magnetic.

RP47 is more like RP5 than RP34, except that it contains more quartz, less feldspar, a smaller concentration of opaque minerals, and more of the sericitic matrix. Hand samples are very weakly magnetic. A trace of weathered thorite was observed in hand specimen. A probable titanium oxide was observed in thin section, as was an unidentified yellowish-green grain showing high relief and possible twinning.

More zircon crystals were counted in the RP47 thin section than in the other two, but zircon was ob-

Table 20. *Classification of "Byram" Granitic Rocks via Feldspar Concentrations Calculated From Flame-Emission Determinations of Percent K_2O and Percent Na_2O*[1]

Sample	K_2O	Calculated K-feldspar	Na_2O	Calculated plagioclase	Percent K-feldspar / percent K-spar + plag.[2]
RP3	5.29	35.3	3.38	33.8	0.51
RP9	6.28	41.9	2.85	28.5	.60
RP11	5.28	35.2	3.52	35.2	.50
RP12	6.17	41.1	3.01	30.1	.58
RP16	5.29	35.3	3.41	34.1	.51
RP17	5.38	35.9	3.13	31.3	.53
RP18	5.21	34.7	3.01	30.1	.54
RP19	6.25	41.7	2.66	26.6	.61
RP20	5.95	39.7	3.05	30.5	.56
RP24[3]	7.79	51.9	2.10	21.0	.71
RP25	5.99	39.9	2.98	29.8	.57
RP26	5.02	33.5	2.94	29.4	.53
RP27[3]	4.23	28.2	3.29	32.9	.46
RP28	5.36	35.7	2.99	29.9	.54
RP29[3]	3.60	24.0	3.86	38.6	.38
RP30	4.75	31.7	3.22	32.2	.50
RP35	5.08	33.9	2.74	27.4	[4].55
RP36	5.75	38.3	3.29	32.9	.54
RP40	5.95	39.7	2.97	29.7	.57
RP46	5.35	35.7	2.19	21.9	.62
RP51	5.95	39.7	3.18	31.8	.55
RP52	4.58	30.5	2.32	23.2	.57
RP59	4.89	32.6	3.54	35.4	.48
RP61	5.39	35.9	3.27	32.7	.52
RP62	6.05	40.3	2.70	27.0	.60
RP65	4.19	27.9	2.28	22.8	.55

[1]Calculations were made assuming that all potash is present as K-feldspar containing 15 percent K_2O and that all soda is present as albite-oligoclase with 10 percent Na_2O.
[2]K-spar, K-feldspar; plag., plagioclase feldspar.
[3]Dubious affinity.
[4]Median.

served in all three. Tourmaline is present in all three, exhibiting zoning from an outer dark brownish-green rim to an inner green core when viewed down the C axis (Figure 26). Garnet was not observed in any of the thin sections. A possible xenotime grain was observed in RP47.

The matrix in all three thin sections is a fine-grained material interpreted to be sericite. There is good agreement between the abundance of this matrix material in the thin sections and the amount of mica estimated by X-ray diffraction.

A triangular plot of K_2O–Na_2O–CaO (Figure 17E) shows the basal Hardyston samples to be high in K_2O and low in Na_2O and CaO, unlike the other lithologies included in this study. This is probably the result of leaching of Na_2O and CaO during the development of the post-Precambrian unconformity, and of the mechanical destruction of feldspars during deposition in a high-energy alluvial environment.

The basal Hardyston samples are also distinct in having a high TiO_2 content, from a minimum of 2.81 percent in RP34 to 7.10 percent in RP47. The world average for sandstones is only 0.25 percent (Turekian, 1977). The high TiO_2 content supports the likelihood that many of the abundant opaque grains are ilmenite. In addition, grains believed to be a titania mineral were observed in the thin section for RP47.

The iron content of the basal Hardyston samples is high, ranging from 11.85 percent total iron expressed as "Fe_2O_3" in RP34 to 35.95 percent in RP5.

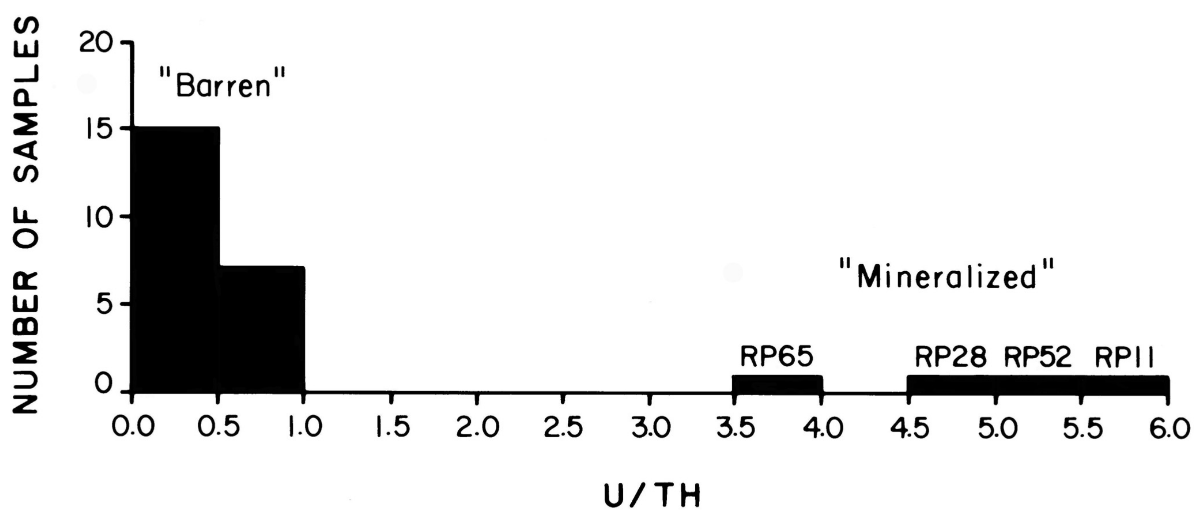


Figure 24. Histogram of the U/Th ratio of the 26 "Byram" samples, including the three deviates RP24, 27, and 29.

Figure 25. Photograph of fossil placer layer of sample RP5 (first bed above hammer head) at the base of the lowermost Cambrian Hardyston Formation, Lehigh County. The foreground is weathered regolith(?) developed on Precambrian gneiss, overlain by sheared rock of unknown origin.

The median for the granites is 1.97 percent, and the world average for sandstones is 1.40 percent (Turekian, 1977). Again, this is a reflection of the abundant opaque grains, believed to be predominantly ilmenite and magnetite in RP5.

The Zr content of the basal Hardyston ranges from 1,000 ppm in RP34 and RP47 to 2,000 ppm in RP5. These results are well above the 220 ppm in the world-average sandstone (Turekian, 1977), reflecting the zircon observed in the thin sections. V and Y also appear to be rather high, particularly the 700 ppm Y in RP47, compared with 150 ppm in RP34 and 10 ppm in the world-average sandstone (Turekian, 1977). This abundance of Y supports a tentative visual identification of xenotime in the RP47 thin section. Higher-than-average B (median equals 150 ppm, versus 35 ppm in the world-average sandstone [Turekian, 1977]) reflects the observed tourmaline.

The quantities of U, Th, and rare-earth elements in the basal Hardyston samples are considerably higher than in the world-average sandstone, although the U/Th ratio is lower. In comparison to the 47 granite samples, the basal Hardyston has less U and more Th and rare-earth elements, reflecting the thorite and zircon observed in hand specimen and thin sections and probable leaching of U prior to lithification. The U/Th ratio for the three basal Hardyston samples ranges from 0.126 in RP5 to 0.031 in RP34, compared with 0.48 in the median Reading Prong granite and 0.31 in the world-average sandstone (Turekian, 1977).

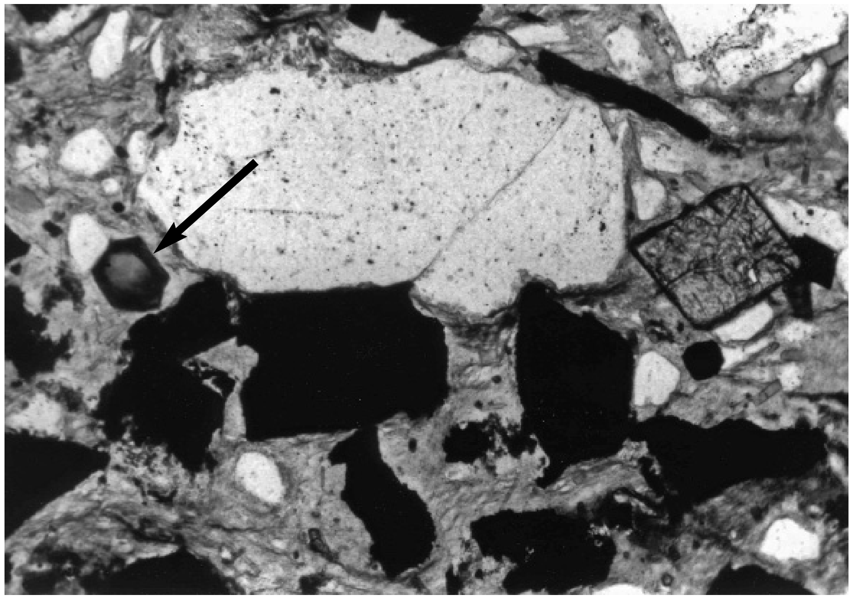


Figure 26. Photomicrograph (123x) of a thin section of sample RP34, a fossil placer at the base of the Hardyston Formation at South Mountain Park, Lehigh County. This view shows euhedral tourmaline (arrow) having a green core and brown rim, and separate euhedral grains of zircon.

Skarns

This suite includes samples RP39, 43, 44, 57, and 60 from Chestnut Hill, Northampton County. They are characterized by major to minor amounts of talc and serpentine-group minerals, such as lizardite, and by major MgO.

The samples were examined by X-ray diffraction scans and by thin section. Raw intensity data from the X-ray scans are listed in Table 21. Raw intensities give only a general indication of relative abundance and reflect other factors, as discussed in Appendix 3. This table also includes data for the hybrid sample, RP38.

RP39, from the C. K. Williams quarry, contains green phlogopite with white tremolite along shears. The X-ray scan also revealed major serpentine and talc and traces of dolomite. Trace pyrite and molybdenite were observed in the hand specimen and thin section.

RP43, from the East Lafayette Street talc quarry, has phlogopite (Figure 27), talc, and tremolite as major constituents, and serpentine as a minor one. Traces of chlorite and dolomite were detected by X-ray diffraction.

RP44, from the West Lafayette Street talc quarry, has dolomite as a major component, with minor serpentine and talc and traces of phlogopite, chlorite, and calcite. Trace pyrite and garnet were observed in hand specimen.

RP57 and RP60 are channel samples from Quarry L. RP57 contains major serpentine, minor phlogopite and talc, and traces of chlorite, dolomite, and calcite. RP60 has a much greater proportion of serpentine to phlogopite and more dolomite, according to the X-ray data.

On the triangular plot of K_2O–Na_2O–CaO (Figure 17F), the five skarn samples fall nearly on the K_2O–CaO leg, reflecting the exceptionally low Na_2O content. CaO values range from 20.30 percent in the high-dolomite sample, RP44, to 0.39 percent in RP57 from Quarry L. K_2O also varies, from 0.32 percent in RP44 to 3.31 percent in RP43. The K_2O variation is sympathetic with that of phlogopite.

The median skarn is lower in Al_2O_3 and higher in MnO and MgO than the other mineralized rock types in the Reading Prong. The MgO content is consistently high, ranging from 29.15 percent in RP43 to 37.05 percent in RP60, not surprising in view of the observed mineral assemblage.

The median Ba content of the median skarn (580 ppm) is the highest of any of the mineralized rock types examined. RP44, with its high carbonate content, had the second highest Ba content of any of the Reading Prong samples, 1,370 ppm.

The U content and U/Th ratio of the median skarn are higher than for other mineralized rock types (Table 10), but the uranium content of the individual skarn samples is actually quite variable. RP39, from the C. K. Williams quarry, and RP57, from Quarry

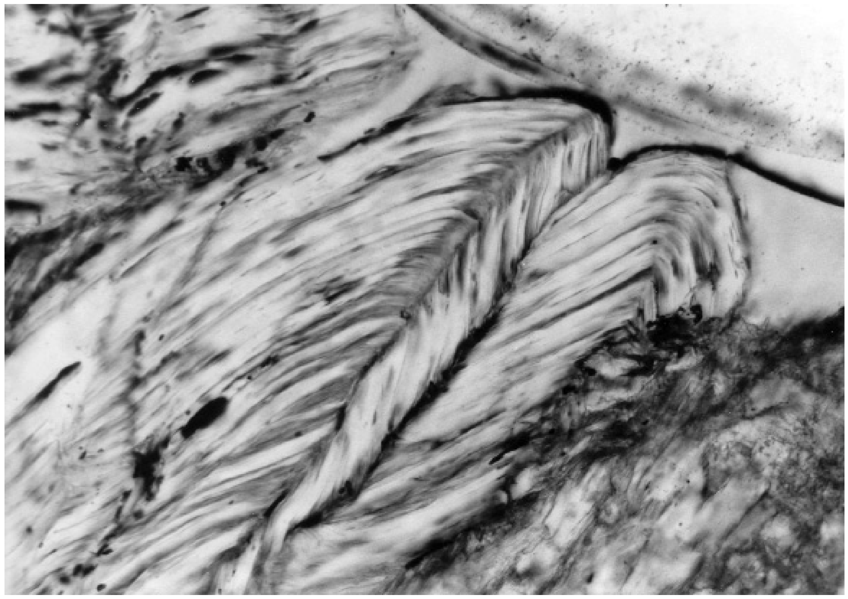


Figure 27. Photomicrograph (123x) of a thin section of sample RP43, from the East Lafayette Street talc quarry in Easton, Northampton County, showing phlogopite that has been deformed into kink bands.

L, each have greater than 1,000 ppm U and U/Th ratios of 4.5 or more, yet RP60, also from Quarry L, has 247 ppm U and a U/Th ratio of 0.858. RP43 and RP44, from the Lafayette Street talc quarries, have U contents of 30.2 and 63.0 ppm, and U/Th ratios of 0.112 and 0.774, respectively.

The related sample, RP38, is a green pyroxene-titanite-tourmaline-bearing gneiss from a reaction zone that is a few meters thick between granitic gneiss and skarn at Schweyer's quarry, near the west end of Chestnut Hill. Titanite concentrate RP67 was extracted from this zone and RP66 and RP68 (Appendix 4) are titanite concentrates from similar pyroxene gneisses. Thin-section examination of RP38 revealed major green pyroxene with pale cores (diopside[?]), strained quartz, microcline, and partly sericitized sodic plagioclase; minor titanite, zoned schorl(?), and calcite; trace subhedral thorite, euhedral zircon, epidote, and altered euhedral pyrite. Semiquantitative X-ray diffraction data are summarized in Table 21.

The location of RP38 on a K_2O–Na_2O–CaO diagram is intermediate between the Mo-bearing granodiorite and quartz monzonite suites and the skarns, suggesting that it is a true hybrid. The U content of 25 ppm and Th content of 243 ppm yield a U/Th ratio of only 0.10. Other anomalous trace elements, such as Nb, Sn, and Y, are discussed in Appendix 4.

Table 21. *Relative Peak Heights Recorded by X-Ray Diffraction for Minerals in Skarns of Chestnut Hill*

Sample	Chlorite 14Å	Phlogopite 10.1Å	Talc 9.3Å	Tremolite 8.4Å	Lizardite 3.66Å	Dolomite 2.89Å	Calcite 3.03Å
RP39	0	67	52	8	132	1	0
RP43	1	85	39	37	26	2	0
RP44	2	2	32	0	35	256	1
RP57	5	35	13	0	85	?[1]	0
RP60	9	4	18	0	156	6	0

[1] Question mark indicates a possible trace of dolomite.

PHASE III: FOLLOW-UP STUDIES OF SELECTED OCCURRENCES

The Phase III study consisted of the selection of nine significant uranium occurrences from the Phase II study for instrumental mapping with a gamma-ray spectrometer and magnetometer, and for mineralogic studies. The purpose of collecting these data was to determine the extent and distribution of near-surface uranium.

SELECTION CRITERIA

The rock-sampling sites of Phase II (samples RP1 through RP60) were evaluated primarily on the basis of total U content, U/Th ratio (Table 6 and Figure 14), and outcrop accessibility.[26] Another factor considered was Mo content. U contents greater than 200 ppm and U/Th ratios greater than 2 were considered favorable for locating possible sizeable U concentrations in this terrane and are indicated with asterisks in Table 6. However, not all of the occurrences that met both of those criteria were studied in detail. The RP10 occurrence, originally found by the senior author and A. W. Rose in 1967, is in an unsafe, rather narrow roadcut of the Northeast Extension of the Pennsylvania Turnpike. For the sake of safety and because of the limited thickness of the layer (15 cm [6 in.]) (Appendix 2), this outcrop was not studied in detail. The RP53 occurrence (Appendix 2), however, was found during follow-up in this area.

The RP32 and RP33 occurrence area, first reported by McKeown and Choquette (1968b), was disrupted by open-pit prospecting. The nearby RP62 occurrence was found during reconnaissance with the Mt. Sopris scintillometer, but that area did not appear to be suitable for instrumental mapping. The RP41 occurrence is in a highly mineralized area, first reported by McKeown and Klemic (1953); however, little undisturbed, fresh accessible rock was available in this moderately built-up area.

[26] In retrospect (April 1, 1987), another possible criterion should have been anomalously high ages estimated from total U, Th, and Pb. Such estimates might have helped to identify occurrences having more uranium at depth than suggested by near-surface samples. It would not, however, have been useful in skarns where hypogene nonradiogenic lead is indicated. Samples that yield ages greater than 800 Ma include RP6, 19, 22, 23, 26, 28, 41, 44 (skarn), 52, 56, 62, 63, and 65, but only semiquantitative data were available for lead. This criterion is based on the geochemical assumption that Pb mobility is small relative to potential uranium leaching in this environment (see, for example, Rose and others, 1979, Fig. A.2).

FIELD METHODS

Each area to be surveyed was first examined by reconnaissance of several hundred square dekameters (dam^2) (several acres) on foot using the Mount Sopris scintillometer around the site where the Phase II rock sample had been collected, observing outcrop locations, apparent lithologic and mineralization trends, direction of slope, and possible interferences to a potential magnetometer survey. Areas ranging from approximately 18 dam^2 (0.5 acre) to 110 dam^2 (2.5 acres) were selected for instrumental study based on these considerations. Most included substantial, relatively undisturbed wooded areas having abundant boulder-sized float. Base stations for surveying and periodic instrument checking were established.

For sites lending themselves to rectangular-coordinate grids (the sites of samples RP6, 11, 23, 28, 52, and the site that includes both RP57 and RP60), two parallel rows of small cairns at 10-m (33-ft) intervals were set up on opposite sides of the area to be studied, using pocket transits and a 50-m tape. Most compass bearings are believed to be accurate to $\pm 1^{\circ}$, and most tape measurements to ± 0.5 m (20 in.). The base stations were similarly surveyed relative to semipermanent nearby features and the nearest cairns. During actual data gathering, the tape was temporarily stretched between corresponding pairs of cairns (or to a third, middle row at Swoveberg [RP52]), and instrument data were collected at 5-m (16-ft) intervals within the rows, which were spaced 10 m (33 ft) apart.

Gamma-ray data, yielding estimates of potassium, uranium, and thorium, were collected using a Geometrics GR–410 Portable Gamma-Ray Spectrometer with a NaI(Tl) detector having a volume of 347 cm^3 (21.2 $in.^3$). For data collection at the rectangular-coordinate grids, the detector was placed in a backpack at a height of 1.25 m (4.10 ft) above the ground. At this height, the detector is believed to obtain two thirds of its counts from a circle having a diameter of approximately 2.5 m (8.2 ft) (Ward, 1981). Thus, two thirds of the counts come from 10 percent of the grid area.

Of the three sites that do not lend themselves to rectangular-coordinate grids, one consisted of large boulders along the crest of a hill, and two consisted of subvertical rock faces. For the hill crest (Chapel Hill; the source of samples RP9, RP37, and RP63), a tape-and-pocket-transit map was made of the individual boulders, and gamma-ray data were collected with the base of the sensor located 25 cm (10 in.) above the top surface of the typically flat rocks. For the subvertical rock faces (Forgedale Route; the source of samples RP16 and RP61), an attempt was made to collect gamma-ray data directly over the outcrop face from which RP16 was collected. RP16 is from an 80-cm (31-in.) excavated channel that was sampled at 10-cm (4-in.) intervals. An attempt was also made to collect gamma-ray data over the outcrop face from which RP61 was collected. RP61 is from a 97-cm (3.2-ft) excavated channel, plus adjoining outcrop, that was sampled at 20-cm (8-in.) intervals. Both sets of data were collected with the sensor 25 cm (10 in.) from the outcrop in a horizontal position. In the RP16 area, the detector was held 30 cm (12 in.) above ground level, and for RP61, 2.4 m (7.8 ft) above the creek level.

At the subvertical quarry face (C. K. Williams quarry, the northern portion of which is the source of sample RP39), a tape-and-pocket-transit map of the quarry outline was made, and data were collected with the gamma-ray spectrometer held in a horizontal position 25 cm (10 in.) from the quarry face and 1.55 m (5 ft) above the quarry floor.

Gamma-ray data were taken over three ten-second collecting periods at each survey point, and the median counts for K, U, and Th were later used for conversion to estimated concentrations. The disadvantage of mixing data from different ten-second collecting periods at a site is believed to be outweighed by rejection of possible spurious high and low counts via median selection. For typical background areas in the surveys, each ten-second collecting period typically yielded 1,000 total counts, 70 counts in the K channel, 25 counts in the U channel, and 20 counts in the Th channel. The medians from 6 sets of 3 ten-second counting periods collected in the same unmineralized area over three different days yielded ranges of 1,010 to 1,120 for total counts, 64 to 90 for K, 24 to 30 for U, and 15 to 26 for Th.

Magnetometer data were collected only on the rectangular-coordinate grids. Data were collected with a GeoMetrics proton precession magnetometer, model G816, with the sensor at a height of approximately 2.5 m (8.3 ft). Such proton magnetometers measure the total magnetic-field intensity. The largest drift-induced precision errors occurred in the Swoveberg survey, which required three days of measurements conducted over a span of seven days. Three magnetometer readings on each of the three days at the reference station suggest typical precision errors of less than ±75 gammas. Errors for the smaller grids done in one day are about one third as large. Contour intervals of 100, 500, or 1,000 gammas, depending on the magnetic relief, were used in the figures to avoid overinterpreting the data.

REDUCTION OF GAMMA-RAY SPECTROMETER DATA

The medians of the three ten-second counts at each survey point were converted into estimates of K, U, and Th through a computation derived by Stromswold and Kosanke (1978). D. C. Stromswold (personal communication, 1981) calibrated the instrument using the five concrete test pads at Walker Field airport, Grand Junction, Colo., each of which contained different amounts of K, U, and Th. Using the custom equations he provided, the counts above background were converted to percent potassium (K), parts per million equivalent uranium (ppm eU), and parts per million equivalent thorium (ppm eTh), following standard usage reflecting the fact that determinations of uranium and thorium are made from the radioactive decay of progeny, rather than the elements in question directly.

Background corrections were not included in the calculation of estimated concentrations from raw count data. This was based in part on the EG&G Geometrics manual for Model GR–410A, page 63, which indicated that, "In most cases it is not necessary to remove the small counting rates introduced by background sources in the instrument and surrounding air."

Estimates of background were taken with this instrument on the fourth span from the east end of the steel Walnut Street bridge over the Susquehanna River in Harrisburg. The median of four trials suggests that the background counts for 10-second accumulations are TC, 115; K, 3; U, 2; and Th, 1. For the reference calibration sites at Swoveberg, Limeport Road, and Quarry L, these background corrections would have reduced the reported K contents by 0.0 to 0.1 percent, eU by 0 to 1 ppm, and eTh by 0 to 1 ppm.

Although the lack of background correction introduced a slight systematic positive bias, it was judged to be insignificant relative to two other sources of error, possible height correction errors and counting errors. Neither the spectrometer manual nor the present manufacturer provided suggestions for possible data correction that might be required by calibration at Grand Junction at a height of 25 cm (10 in.) and data collection at 1.25 m (4.10 ft).

Because of its larger size and the consequent extended duration of data collection, the Swoveberg grid appears to represent a statistical worst-case scenario. Six sets of data collected at the Swoveberg reference site yielded observed means and standard deviations of 1.92±0.31 percent K, 5.2±0.7 ppm eU, and 16.3±3.0 ppm eTh. The one standard deviation counting error statements for the individual data, which were generated from equation 22 of Stromswold and Kosanke (1978), are approximately K, ±0.4 percent; eU, ±2 ppm; and eTh, ±4 ppm. The fact that the latter counting errors are larger than the former observed precision is due in part to the fact that the medians used are more precise than the individual net counts from which they were derived would indicate. This was suggested by the drop in calculated errors for the Swoveberg reference site to K, ±0.2 percent; eU, ±1 ppm; and eTh, ±2 ppm when the *sums* of the three 10-second accumulations were used in equation 22 of Stromswold and Kosanke (1978). In any case, the chosen contour intervals of 1 percent for K, 10 ppm for eU, and 10 ppm for eTh are large with respect to the anticipated errors.

CONTACT METAMORPHIC SERPENTINE-PHLOGOPITE HOST

Name: Quarry L

Samples: RP57, RP60

Location: On the west side of Bushkill Gap through Chestnut Hill, at a point 2.7 km (1.65 mi) northwest of the confluence of the Lehigh and Delaware rivers.

7.5-Minute Quadrangle: Easton
Latitude: 40°41'58"N
Longitude: 75°13'58"W
County: Northampton
City: Easton

Exposure: Moderately steep wooded slope and small, abandoned terrazzo or filler quarry.

Maps: Figures 28–32.

Tectonic setting: Chestnut Hill nappe as used herein.

Petrology: Phlogopite-serpentine.

Trend of Mineralization: Though difficult to visualize because of topography, mineralization appears to follow relict compositional bedding in the quarry face, here estimated to trend N85°E, 42°S. The U and Th is enriched in phlogopitic beds.

Comments: Similar mineralization, from west to east, occurs at Schweyer's quarry, RP44 area, RP43 area, Easton reservoir site (Montgomery, 1957), C. K. Williams quarry, and Royal Green Marble quarry (Montgomery, 1957). Titanite-bearing hybrid skarn-gneiss zones at Quarry L, Schweyer's quarry, and C. K. Williams quarry are enriched in Nb, Sn, and Y (Appendix 4). The hybrid contact-skarn at Quarry L is located at the extreme northeast corner of the grid. It is very well defined as both magnetic and K anomalies and less well defined as an eTh anomaly. As expected from the U/Th ratio of the RP66 titanite concentrate (U/Th=465/4,250), this area does not yield an eU anomaly. The lack of magnetic anomalies other than the one near the skarn in the northeastern part of the grid suggests that no other contact skarns are present within the grid area. That is, the area of serpentine-phlogopite extends well beyond the grid. The general south slope of the magnetic relief also suggests that the serpentine-phlogopite body dips to the south, consistent with the dip of compositional layering across the gap at Schweyer's quarry.

The coincidence of total gamma, eU, and eTh, but not K, at the mineralized area to the northwest of the quarry suggests that these anomalies might not be related to phlogopitic beds. See the summaries of Grauch and Ludwig (1979) and Smith (1977) in the section "Previous Studies."

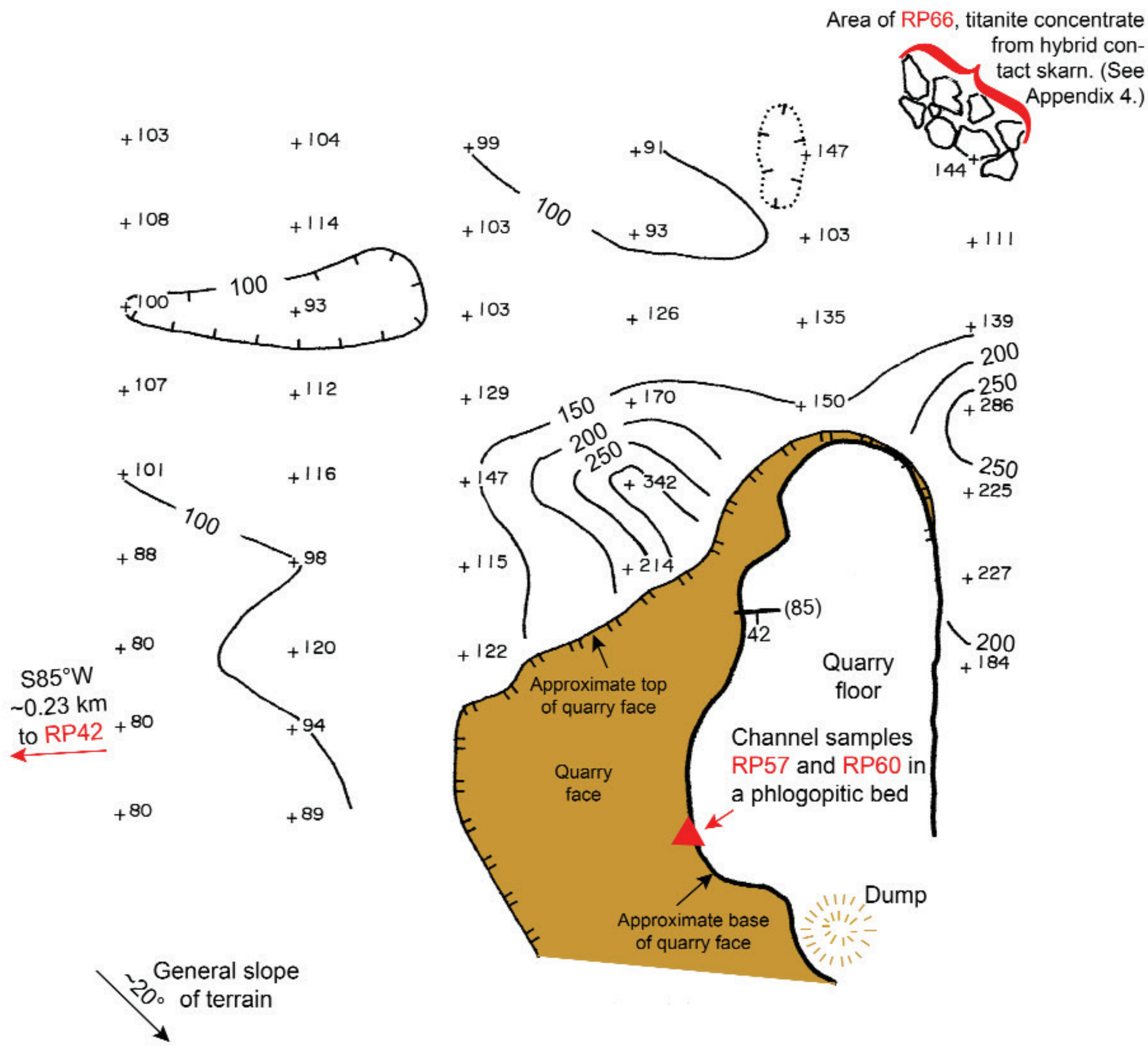
Primary "ore" minerals: Thorian uraninite (Smith, 1977) (see also Appendix 4 of this report). Trace pyrite as tiny inclusions in gray, wafer-thin, partial rims and fracture fillings of low-Th uraninite(?).

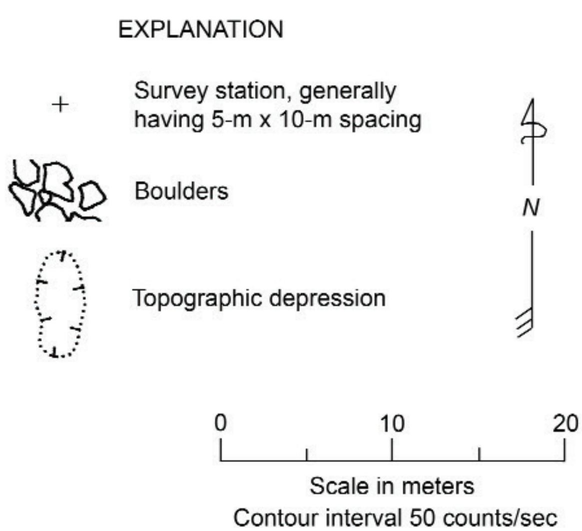
Secondary "ore" minerals: Thorogummite (pale yellow) and wolsendorfite(?) (Smith, 1977). Quarry L appears to lack the structural and mineralogic variability observed by Montgomery (1957) for the C. K. Williams quarry.

Assays: **RP57,** 1.22 m of phlogopite-serpentine perpendicular to bedding: 1,130 ppm U and 250 ppm Th. **RP60,** 1.0 m of phlogopite-serpentine perpendicular to bedding: 247 ppm U and 288 ppm Th. See also RP4, 15, 21, 22, 38, 39, 41, 42, 43, 44, 66, 67, and 68 from elsewhere along Chestnut Hill.

Possible volumes: A 1- x 10- x 20-m block (600 short tons) of 500-ppm U-mineralized rock within the grid area appears to be a reasonable possibility.

Suggestions for further study: If the area were unpopulated, resource studies for U and possibly other metals would be appropriate. As it is, the area appears to warrant environmental monitoring for radionuclides and gamma flux. The presumably undisturbed anomaly on the northwest side of the quarry appears to lend itself to pilot studies and an effort should be made to correlate it with rock exposed in the quarry face.





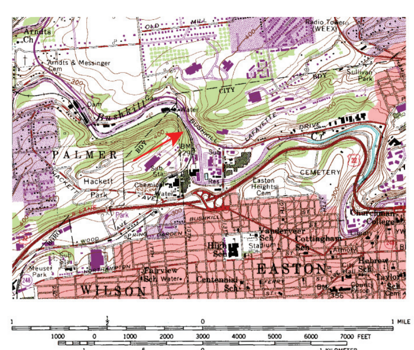
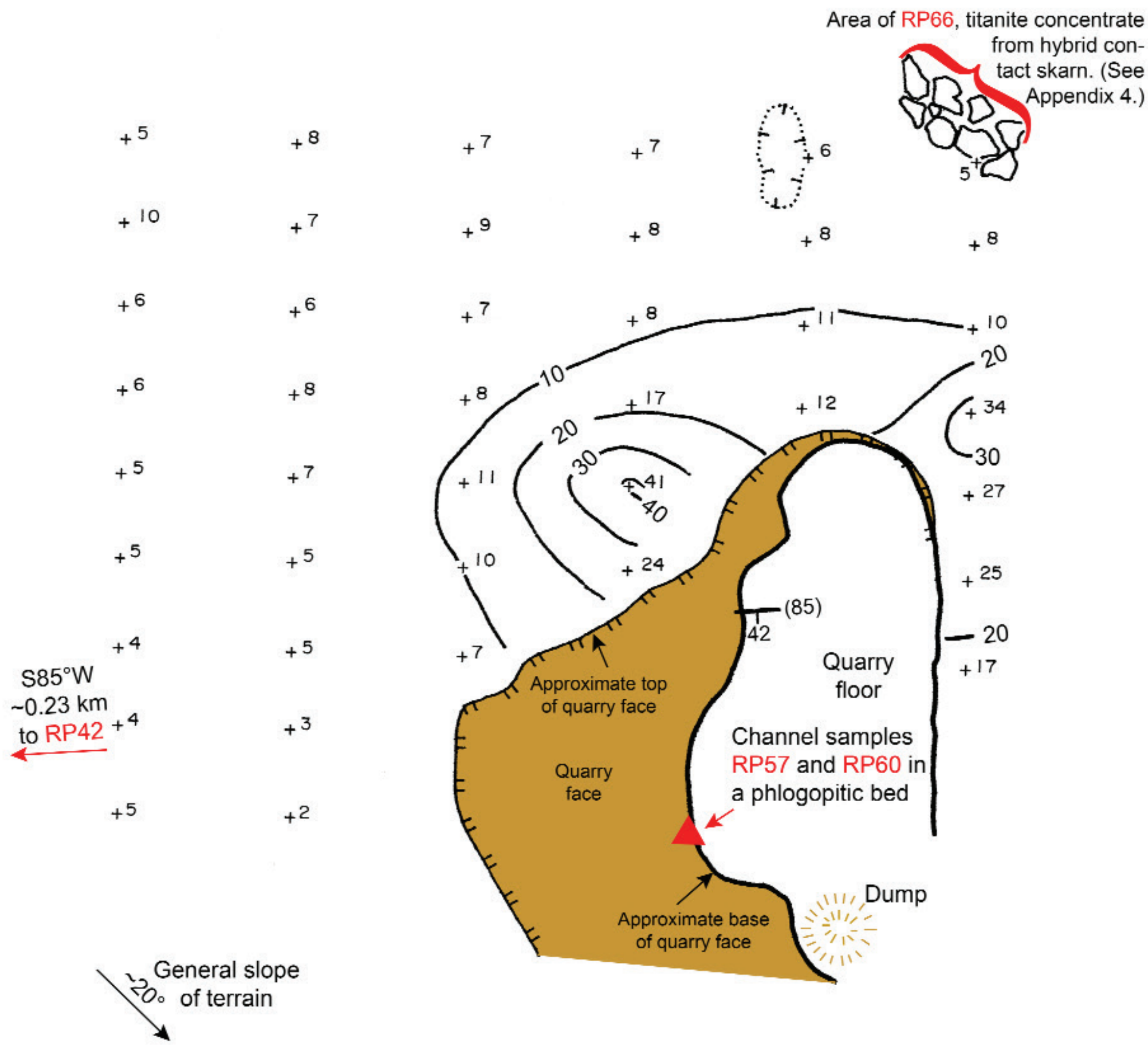
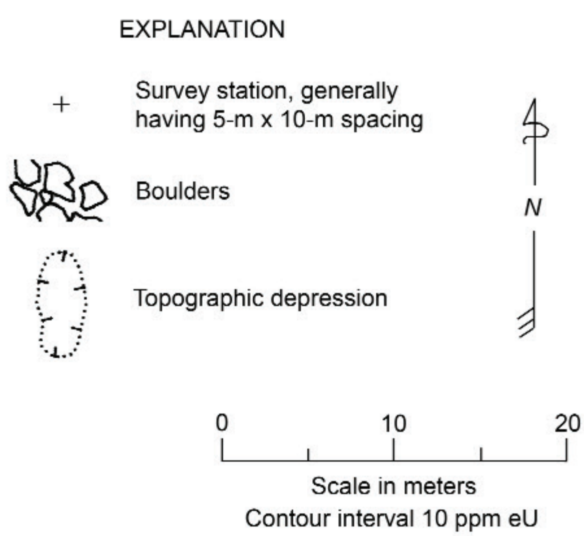


Figure 28. Contour map of total gamma counts per second at the Quarry L anomaly, city of Easton, Northampton County. Easton 7.5-minute quadrangle; 40°41'58"N, 75°13'58"W.





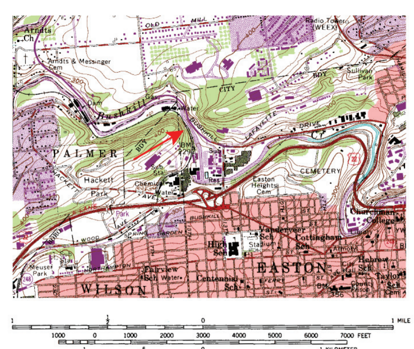
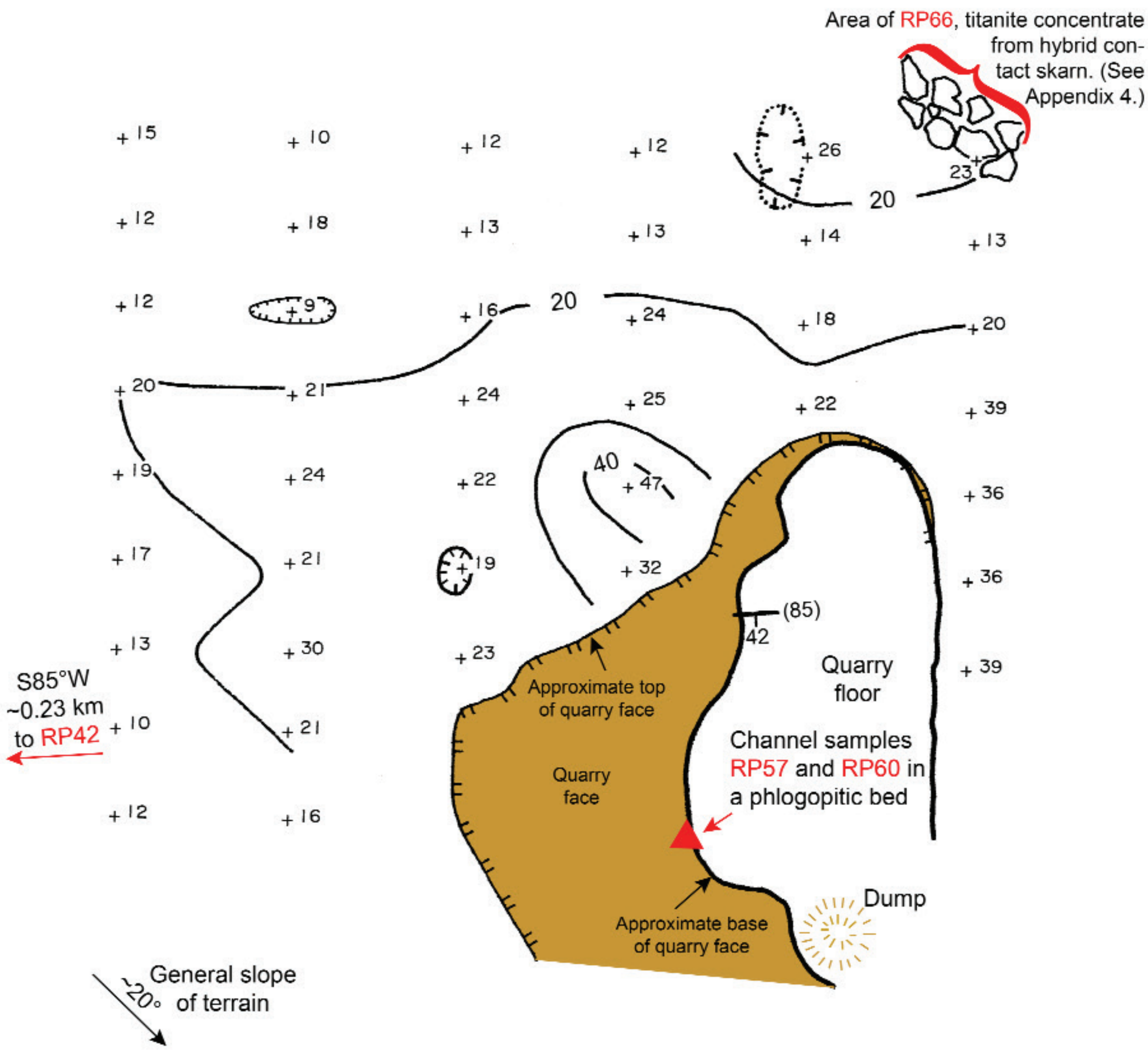
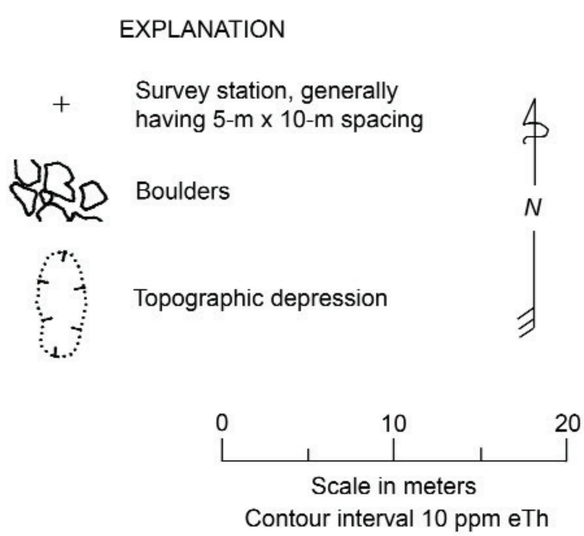


Figure 29. Contour map of radiometric equivalent U in ppm at the Quarry L anomaly, city of Easton, Northampton County. Easton 7.5-minute quadrangle; 40°41'58"N, 75°13'58"W.





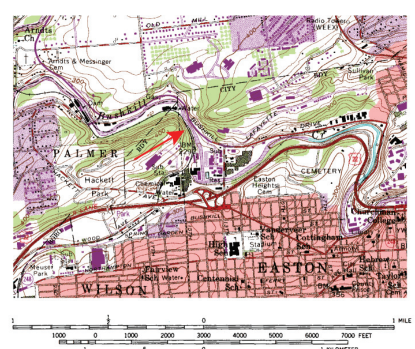


Figure 30. Contour map of radiometric equivalent Th in ppm at the Quarry L anomaly, city of Easton, Northampton County. Easton 7.5-minute quadrangle; 40°41'58"N, 75°13'58"W.

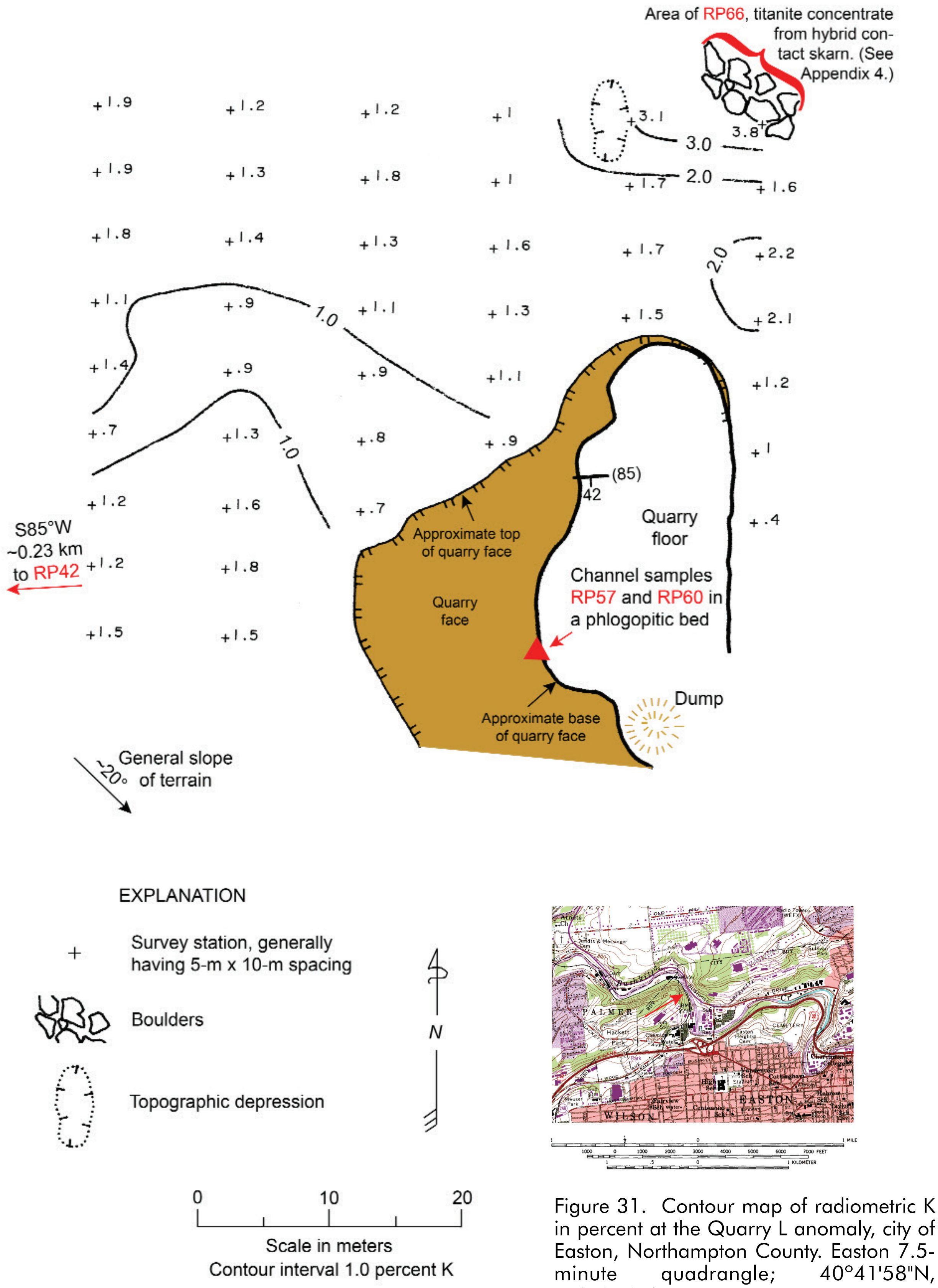
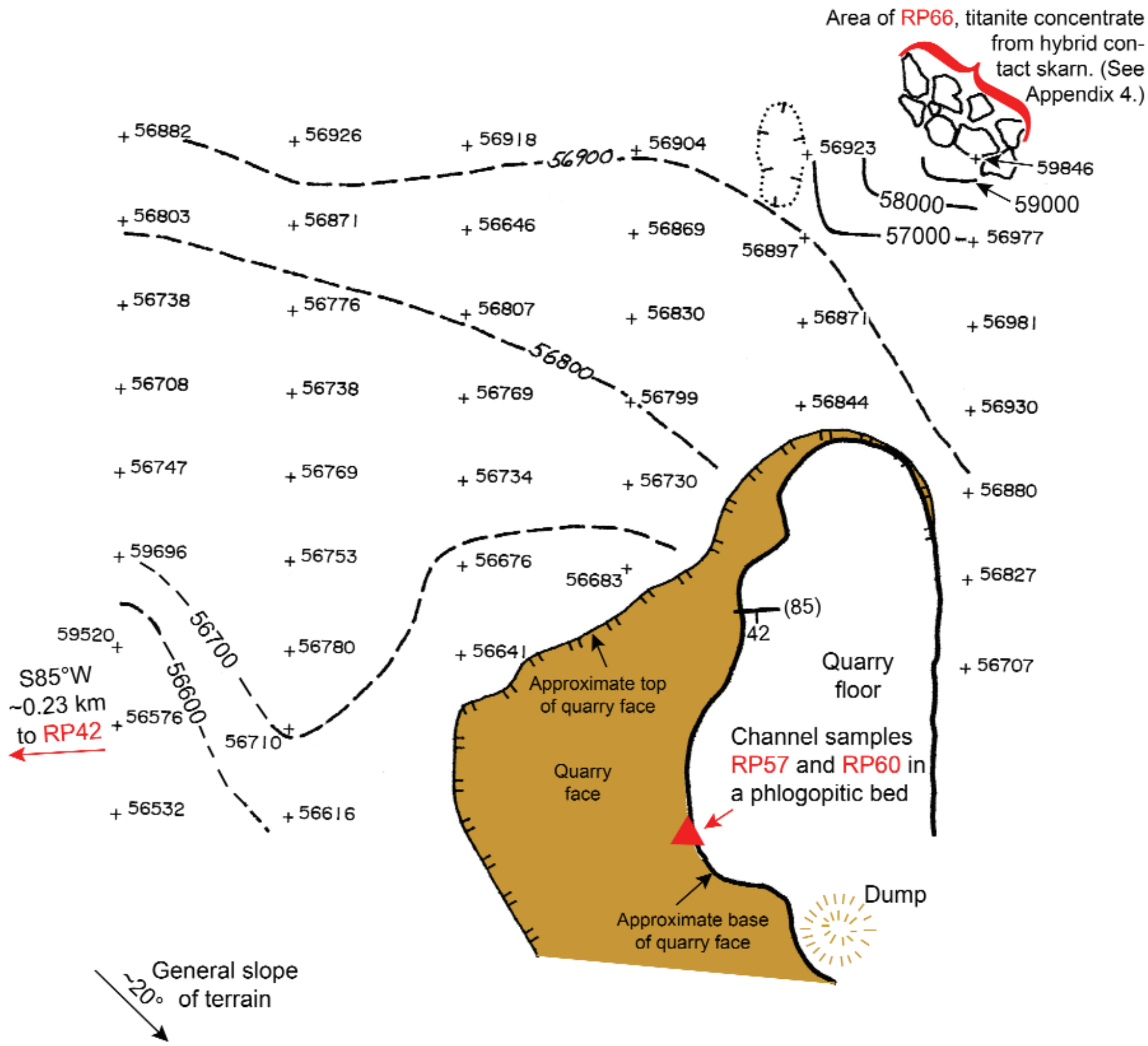
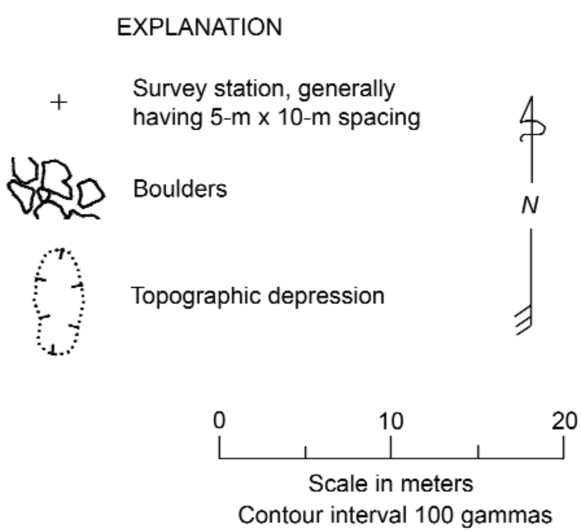


Figure 31. Contour map of radiometric K in percent at the Quarry L anomaly, city of Easton, Northampton County. Easton 7.5-minute quadrangle; 40°41'58"N, 75°13'58"W.





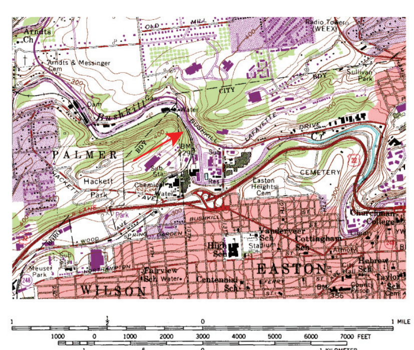


Figure 32. Contour map of total magnetic flux in gammas at the Quarry L anomaly, city of Easton, Northampton County. Easton 7.5-minute quadrangle; 40°41'58"N, 75°13'58"W.

Name: C. K. Williams quarry, north part

Location: On the southeast side of Chestnut Hill at a point 2.1 km (1.3 mi) north-northeast of the confluence of Bushkill Creek and the Delaware River.

Sample: RP39

7.5-Minute Quadrangle: Easton
Latitude: 40°42'50"N
Longitude: 75°11'48"W
County: Northampton
Township: Forks

Exposure: Medium-sized abandoned terrazzo and filler quarry with steep faces and demolition rubble across the quarry floor.

Maps: Figures 33–36.

Tectonic setting: Chestnut Hill nappe as used herein.

Petrology: Phlogopite-serpentine.

Trend of Mineralization: The assayed zone appears to have a subhorizontal attitude, but elsewhere the mineralization may be associated with shear zones, the trends of which were not determined.

Comments: As noted in "Previous Studies," the C. K. Williams quarry area has long been a mecca for mineral collectors and mineralogists.

The figures suggest a general positive correlation between U, Th, and K, which is consistent with Montgomery's identification of the primary mineral as uraninite-thorianite and recent observations that the phlogopitic zones are typically enriched relative to serpentine zones. See Appendix 4 on the titanite study and also note that monazite and molybdenite were verified in an outcrop of rock resembling tourmalite 1.2 km (0.8 mi) to the northeast.

Primary "ore" minerals: Uraninite-thorianite, molybdenite, and pyrite. Thorite occurs in the southernmost outcrop, between the southern part of the quarry and Pa. Route 611. Altered titanite (Figure 37) occurs with thorite and pyrite in sample RP4 from the south part of the quarry.

Secondary "ore" minerals: Unidentified uranium secondaries at and near assay site. Montgomery (1957) and Smith (1978b) listed the species found elsewhere in the C. K. Williams quarry.

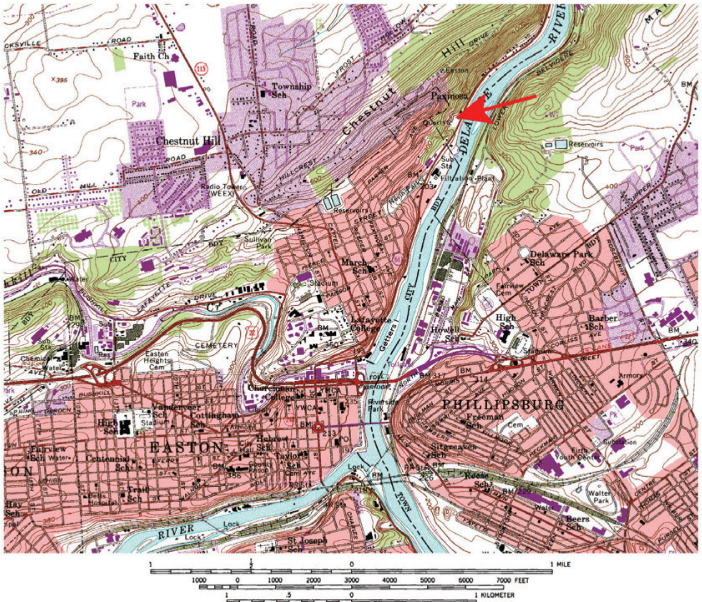
Amounts of U and Th: Amounts unknown, but the large number of occurrences in granitic and skarn hosts along Chestnut Hill suggests the possibility of major uranium enrichments in the area.

Assays: **RP39,** a 0.25-m vertical channel sample, yielded 1,080 ppm U and 200 ppm Th. The assayed zone can be traced for 3 m along the horizontal using a 2,000-counts/sec cutoff with the Mt. Sopris scintillometer, and projects upward, out of reach, to the northeast of the assay site. Its thickness varies from 0.3 m on the southwest to 1 m on the northeast.

Possible volumes: A 0.5- x 5- x 5-m block having 1,000 ppm U and 200 ppm Th appears to be a reasonable possibility. Between the northern part of the C. K. Williams quarry on the east and Quarry L on the west there could easily be 3,000-m^3 (9,000-ft^3) bodies of the same grade.

Suggestions for further study: The existing thorough study by Montgomery (1957) and the declining quality of the exposure limit additional studies. The mineralogically and structurally less complex Quarry L area is more deserving of basic research. Structural complexities in the C. K. Williams quarry area (Drake, 1967) appear to make the finding of large volumes of uranium-enriched rock difficult.

The large number of uranium occurrences in Chestnut Hill and the press reports of high indoor radon levels in 1985 suggest the continued need for diligence with respect to natural radionuclides and their gamma flux.



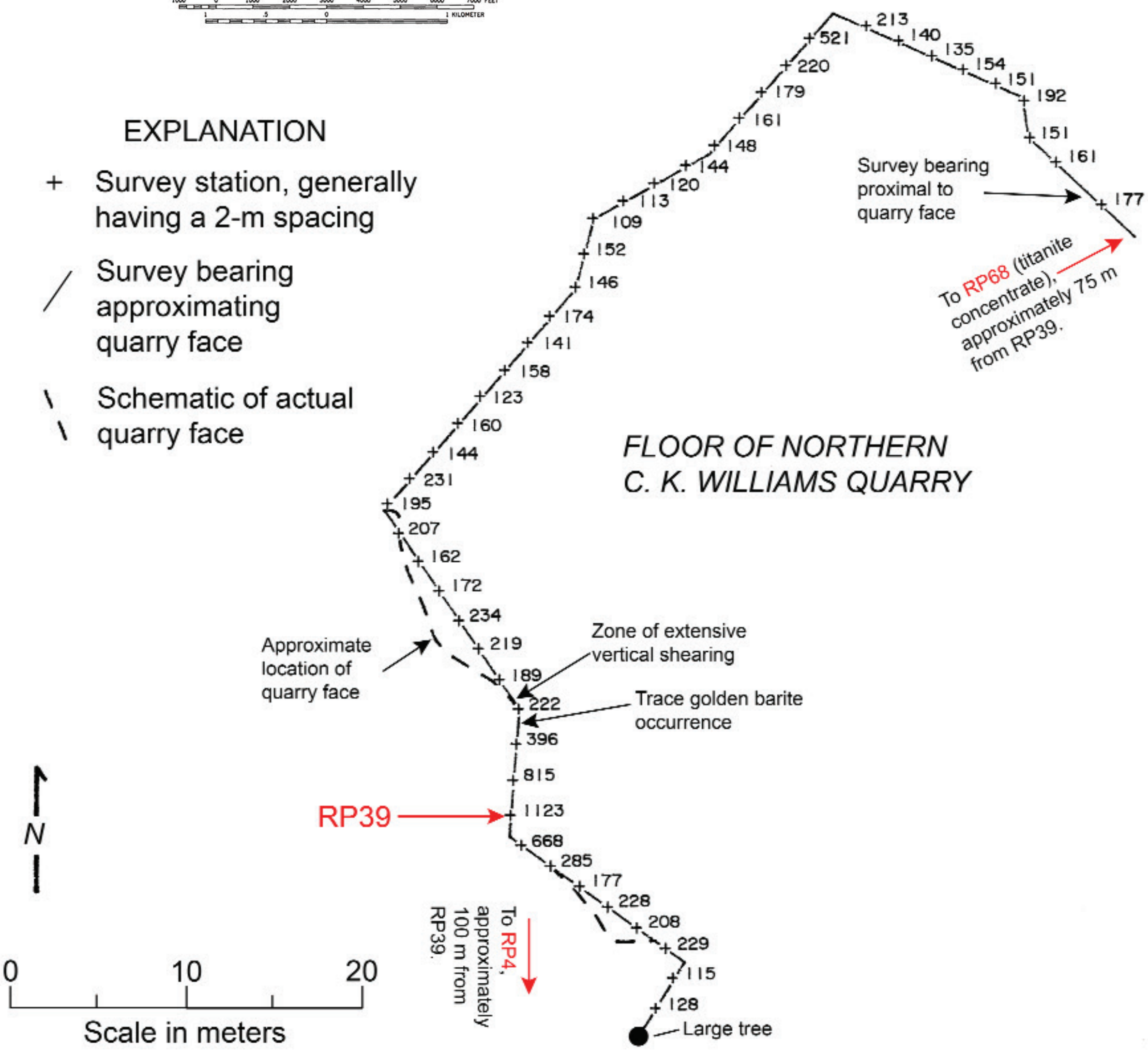
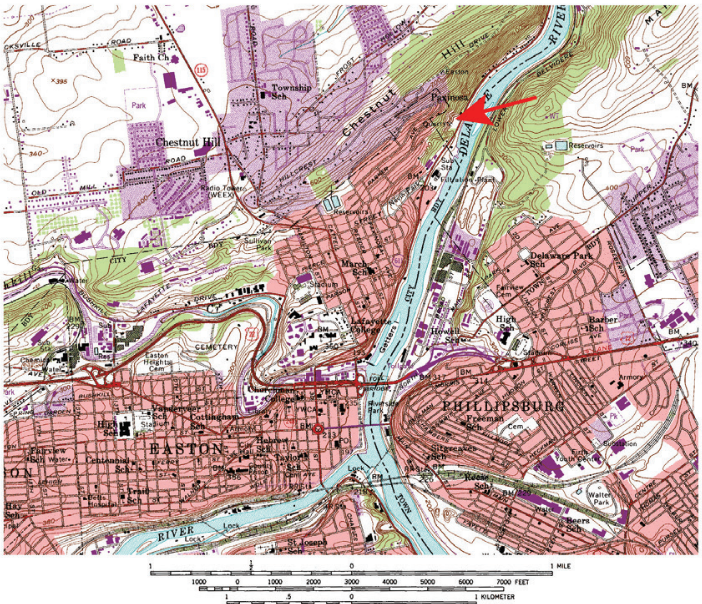
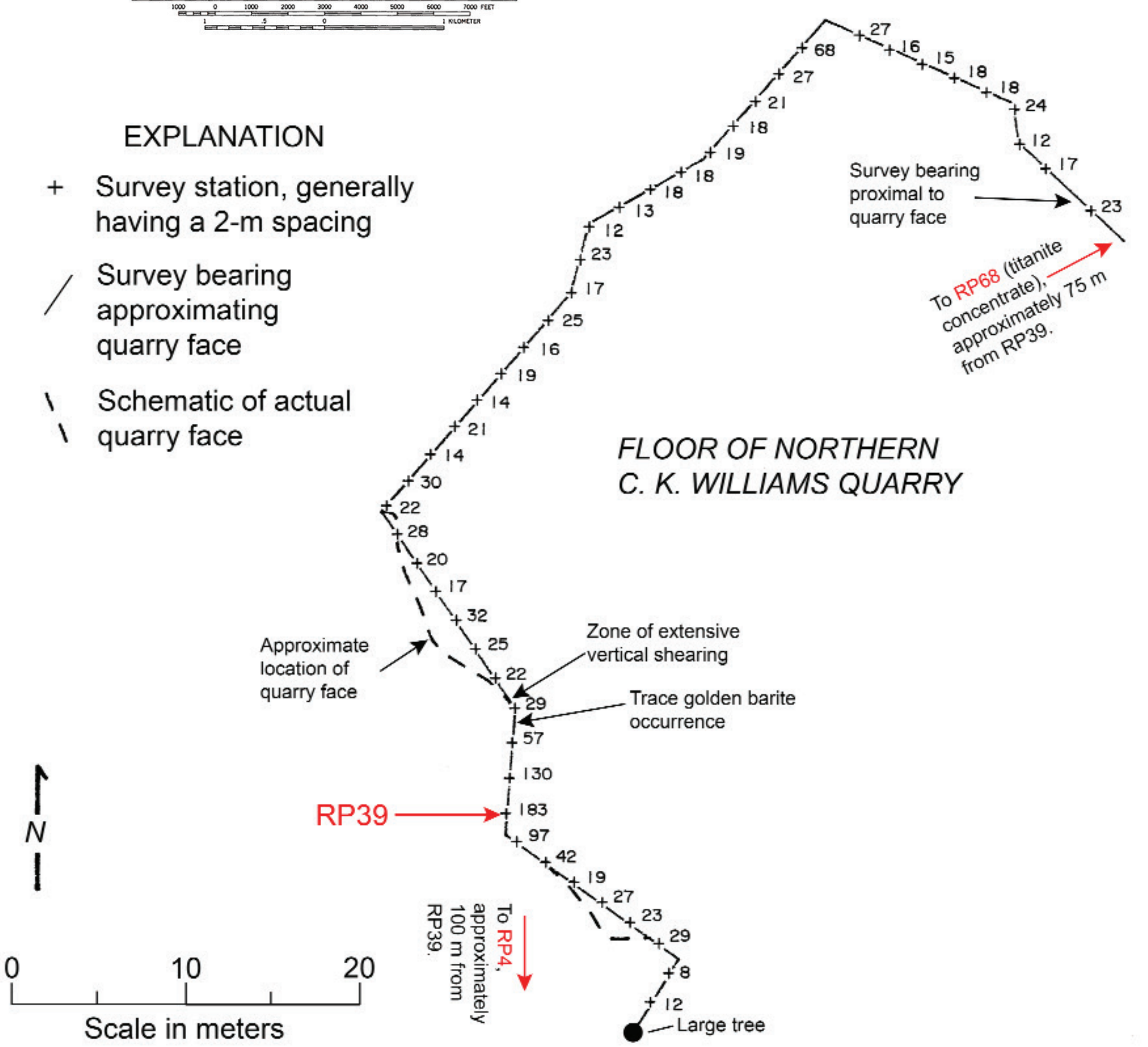


Figure 33. Map of total gamma counts per second at the abandoned northern C. K. Williams quarry anomaly, Forks Township, Northampton County. Easton 7.5-minute quadrangle; 40°42'50"N, 75°11'48"W.

Figure 34. Map of radiometric equivalent U in ppm at the abandoned northern C. K. Williams quarry anomaly, Forks Township, Northampton County. Easton 7.5-minute quadrangle; 40°42'50"N, 75°11'48"W.





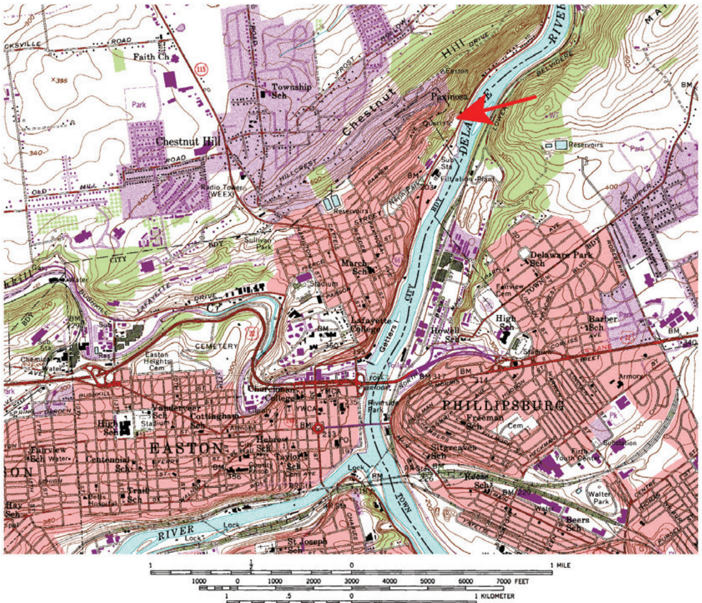
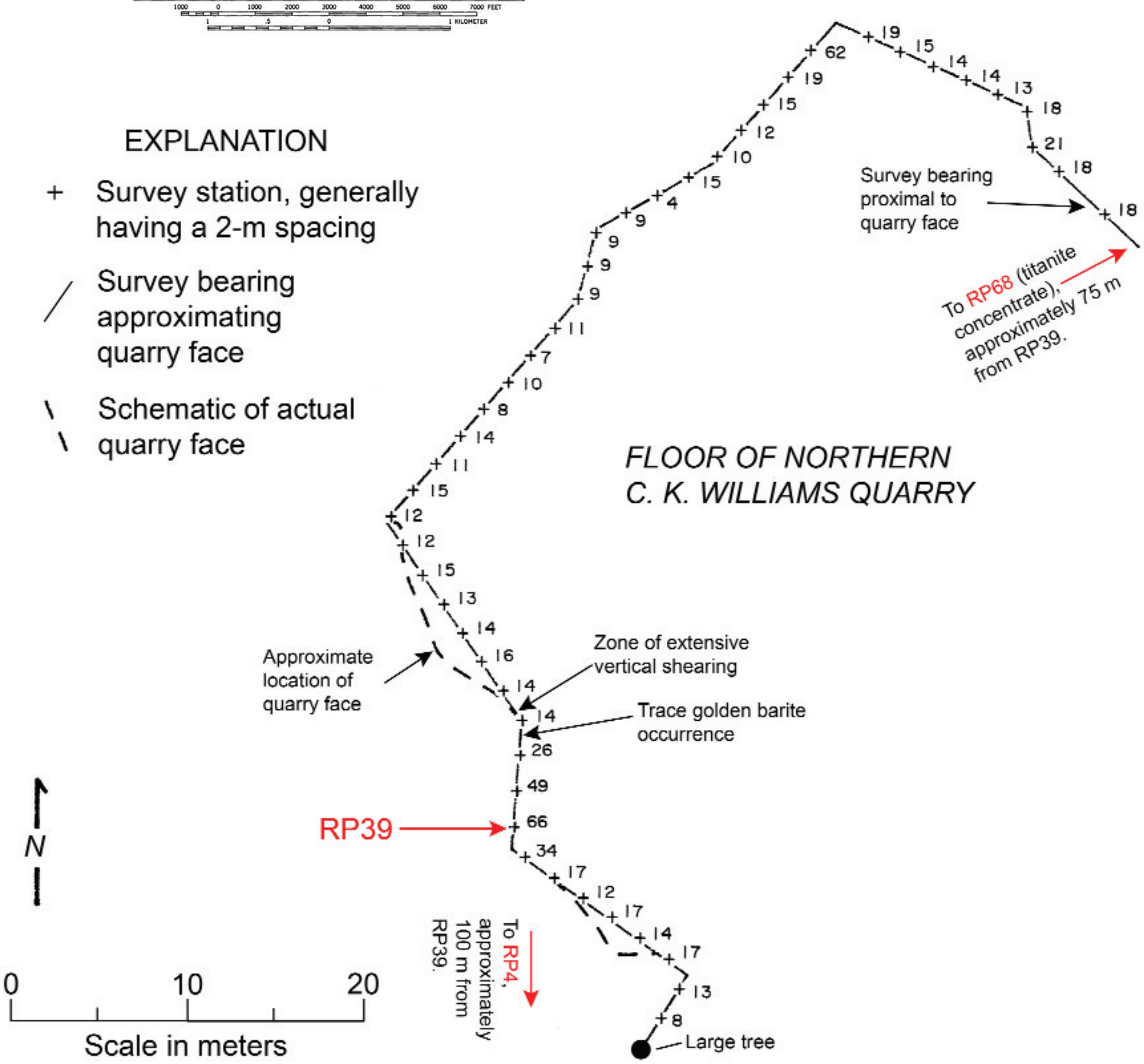


Figure 35. Map of radiometric equivalent Th in ppm at the abandoned northern C. K. Williams quarry anomaly, Forks Township, Northampton County. Easton 7.5-minute quadrangle; 40°42'50"N, 75°11'48"W.



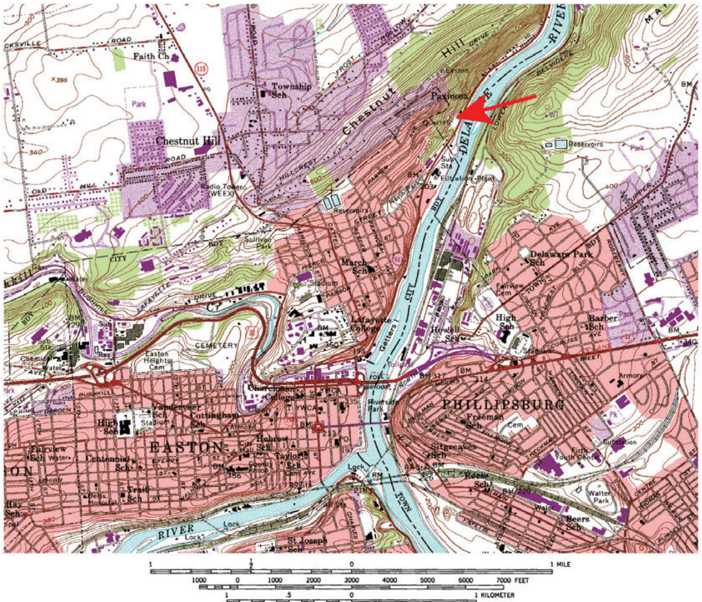
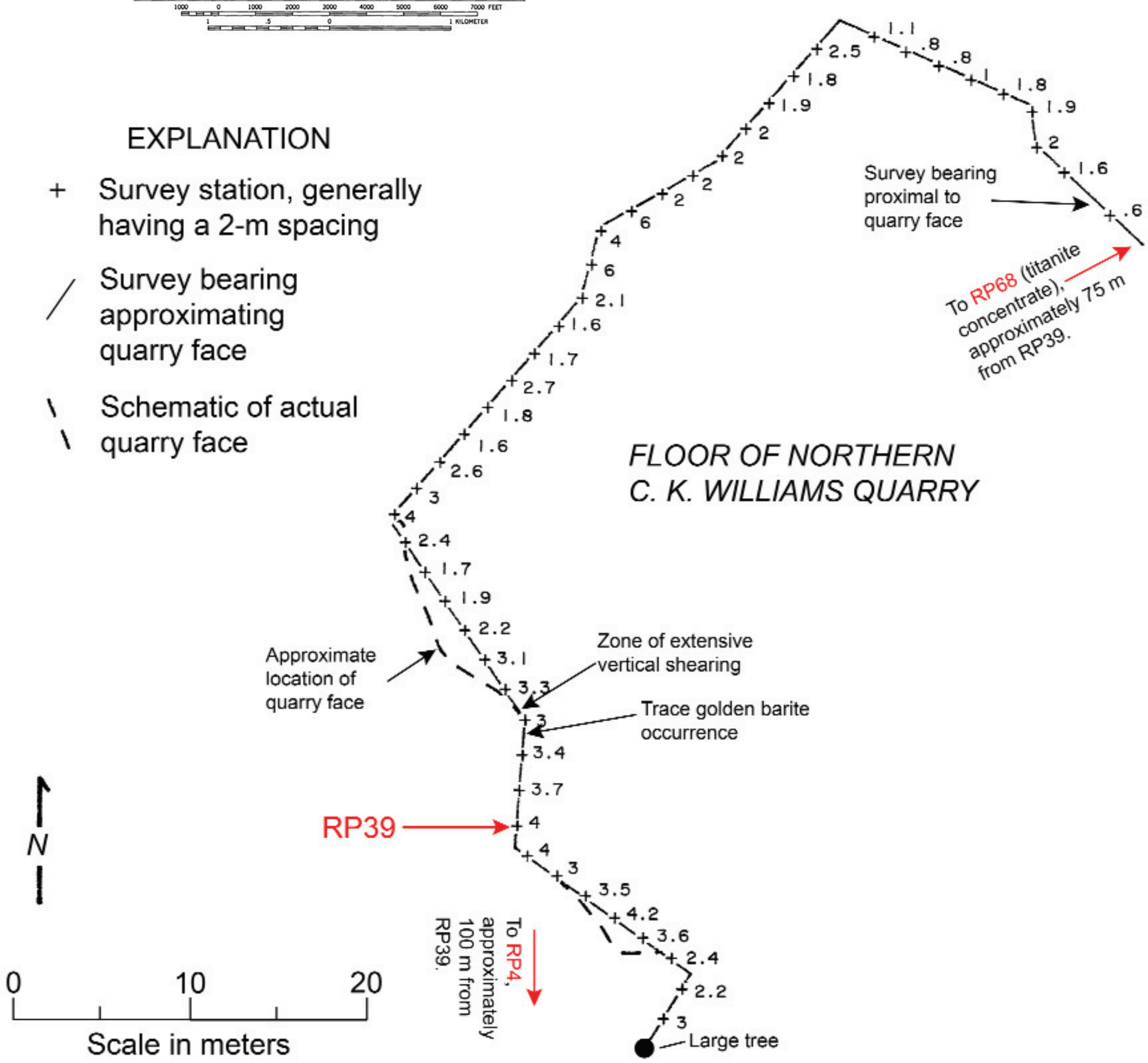


Figure 36. Map of radiometric K in percent at the abandoned northern C. K. Williams quarry anomaly Forks Township, Northampton County. Easton 7.5-minute quadrangle; 40°42'50"N, 75°11'48"W.



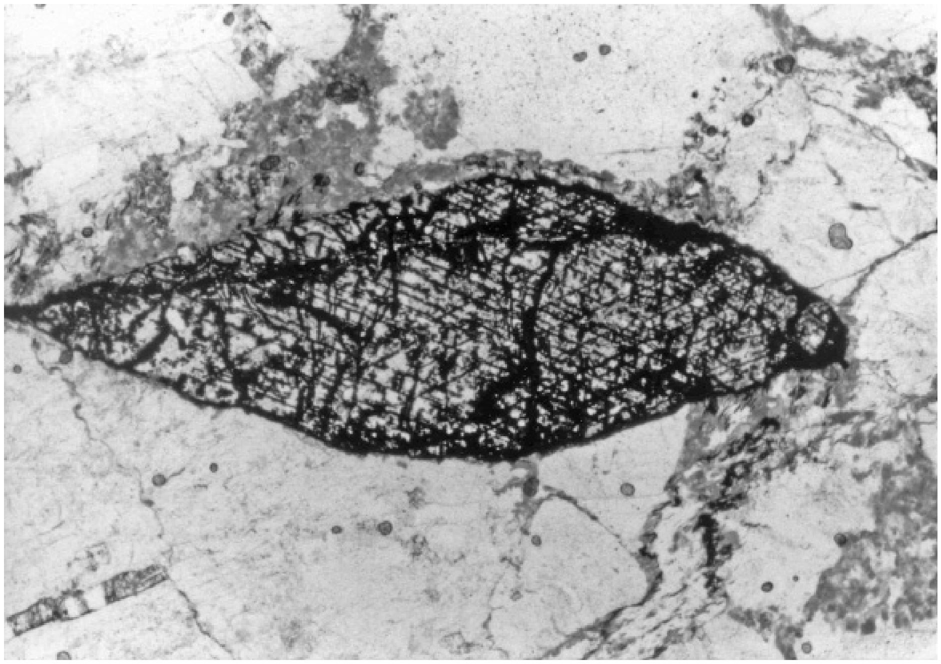


Figure 37. Photomicrograph (31x) of a thin section of sample RP4, from the C. K. Williams quarry, Northampton County, showing outline of euhedral titanite, now altered to linear rows of tiny, euhedral TiO_2 crystals surrounding calcite.

GRANITIC HOST

Name: Chapel Hill anomaly

Location: Boulder ridge on southwest portion of Chapel Hill, 2.1 km (1.3 mi) southeast of the intersection of Pricetown Road, Antietam Road, and Oley Road at Alsace Manor.

Samples: RP9, RP37, RP63

7.5-Minute Quadrangle: Fleetwood
Latitude: 40°22'59"N
Longitude: 75°51'01"W
County: Berks
Township: Alsace

Exposure: Natural bouldery ridge crest and wooded slopes.

Maps: Figures 38–41.

Tectonic setting: North edge of Applebutter nappe.

Petrology: Assigned to the Mo-bearing quartz monzonite suite on the basis of the "best fit," but the evidence for Mo is scant. The host rock contains a minor amount of a pink garnet (Figure 42) and a trace of possible reddish-brown hematite along plagioclase twin planes (Figure 43).

Trend of Mineralization: Appears to follow the northeast-trending ridge crest toward RP9.

Comments: Based on comparisons of radiometric estimates and actual assays for the RP37 and RP63 sites, the eU data shown in Figure 39 for the individual boulders are probably moderately low, and the eTh data shown in Figure 40 are substantially high; that is, the gamma-ray spectrometer underestimates U and overestimates the Th content of rock.

The center of the boulder ridge is probably nearly in place. Its linear northeast trend suggests the possibility of a dikelike intrusion.

Primary "ore" minerals: Thorite(?) as reddish grains with a conchoidal fracture.

Secondary "ore" minerals: Boltwoodite and rare phurcalite.

Assays: **RP37,** a 65-cm channel sample across gneissic foliation in a large boulder yielded 271 ppm U and 63 ppm Th. **RP63,** a 30-cm channel sample across gneissic foliation in a large boulder yielded 154 ppm U and 34 ppm Th.

Possible volumes: A zone at least 10 m wide x 10 m deep x 100 m long having 30 ppm U seems reasonable (Figure 39). This equals approximately 30,000 short tons or more of mineralized rock.

Suggestions for further study: Enlarge the area of the gamma-ray spectrometer grid to include unmineralized rocks. Attempt to verify a possible continuity at depth with the RP9 area to the northeast. Compare the ground gamma-ray spectrometer data with the NURE airborne data for flight line no. 9 of the Newark 1- x 2-degree quadrangle (LKB Resources, 1978).

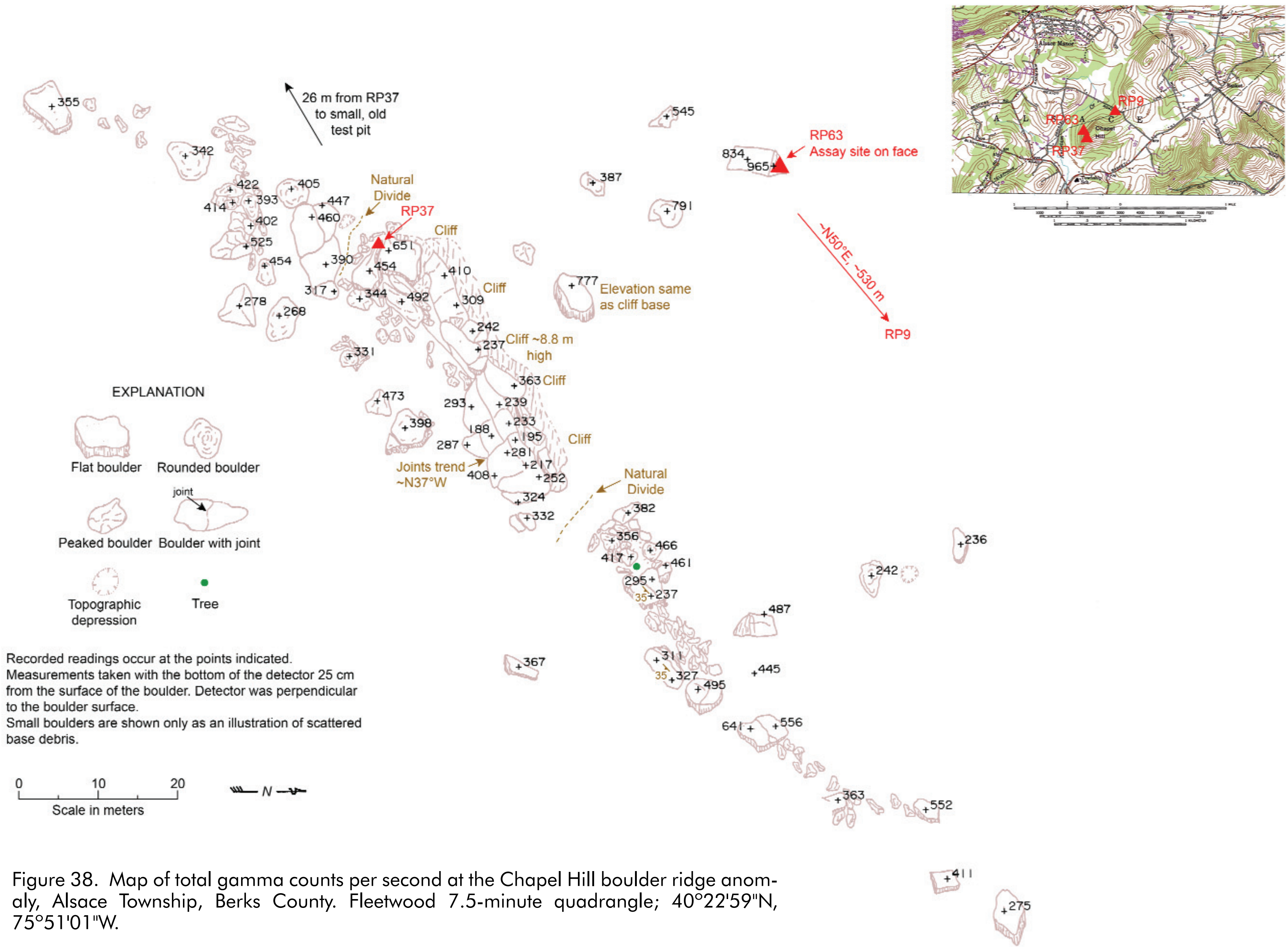


Figure 38. Map of total gamma counts per second at the Chapel Hill boulder ridge anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°22'59"N, 75°51'01"W.

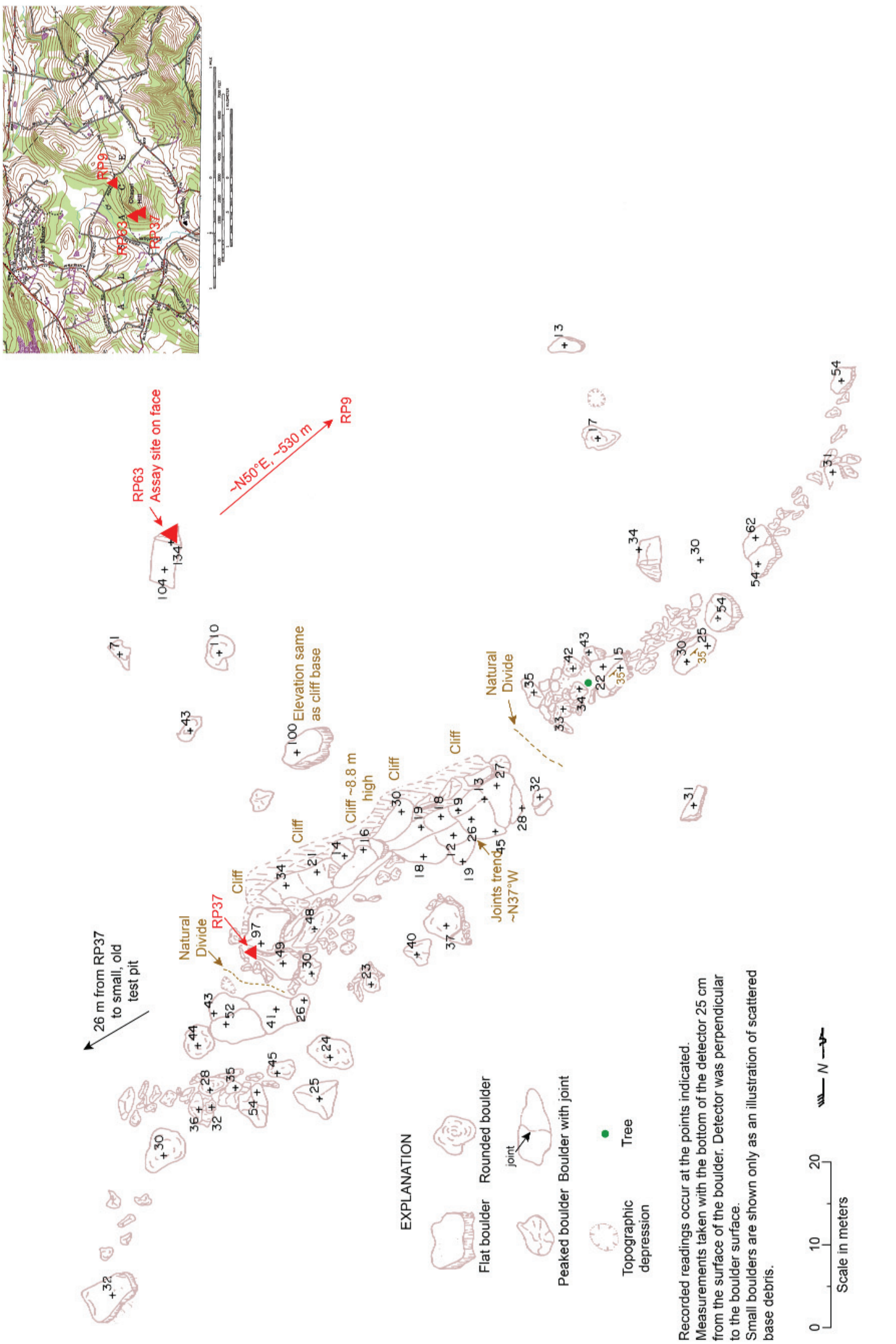


Figure 39. Map of radiometric equivalent U in ppm at the Chapel Hill boulder ridge anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°22'59"N, 75°51'01"W.

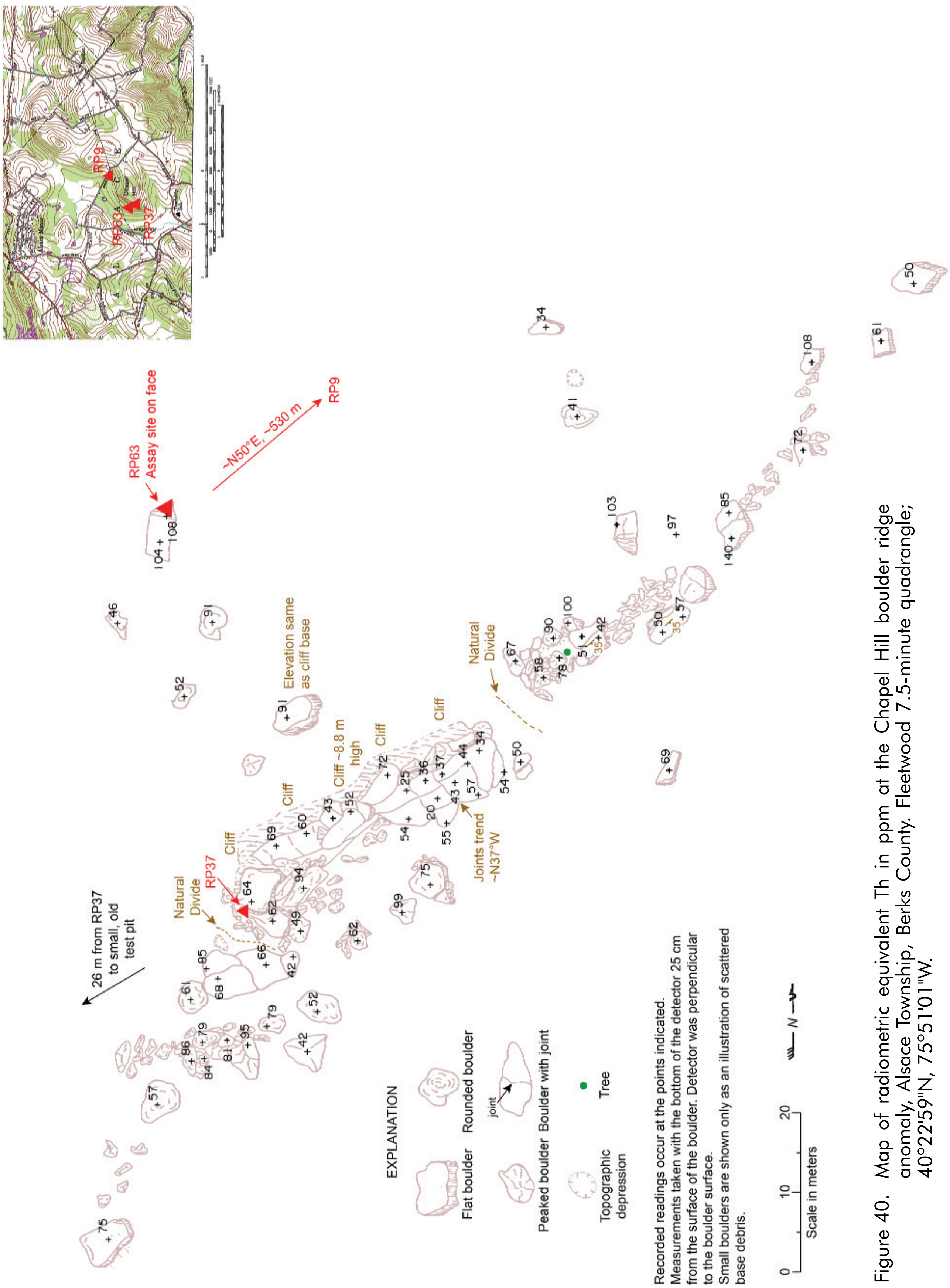


Figure 40. Map of radiometric equivalent Th in ppm at the Chapel Hill boulder ridge anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°22'59"N, 75°51'01"W.

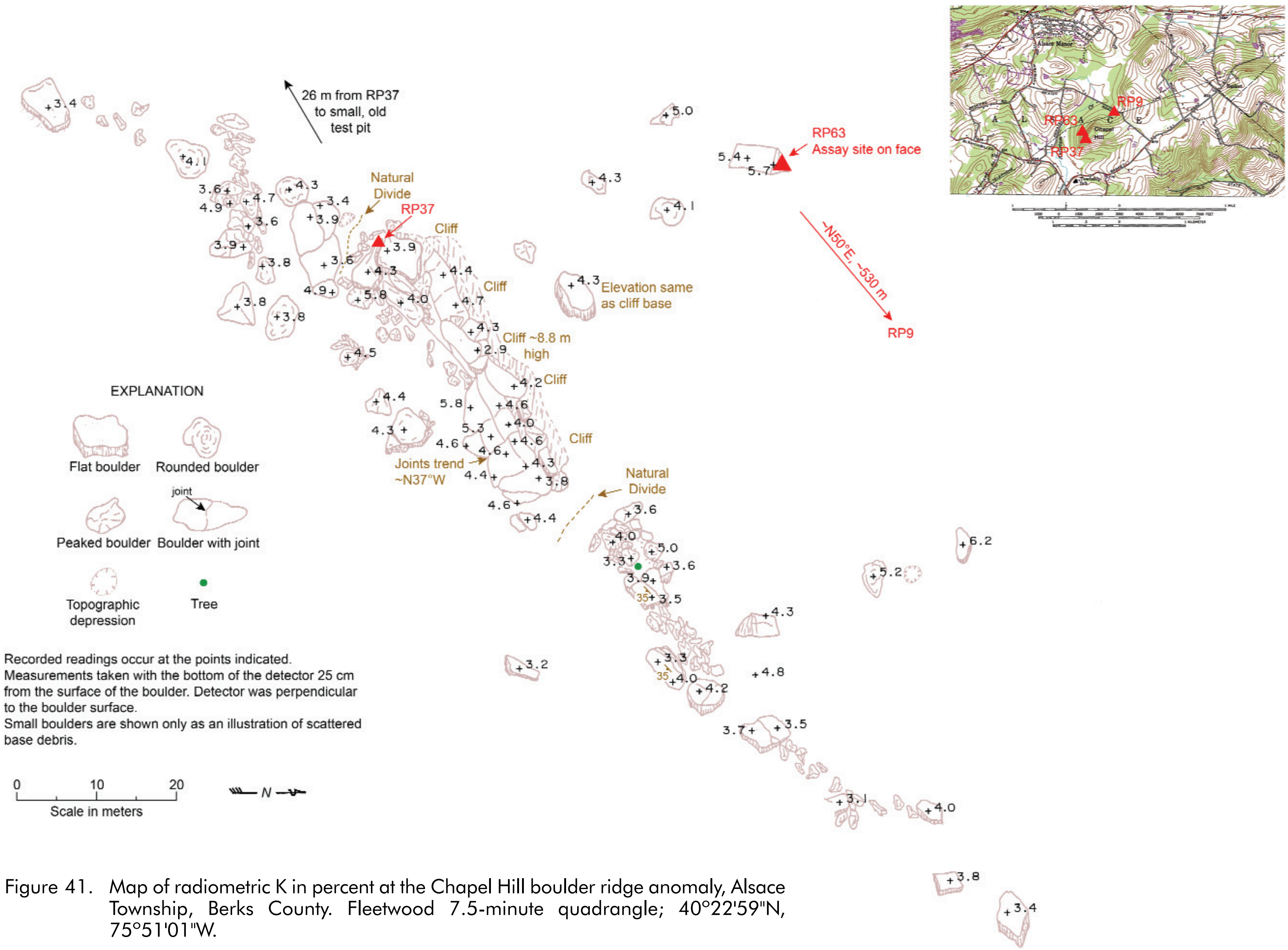


Figure 41. Map of radiometric K in percent at the Chapel Hill boulder ridge anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°22'59"N, 75°51'01"W.

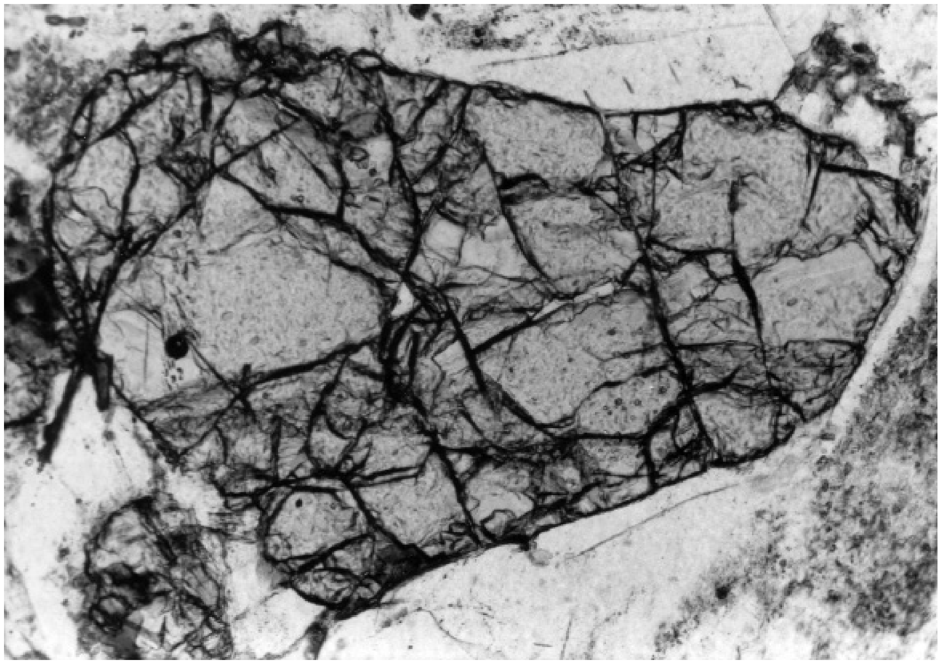


Figure 42. Photomicrograph (123x) of a thin section of sample RP37, from the southwest crest of Chapel Hill, Berks County, showing a large anhedral garnet crystal.

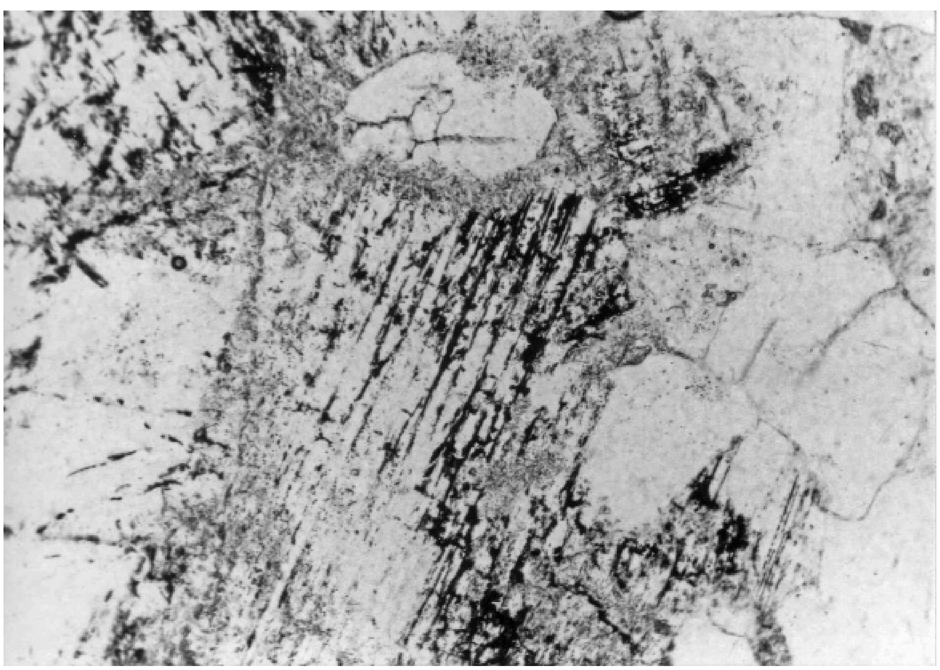


Figure 43. Photomicrograph (123x) of a thin section of sample RP37, from the southwest crest of Chapel Hill, Berks County, showing reddish-brown hematite(?) along plagioclase twin planes.

Name: Forgedale Route anomaly

Location: Outcrops along Forgedale Route 2.3 km (1.45 mi) north-northwest of Bally. RP16 was collected along the east shoulder of the road and RP61 from an outcrop between the West Branch Perkiomen Creek and Forgedale Route at a point approximately 75 m (250 ft) north of RP16.

Samples: RP16, RP61

7.5-Minute Quadrangle: East Greenville
Latitude: (RP16) 40°24'20"N
(RP61) 40°24'22"N
Longitude: (RP16) 75°36'50"W
(RP61) 75°36'51"W
County: Berks
Township: Washington

Exposure: Good small outcrops.

Maps: Figures 44–47.

Tectonic setting: Near the southeast edge of the Applebutter nappe.

Petrology: "Byram gneiss," as used in the Phase II studies. Hand samples strongly resemble those from RP20.

Trend of Mineralization: Unknown. Gneissic foliation at RP16 dips steeply to the south, and the RP61 occurrence (Appendix 2) is 0.85 km (0.5 mi) due east of the Forgedale Route anomalies. These suggest the possibility of an east-west trend.

Comments: The delayed neutron activation analyses from RP16 are 4 times higher than the gamma-ray spectrometer estimates, and those from the larger RP61 outcrop are 2 times higher. Thus, surfaces larger than a few square meters appear to be needed to obtain reasonable radiometric estimates. Nevertheless, the radiometric estimates for the 1.5-m-wide, N75°E-trending joint face to the south of RP16 expand the apparent width of the mineralized zone.

Primary "ore" minerals: Allanite-(Ce) as crystals up to 3 cm long and thorite as reddish grains having a conchoidal fracture up to 1 mm. Zircons with distinct zoning are present (Figure 48).

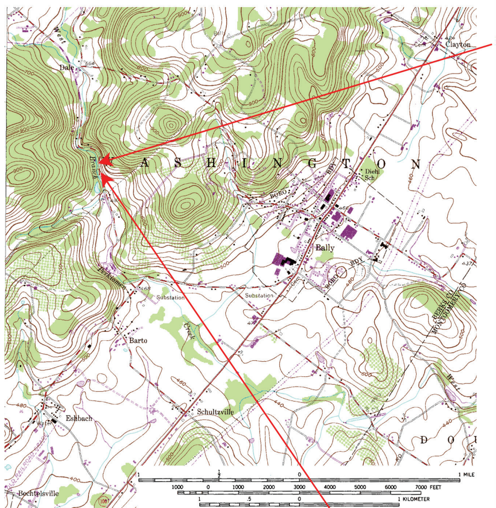
Secondary "ore" minerals: Rare powdery, yellow coatings of an unknown mineral closely associated with allanite-(Ce).

Assays: **RP16,** an 80-cm channel sample, contains 130 ppm U and 331 ppm Th. **RP61,** a 97-cm channel sample, contains 51 ppm U and 229 ppm Th.

Possible volumes: Unknown. The radiometric data along the outcrop at and near RP61 suggests possible widths of ≥2.2 m for ≥20 ppm U rock.

Suggestions for further study: Total-gamma reconnaissance with a handheld scintillometer appears warranted on the hills on both sides of the creek.

Figure 44. Sketch maps of total gamma counts per second at the Forgedale Route anomaly, Washington Township, Berks County. East Greenville 7.5-minute quadrangle; 40°24'20"N, 75°36'50"W and 40°24'22"N, 75°36'51"W, respectively, for RP16 and RP61.



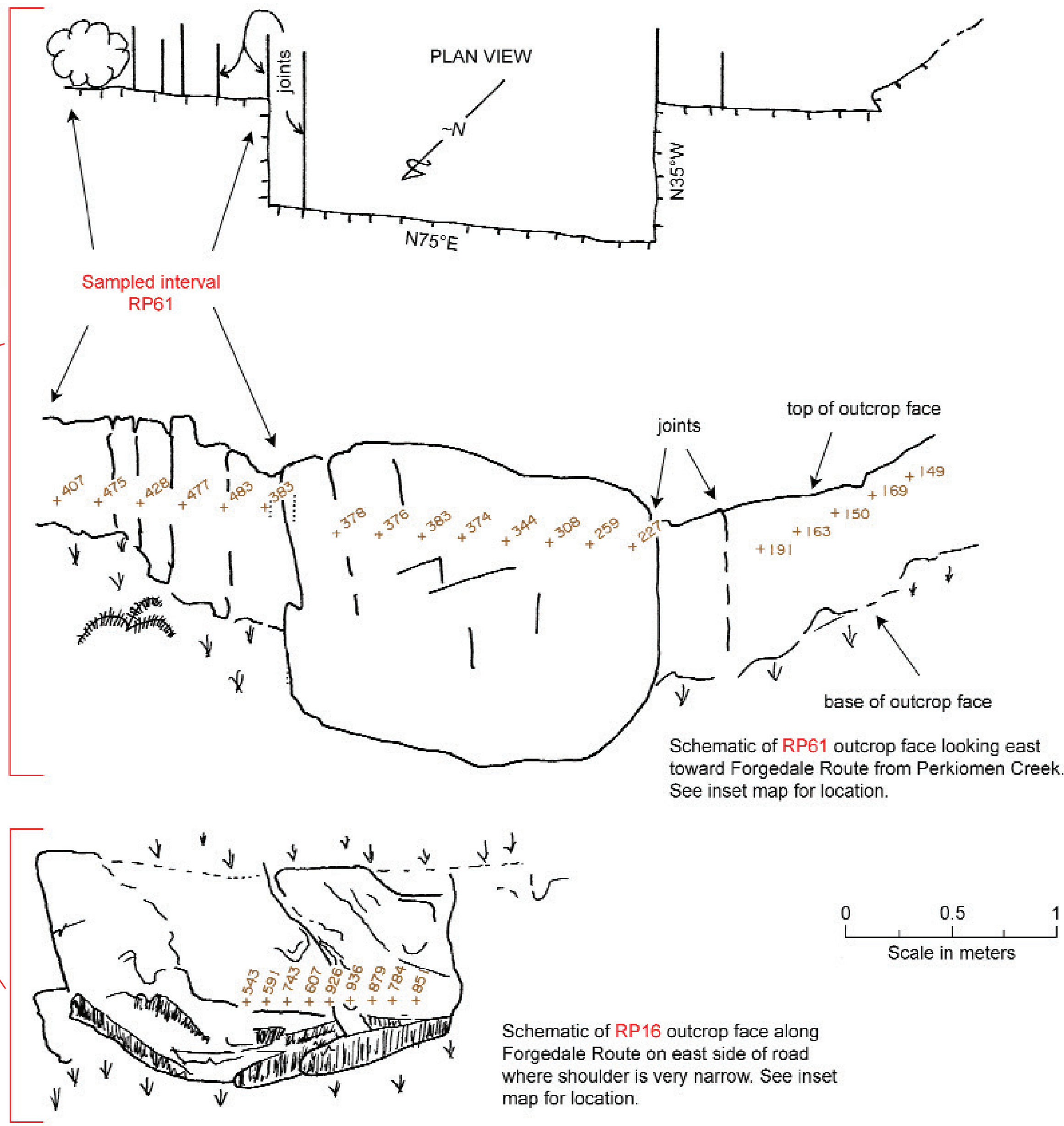
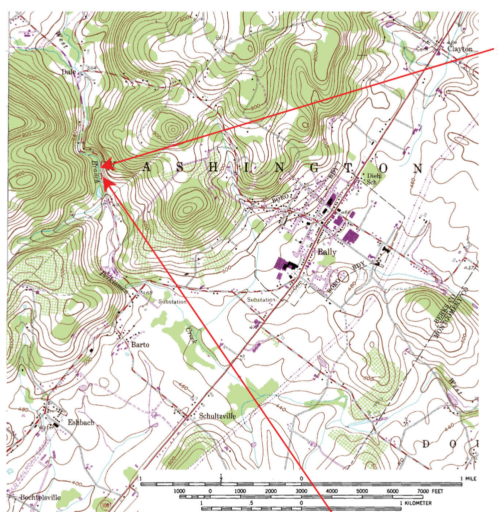


Figure 45. Sketch maps of radiometric equivalent U in ppm at the Forgedale Route anomaly, Washington Township, Berks County. East Greenville 7.5-minute quadrangle; 40°24'20"N, 75°36'50"W and 40°24'22"N, 75°36'51"W, respectively, for RP16 and RP61.



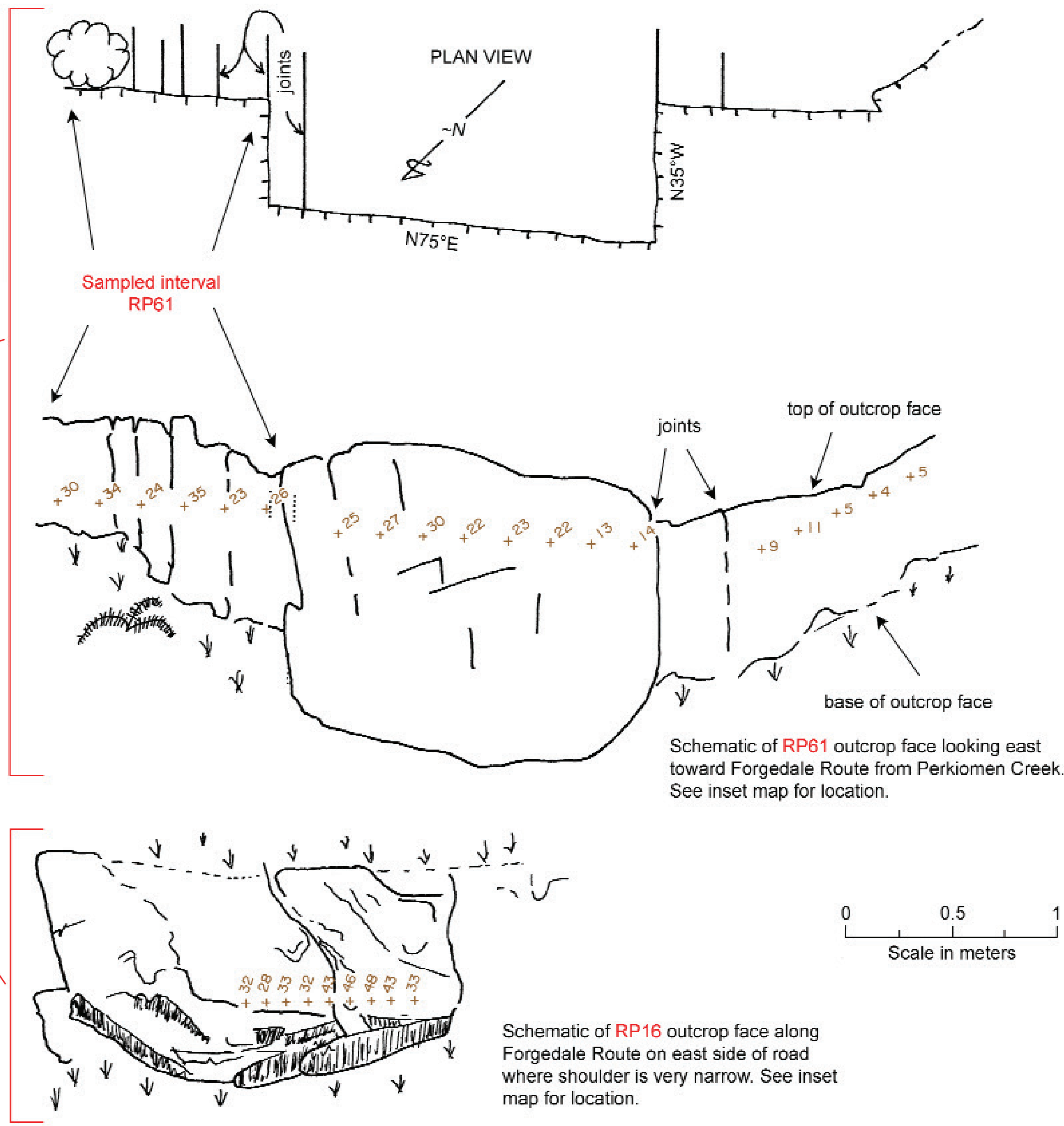
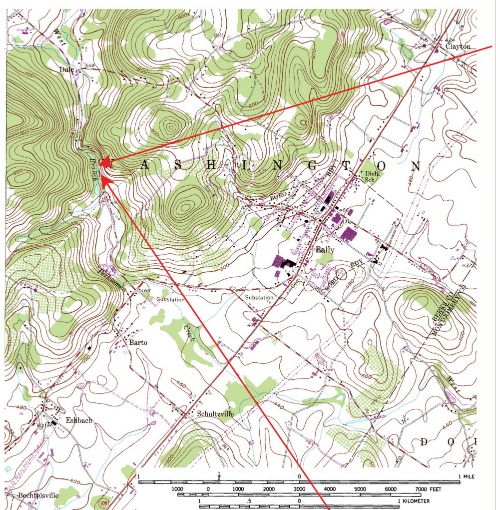
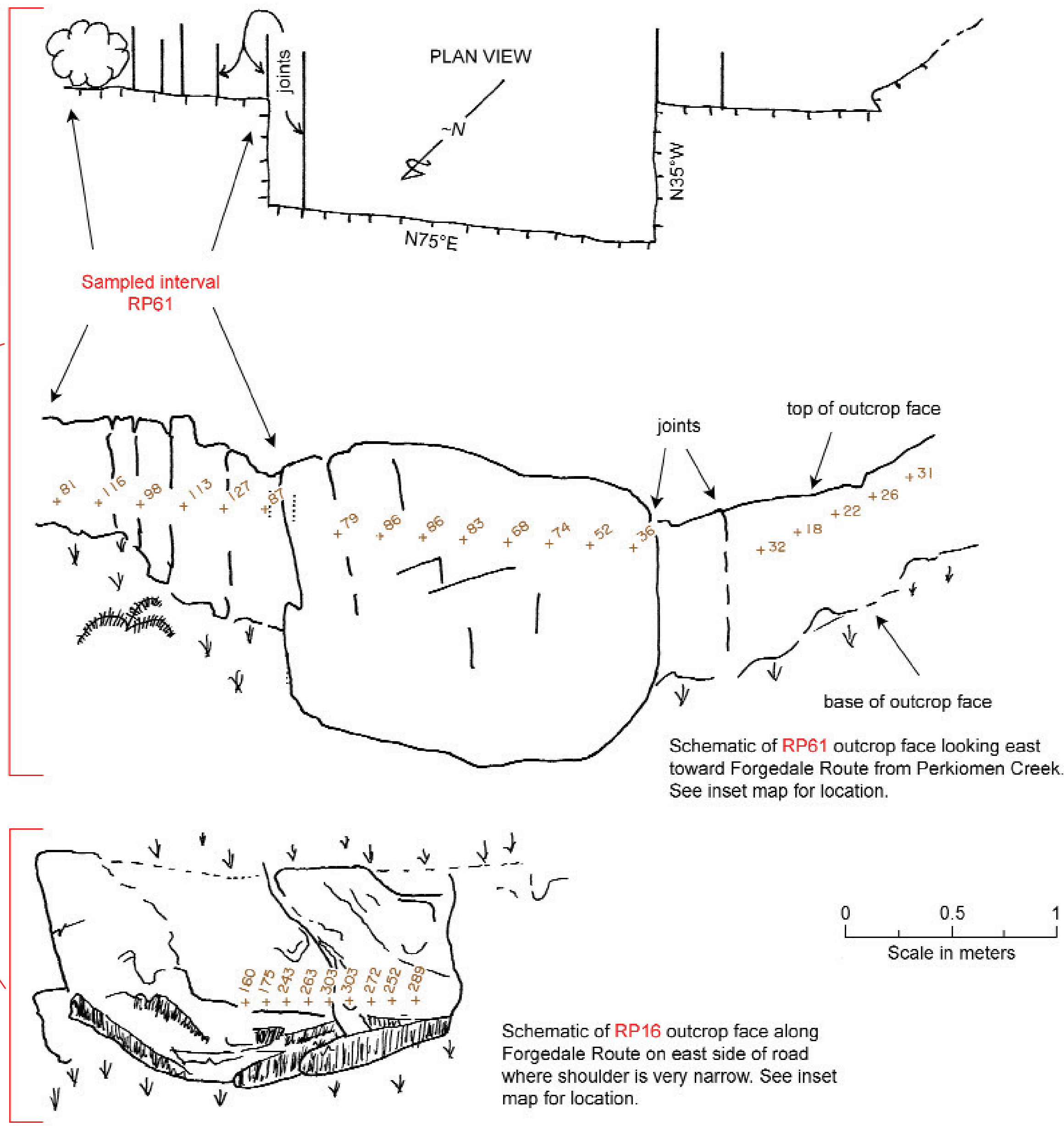


Figure 46. Sketch maps of radiometric equivalent Th in ppm at the Forgedale Route anomaly, Washington Township, Berks County. East Greenville 7.5-minute quadrangle; 40°24'20"N, 75°36'50"W and 40°24'22"N, 75°36'51"W, respectively, for RP16 and RP61.





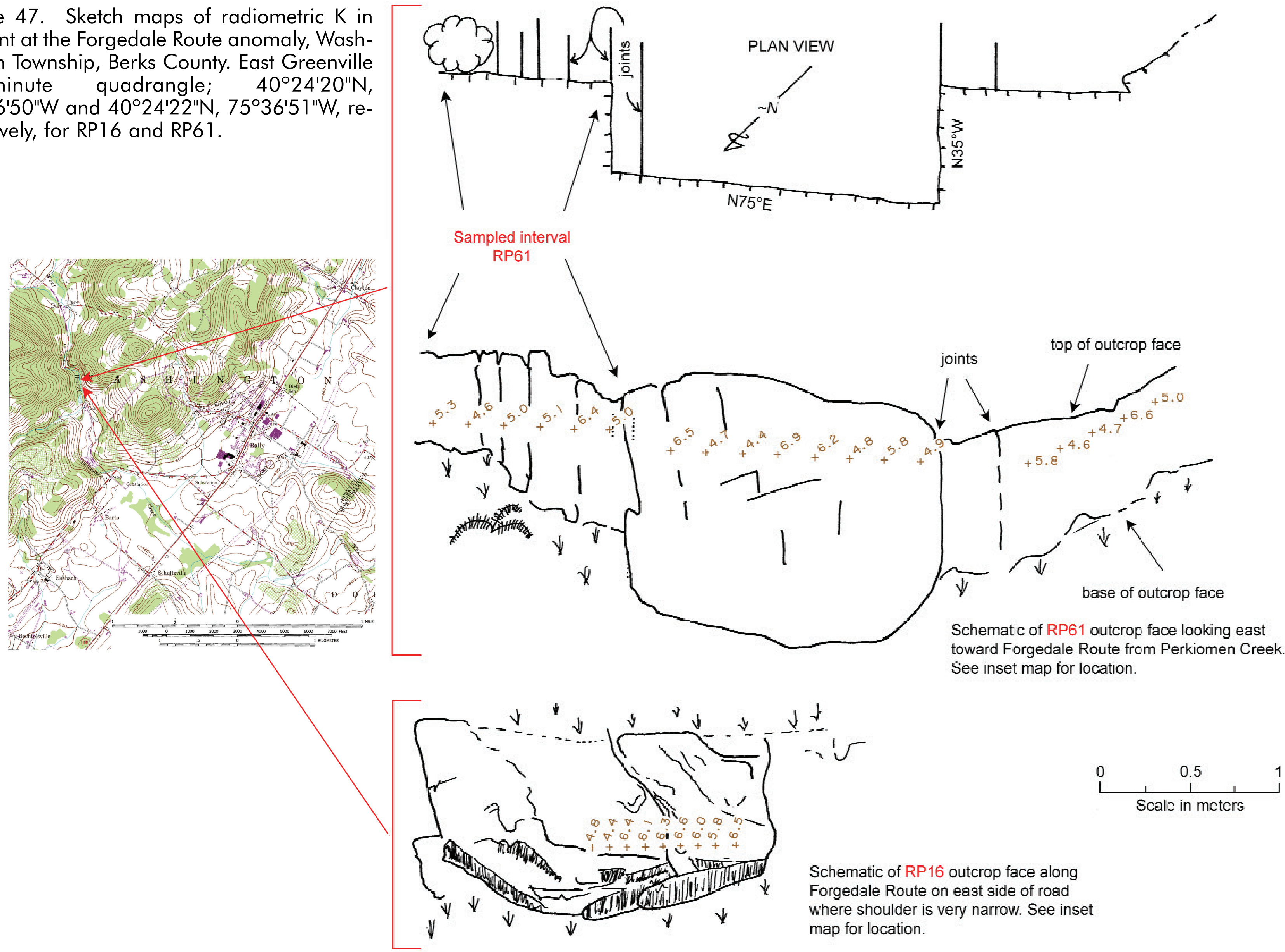


Figure 47. Sketch maps of radiometric K in percent at the Forgedale Route anomaly, Washington Township, Berks County. East Greenville 7.5-minute quadrangle; 40°24'20"N, 75°36'50"W and 40°24'22"N, 75°36'51"W, respectively, for RP16 and RP61.

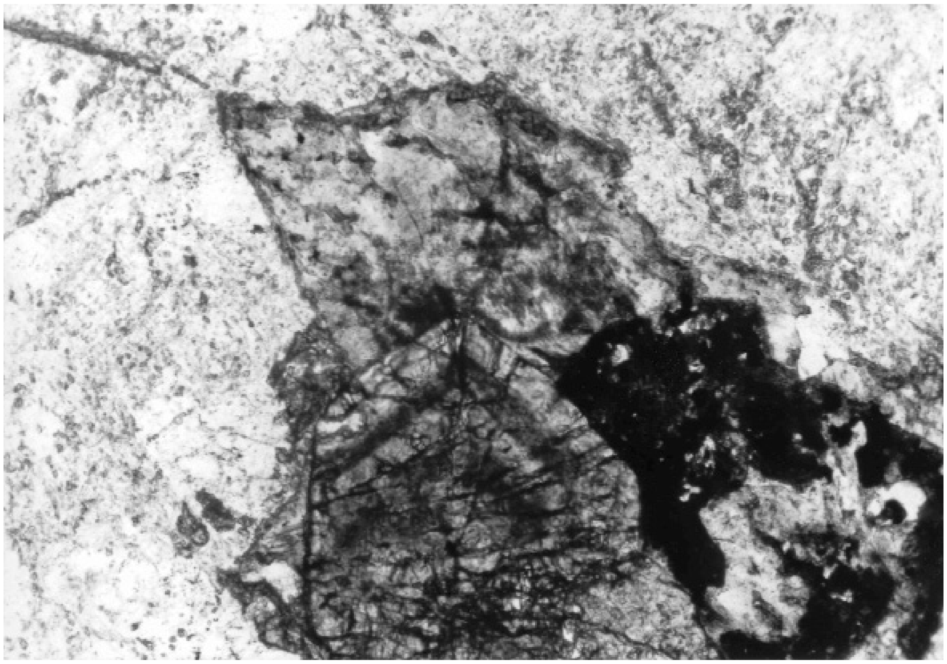


Figure 48. Photomicrograph (123x) of a thin section of sample RP16 from the Forgedale Route anomaly, Berks County, showing a zoned euhedral crystal of zircon pointing toward allanite-(Ce).

Name: Hoch-Frederick anomaly

Location: In the area of a small, abandoned, enriched chicken grit and soil dressing quarry about 0.1 km (0.05 mi) north of Churchview Road at a point 1.1 km (0.7 mi) northeast of Old Zionsville.

Sample: RP28

7.5-Minute Quadrangle: East Greenville
Latitude: 40°29'20"N
Longitude: 75°30'32"W
County: Lehigh
Township: Upper Milford

Exposure: Small abandoned quarry having fresh artificial exposures and natural wooded slopes to the north.

Maps: Figures 49–53.

Tectonic setting: Near the north edge of the Applebutter nappe.

Petrology: “Byram gneiss” as used in the Phase II studies section.

Trend of Mineralization: Appears to be relatively uniform within the granitic rock, the outer contact of which appears to correspond roughly to the 200-counts/sec contour.

Comments: Within the area of the grid studies, there appears to be a general correlation between the total count, eU, eTh, and K data, but not with the magnetic data. Gamma-ray flux increases toward the quarry more than would be expected solely from the decrease of soil cover in that direction. A geologic contact appears to be indicated. The strong eTh anomaly in the northwest corner of the grid is dimly reflected by the total count and eU data, but not by K. Regrettably, it was not field checked, but it may represent a dikelike intrusion of a less potassic rock than represented in the RP28 assay sample.

The magnetic data suggest a northeast-plunging trough in the compositional layering that tends to be subparallel to the radiometric data but normal to the direction of maximum slope. This suggests that surficial movement of the colluvium providing the radiometric signature is much less than in the study areas to the east, such as the Limeport Road and Korn-Stelts anomalies, and that the apparent trends are “real” and useful. These ground magnetic data, however, have a trend that is normal to that of the aeromagnetic data of Bromery, Zandle, and others (1959).

Large slickensided faces occur in the north corner of the quarry, approximately 7 m (20 ft) northwest of the assay site. The slickensided faces trend N75°E and the slickenlines tend to be subvertical.

Primary “ore” minerals: None noted.

Secondary “ore” minerals: Small, rounded, orange U(?) secondary.

Assays: **RP28,** a 3.25-m channel sample across gneissic foliation, yielded 97 ppm U and 21 ppm Th.

Possible volumes: If one makes the assumption that the quarry area is underlain by mineralized granitic rock, then nearly 50 percent of the grid area would be underlain by >20 ppm eU. The apparent contacts based on radiometric data and apparent mineralogic and radiometric uniformity within the granitic rock suggest that it might be an intrusion of Grenvillian Byram affinity. If so, it may be a stock or plug with moderate continuity at depth.

Suggestions for further study: Improved 1:24,000-scale geologic mapping of the East Greenville portion of the Reading Prong is needed. Increasing the size of the area studied might also improve the ability to interpret the existing data.

If the mineralized rock is part of an intrusion, then vertical zoning should not be ruled out.

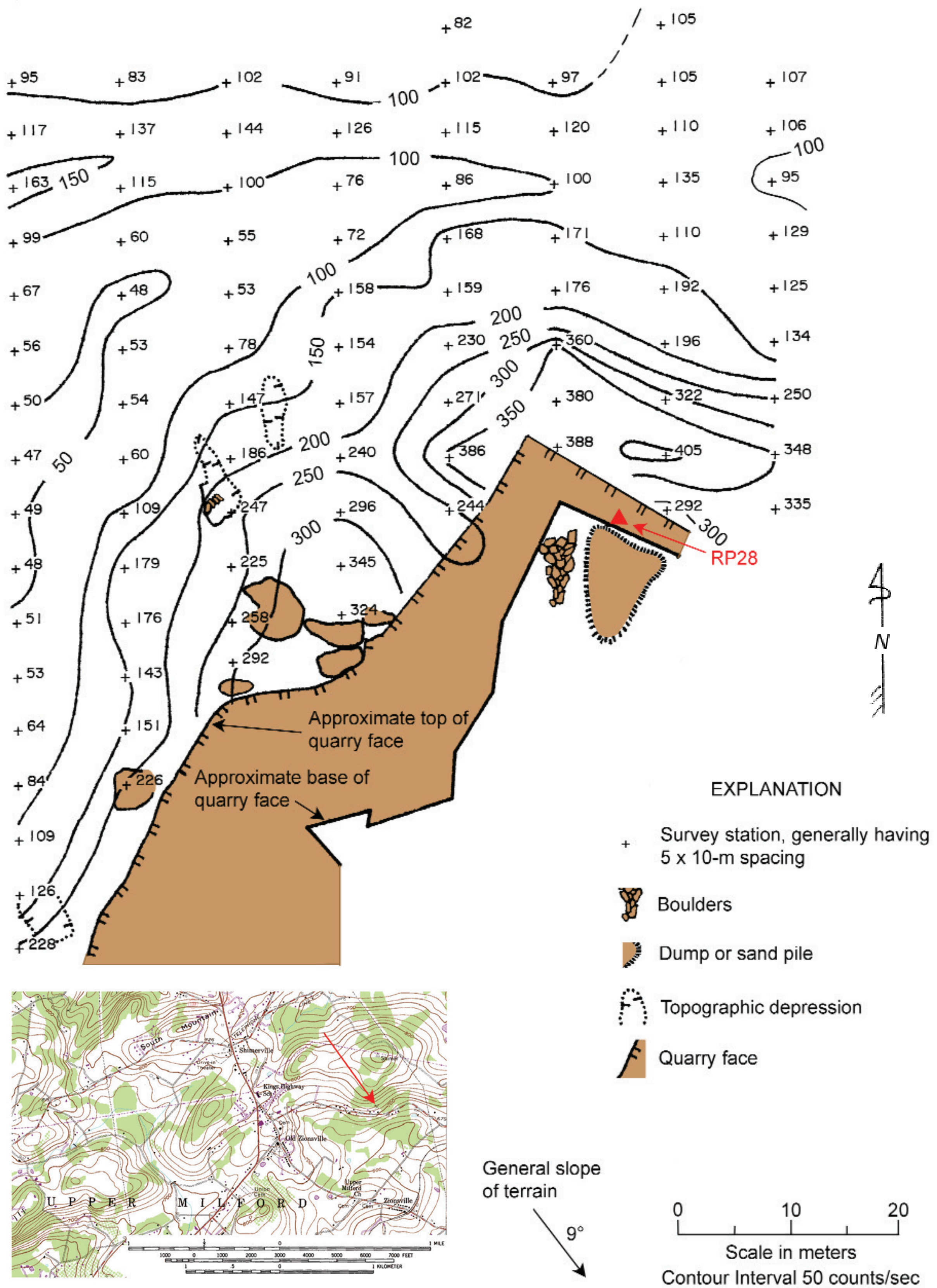


Figure 49. Contour map of total gamma counts per second at the Hoch-Frederick anomaly, Upper Milford Township, Lehigh County. East Greenville 7.5-minute quadrangle; 40°29'20"N, 75°30'32"W.

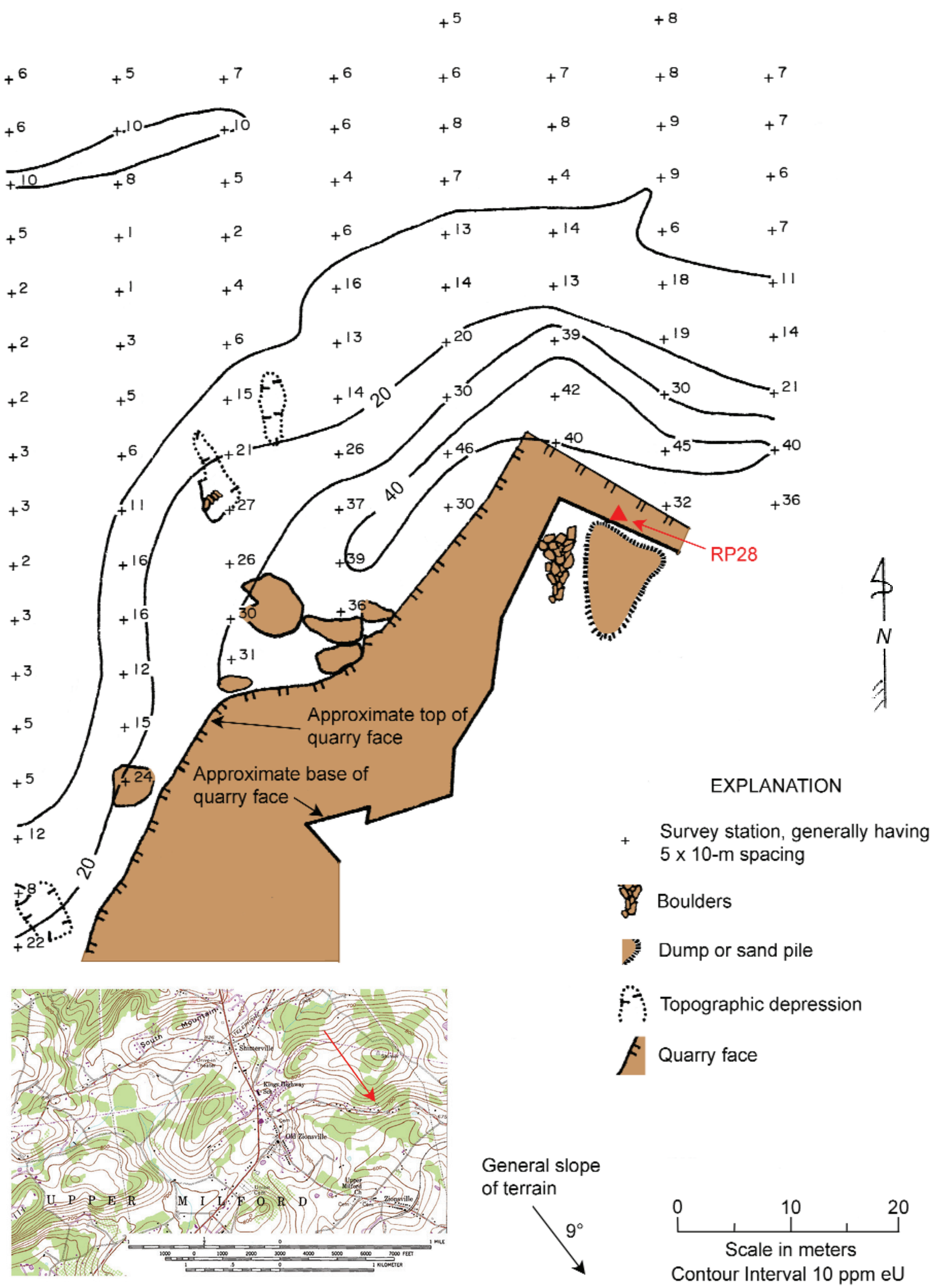


Figure 50. Contour map of radiometric equivalent U in ppm at the Hoch-Frederick anomaly, Upper Milford Township, Lehigh County. East Greenville 7.5-minute quadrangle; 40°29'20"N, 75°30'32"W.

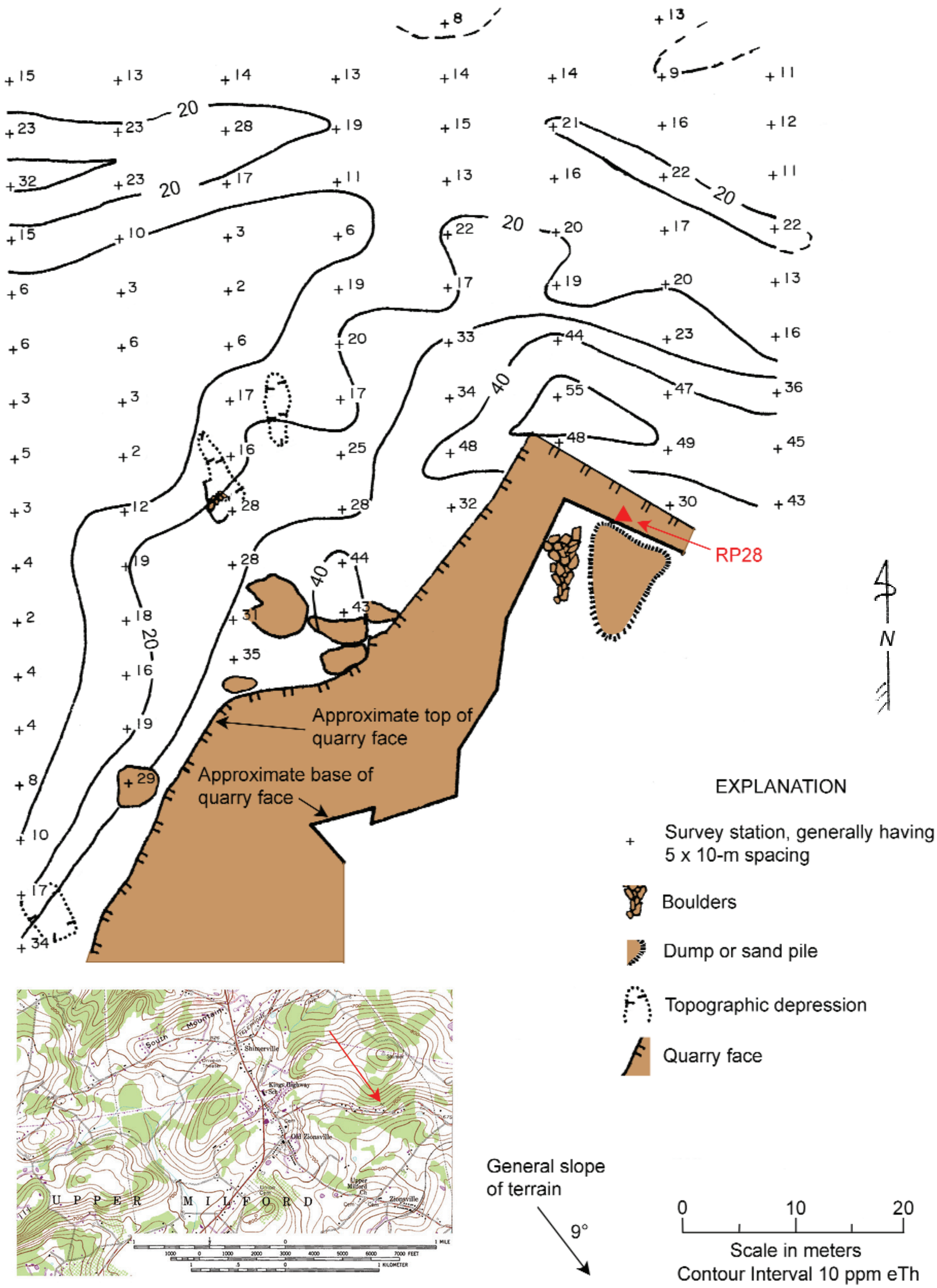


Figure 51. Contour map of radiometric equivalent Th in ppm at the Hoch-Frederick anomaly, Upper Milford Township, Lehigh County. East Greenville 7.5-minute quadrangle; 40°29'20"N, 75°30'32"W.

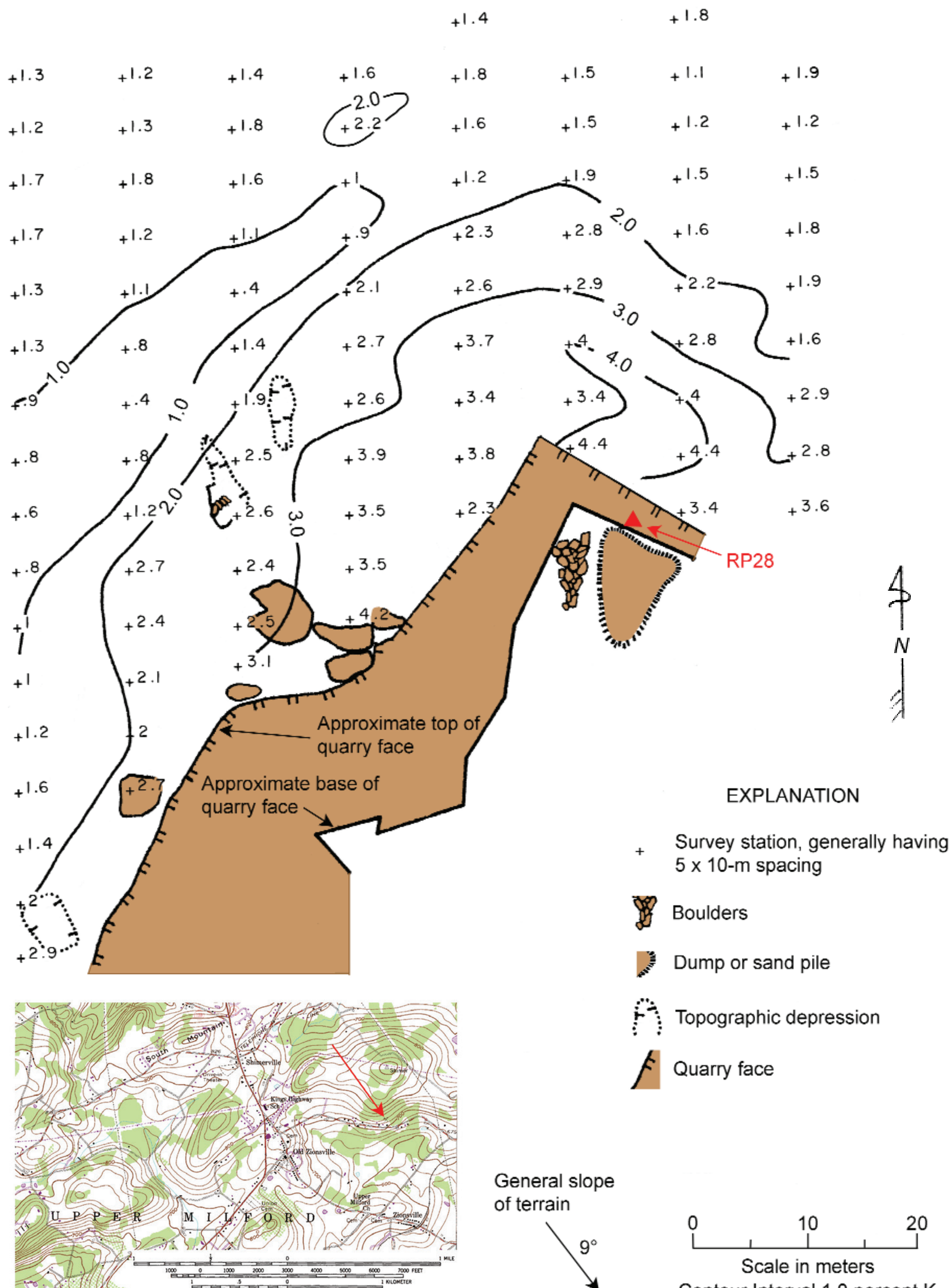


Figure 52. Contour map of radiometric K in percent at the Hoch-Frederick anomaly, Upper Milford Township, Lehigh County. East Greenville 7.5-minute quadrangle; 40°29'20"N, 75°30'32"W.

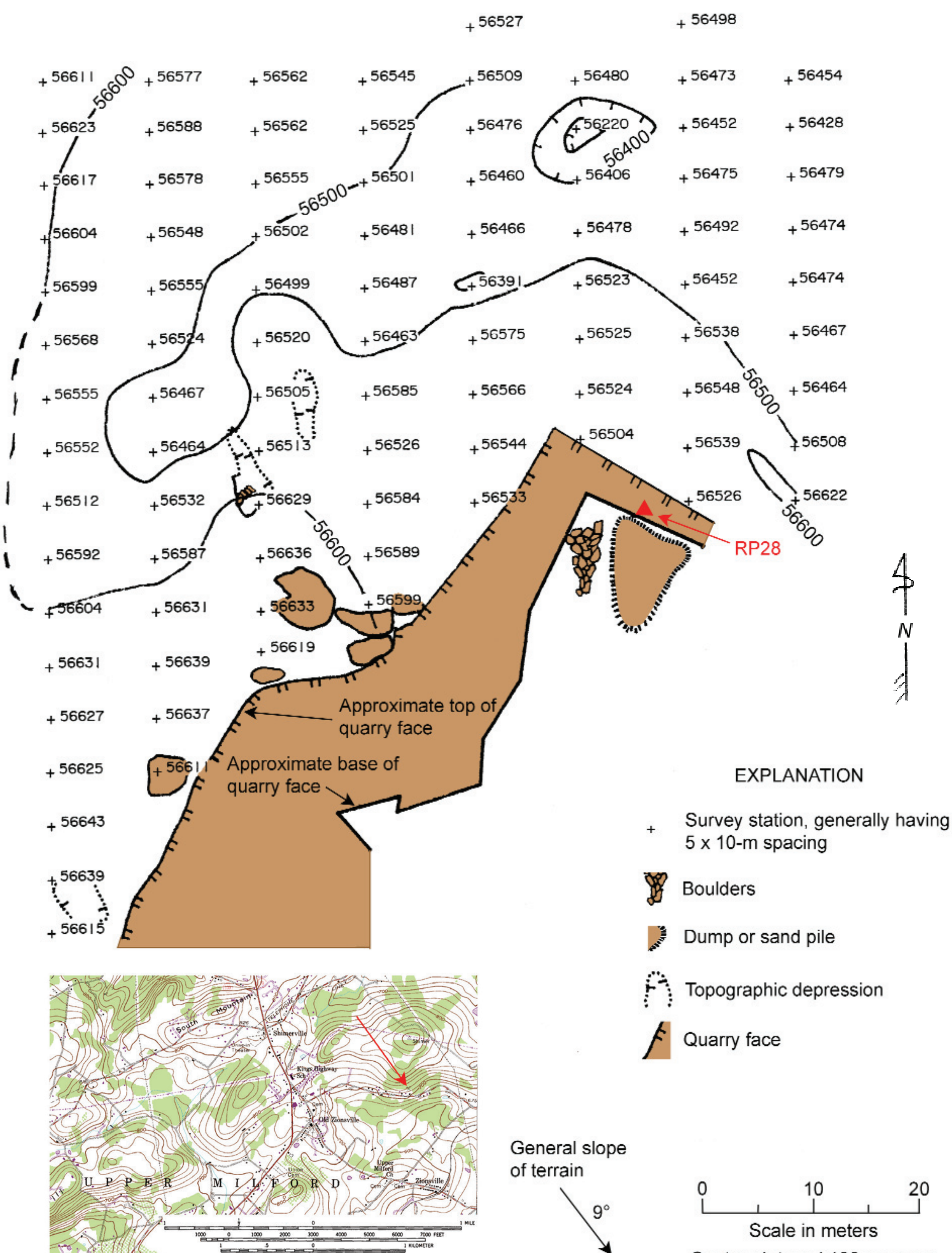


Figure 53. Contour map of total magnetic flux in gammas at the Hoch-Frederick anomaly, Upper Milford Township, Lehigh County. East Greenville 7.5-minute quadrangle; 40°29'20"N, 75°30'32"W.

Name: Korn-Stelts anomaly

Location: In a wooded area just northwest of a small orchard on the southwest side of Chestnut Hill Road 0.3 km (0.2 mi) northwest of the intersection with Applebutter Hill Road. Elevation approximately 670 feet (200 m).

Samples: RP23, RP64

7.5-Minute Quadrangle: Allentown East
Latitude: 40°31'26"N
Longitude: 75°26'14"W
County: Lehigh
Township: Upper Saucon

Exposure: Natural wooded slope bordered by a fieldstone fence on the southeast. No outcrop within grid area.

Maps: Figures 54–58.

Tectonic setting: North edge of Applebutter nappe.

Petrology: Mo-bearing quartz monzonite suite. RP64 and the nearby samples RP23 and RP24 can also be characterized as containing minor titanite, some of which encloses ilmenite. Chemically, the RP24 sample best fits the Mo-bearing suites except for the lack of Mo. It remains an enigma.

Trend of Mineralization: Unknown because of slope and float movement. If the geochemically and mineralogically similar RP64 and RP23 (see Appendix 2) occurrences are related, then the trend may be north-northwest.

Comments: Within the area of the radiometric grid, there appear to be two somewhat distinct total-count gamma-ray anomalies. The upslope anomaly is enriched in Th relative to the downslope anomaly, and conversely, the downslope is enriched in U. This is not the situation observed at the other study areas and suggests the possibility of separate loci of primary U and Th enrichment rather than just geochemical mobility. The radiometric data for K trend in a more northerly direction than those for U or Th and at a 30° angle relative to slope. The reason for the former is unknown. The magnetic low seems to be too intense to relate to magnetic trash in the stone fence.

The geology of the RP23-RP24-RP64 area is complex. Diopside-epidote-garnet-hornblende skarn with minor titanite occurs on the knoll just east of the RP24 sample area. This, and the presence of titanite and leucoxene in RP23, RP24, and RP64, as well as the presence of trace elements that are typically enriched in titanite (see Appendix 4), such as Nb, Sn, and Y, suggest that the U mineralization in this area may be related to reaction with a calcareous unit. If so, there may be a preferred spatial relationship to particular metasedimentary units.

Primary "ore" minerals: Uraninite(?) as rare tiny blebs within orange hexagonal crystals (Figure 59), titanite, and allanite-(Ce). RP24 also contains brick-red thorite(?).

Secondary "ore" minerals: "Leucoxene." Unknown orange transparent uranium(?) secondaries in RP23 and RP64. Unknown powdery yellow uranium(?) secondaries in RP24.

Assays: **RP64,** a composite of twenty-five 3- to 5-cm chips from a hand-dug hole, contains 718 ppm U and 320 ppm Th. **RP23,** a composite of seven ≥5-cm chips from two boulders, contains 960 ppm U and 240 ppm Th. See also RP24 and note the moderately enriched rare-earth data for this area.

Possible volumes: Unknown. The eU data, however, suggest that about one third of the area studied contains a minimum of 20 ppm U.

Suggestions for further study: Evaluate the environmental significance of the localized high gamma-ray flux. Measure and compare the fluxes of Rn^{220} and Rn^{222} in soils at the two gamma anomalies. Attempt to project and trace the mineralization northwest to the outcrops, known to be anomalously radiometric, at the intersection of Chestnut Hill Road with Limeport Pike, 1.2 km (0.8 mi) to the northwest. Attempt to verify the role of structure suggested by the highly sheared and sutured quartz in RP24 a short distance to the northwest. Test the role of stratigraphy or contact reaction between the granitic and hornblende gneisses by performing a reconnaissance parallel to the contact. This occurrence may be a geochemical "missing link" between the Chestnut Hill area skarn occurrences and those in the main portion of the Reading Prong in Mo-bearing grandiorites and quartz monzonites.

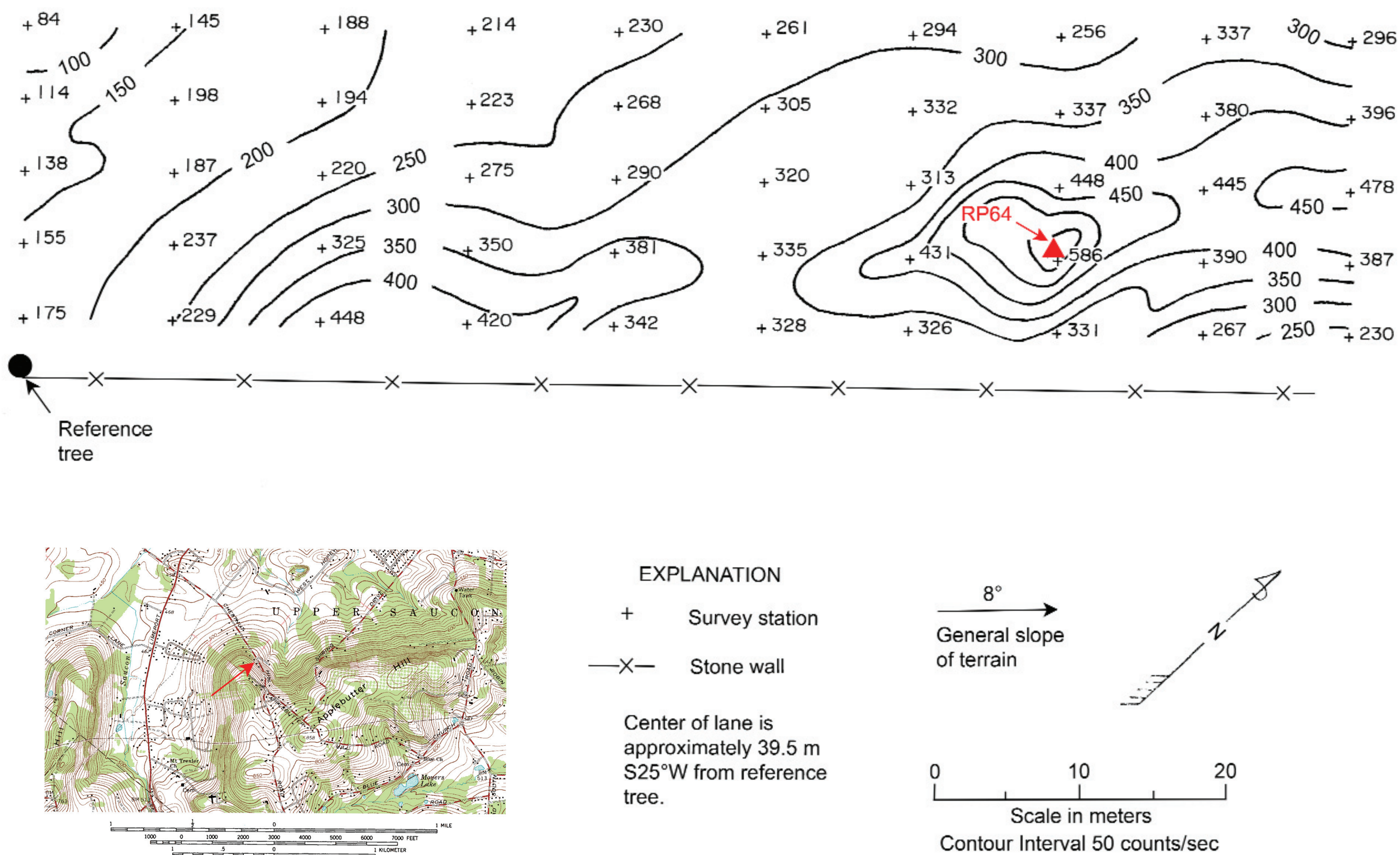


Figure 54. Contour map of total gamma counts per second at the Korn-Stelts anomaly, Upper Saucon Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°31'26"N, 75°26'14"W.

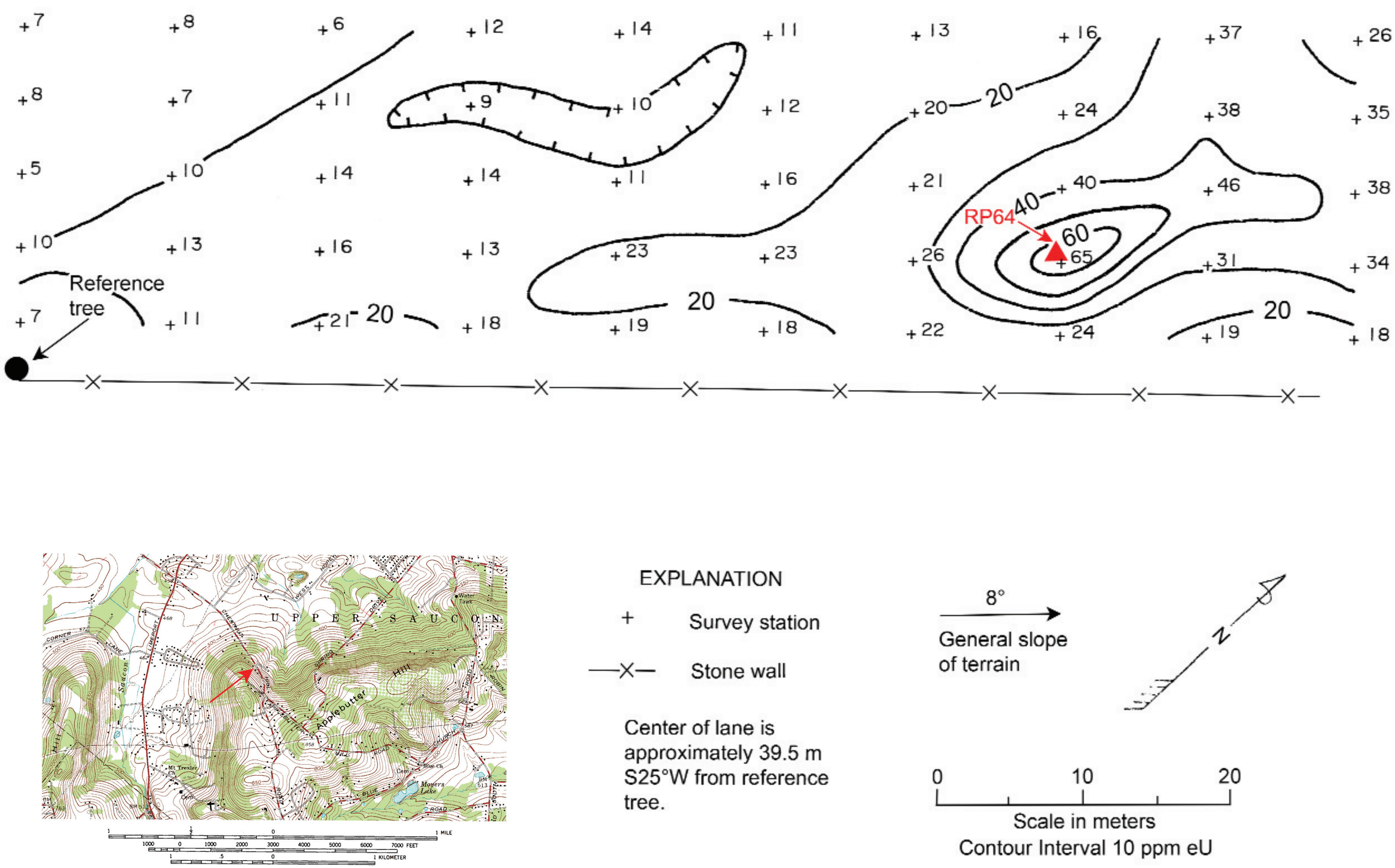


Figure 55. Contour map of radiometric equivalent U in ppm at the Korn-Stelts anomaly, Upper Saucon Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°31'26"N, 75°26'14"W.

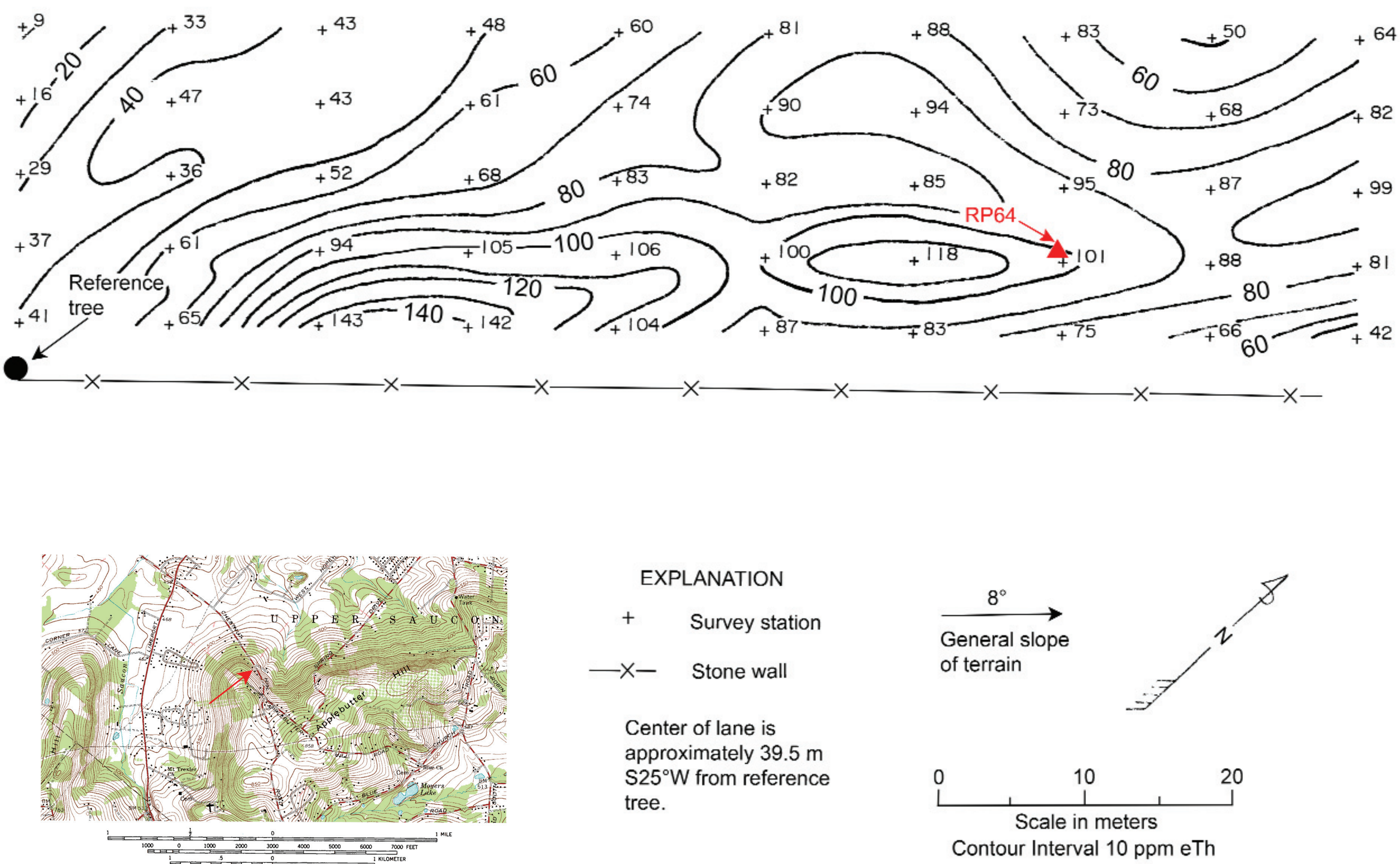


Figure 56. Contour map of radiometric equivalent Th in ppm at the Korn-Stelts anomaly, Upper Saucon Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°31'26"N, 75°26'14"W.

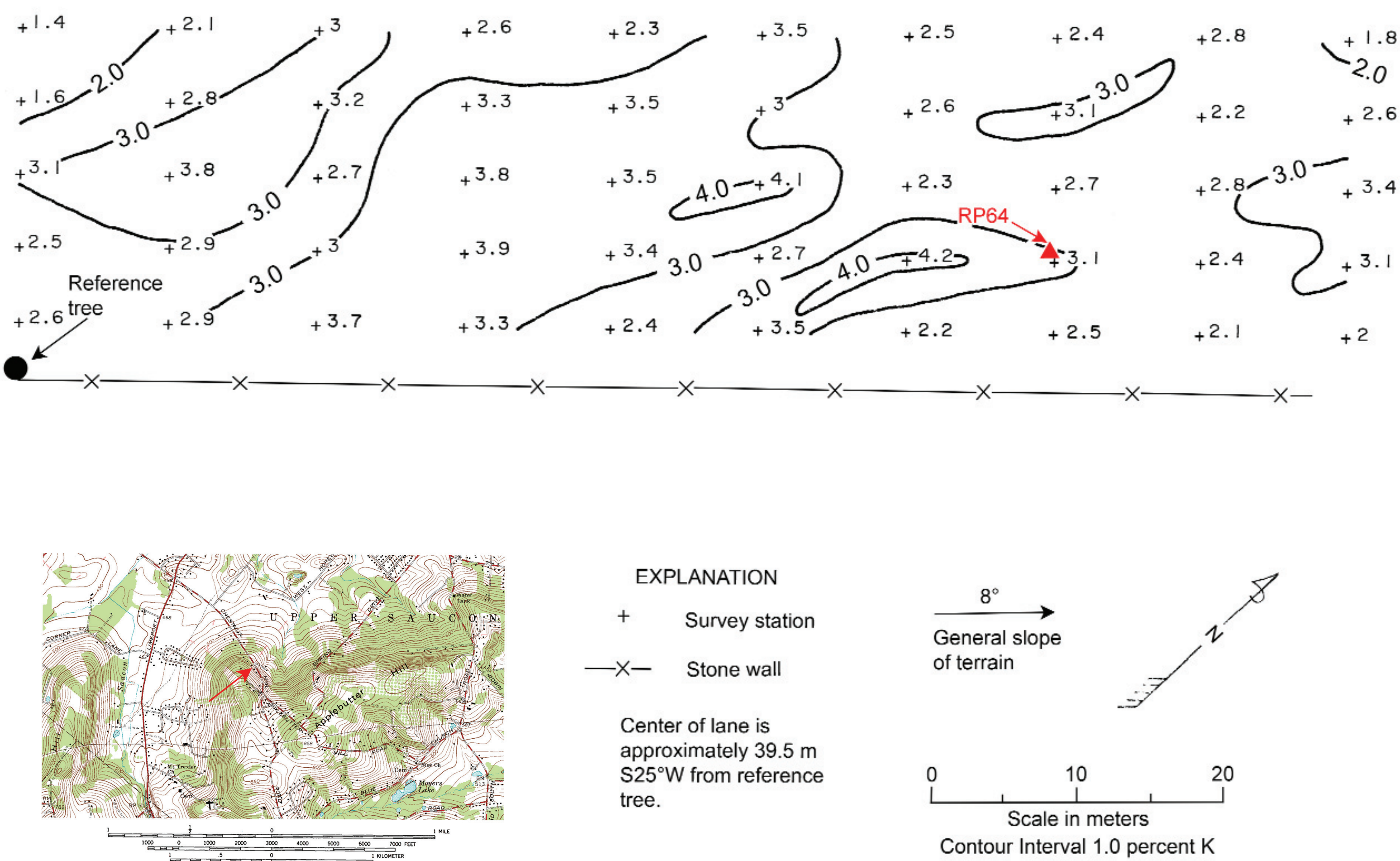


Figure 57. Contour map of radiometric K in percent at the Korn-Stelts anomaly, Upper Saucon Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°31'26"N, 75°26'14"W.

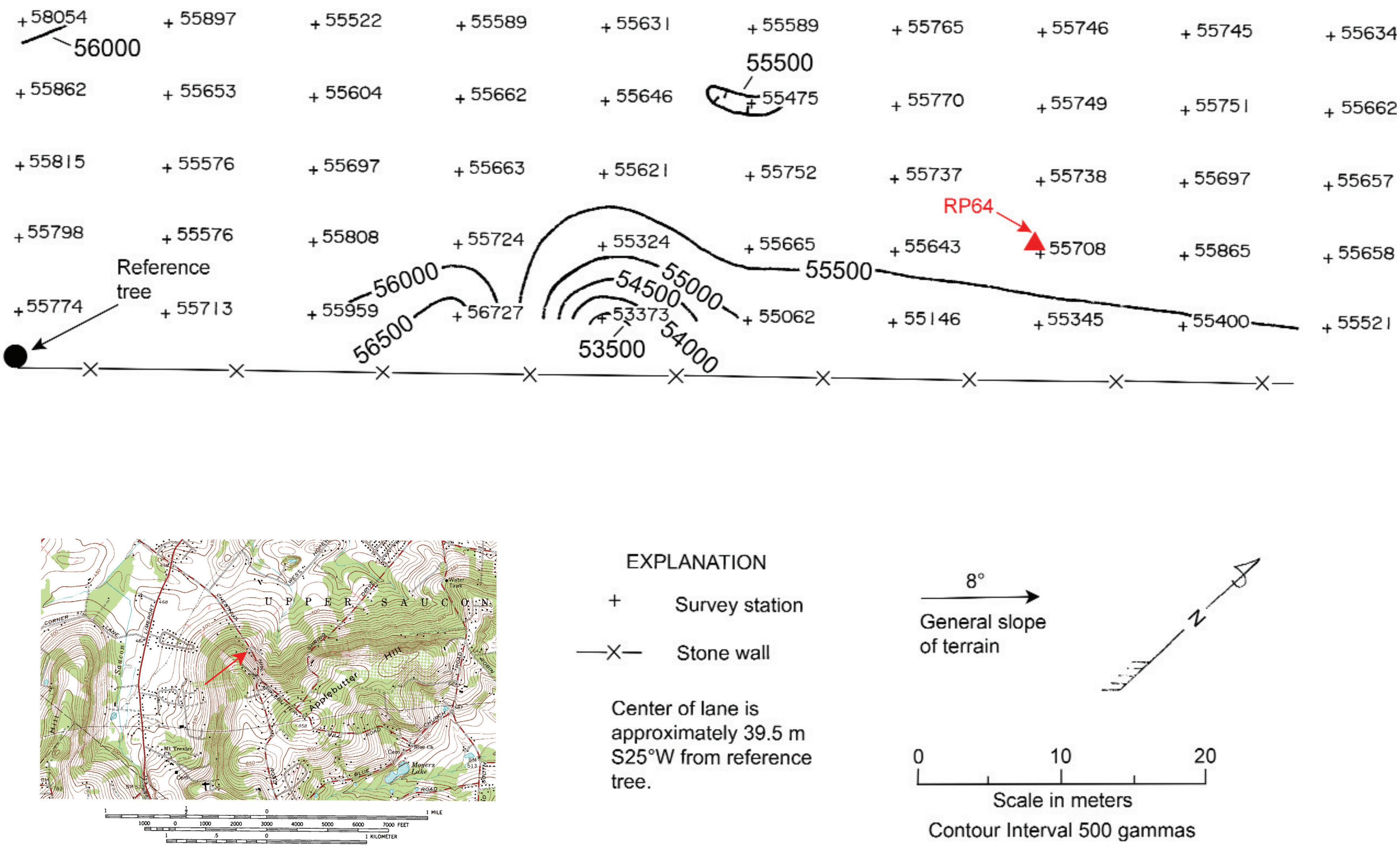


Figure 58. Contour map of total magnetic flux in gammas at the Korn-Stelts anomaly, Upper Saucon Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°31'26"N, 75°26'14"W.

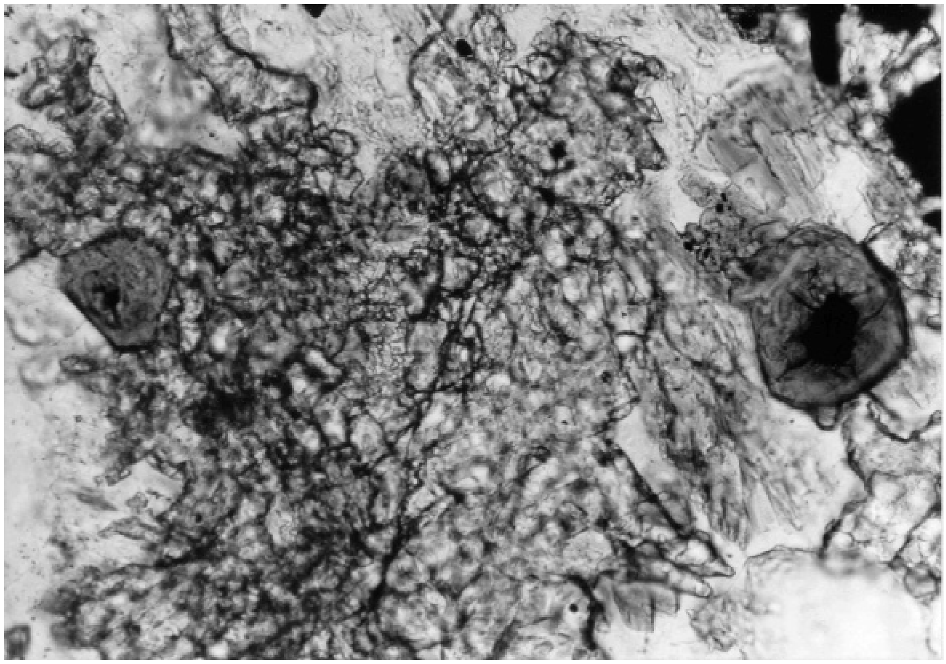


Figure 59. Photomicrograph (310x) of a thin section of sample RP23, identified in this report as "Heller's 2 boulders," from Limeport, Lehigh County. This view shows opaque cores of possible uraninite surrounded by orange hexagonal rims of a possible secondary uranium mineral.

Name: Limeport Road anomaly

Location: On the south side of Limeport Road at a point 1.95 km (1.2 mi) west of Limeport and 2.1 km (1.3 mi) east-northeast of Vera Cruz.

Sample: RP6

7.5-Minute Quadrangle: Allentown East
Latitude: 40°30'37" N
Longitude: 75°28'15" W
County: Lehigh
Township: Upper Milford

Exposure: Natural wooded slope surrounded by anthropogenic features. No outcrop.

Maps: Figures 60–64.

Tectonic setting: North edge of Applebutter nappe.

Petrology: Included in Mo-bearing quartz monzonite suite.

Trend of Mineralization: Surficial float appears to follow slope, here trending north-northwest, whereas magnetic data suggest a possible northwest-southeast trend to the composition of bedrock.

Comments: The coincidence of total-gamma, ppm eU, and ppm eTh anomalies suggests that: (1) total-gamma is a useful indicator of uranium; and (2) there is no apparent U/Th zoning at the occurrence. The correlation of total gamma, ppm eU, and ppm eTh with percent K is somewhat weaker, but still suggests the possibility of a central north-south zone of U-Th mineralization through the tract.

The mineralized float seen by the gamma-ray spectrometer survey may be originating within the magnetic low that is less than 56,300 gamma. This and the low total iron content (1.82 percent "Fe_2O_3") of RP6 suggests that the mineralization is not associated with magnetite.

Primary "ore" minerals: Uraninite(?) as small blebs with thin yellowish rims, allanite-(Ce) as subhedral grains up to 2 mm with orange altered rims (Figure 65), rare $<$0.5-mm molybdenite flakes, and probable xenotime (Figure 66).

Secondary "ore" minerals: Uranophane and uncommon hyalite opal.

Assays: **RP6** from one 20-kg boulder contained 1,120 ppm U and 230 ppm Th.

Possible volumes: Unknown. However, the gamma-ray spectrometer ppm eU data suggests that about one third of the area studied contains a minimum of 20 ppm U.

Suggestions for further study: Lack of outcrop and the small size of undeveloped areas free of power lines seem to limit field studies in the immediate area. Other occurrences could doubtless be found along the northern margin of the Applebutter nappe. A possible relationship of U-Th mineralization to distance from hornblende gneiss should be considered.

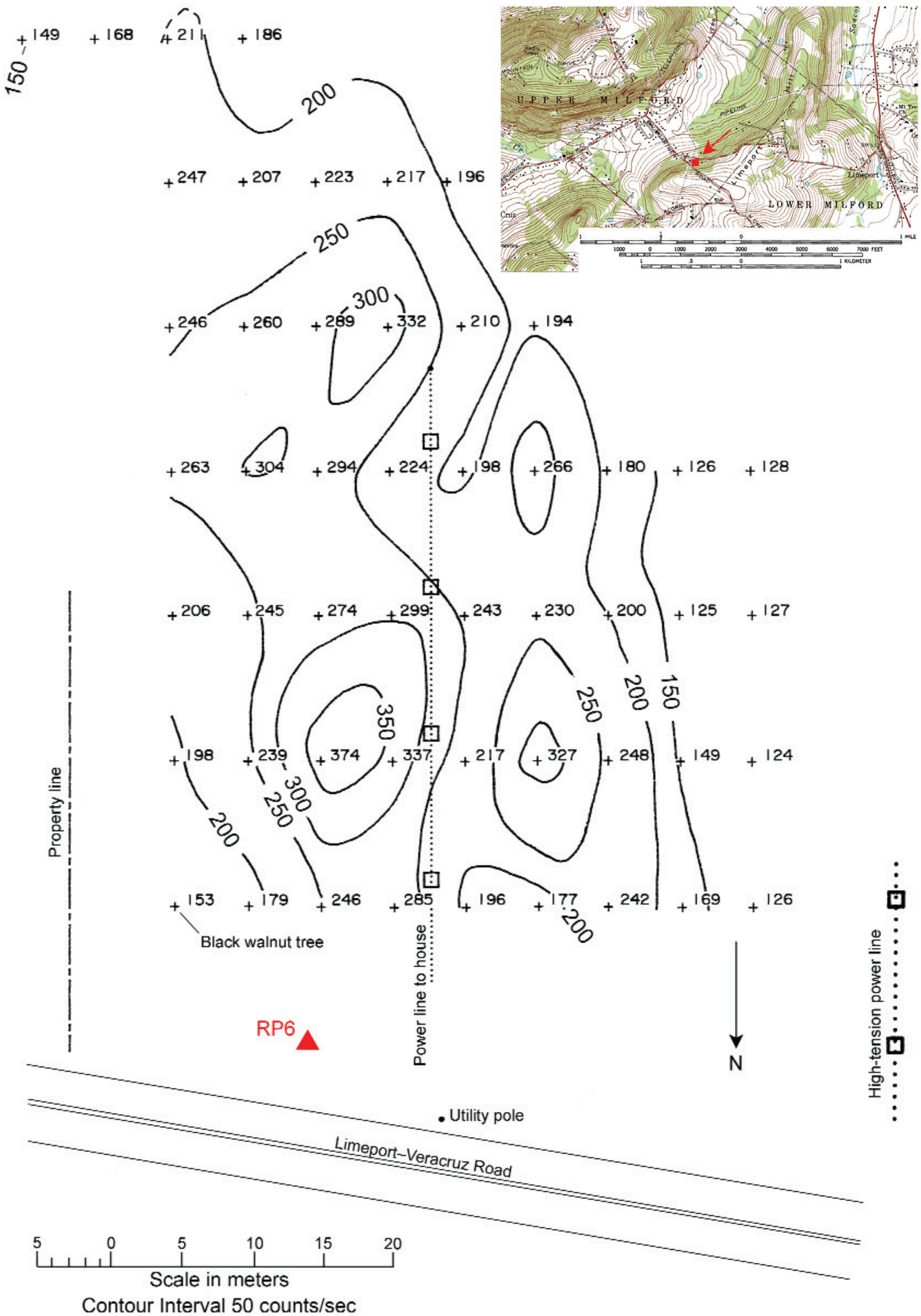


Figure 60. Contour map of total gamma counts per second at the Limeport Road anomaly, Upper Milford Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°30'37"N, 75°28'15"W.

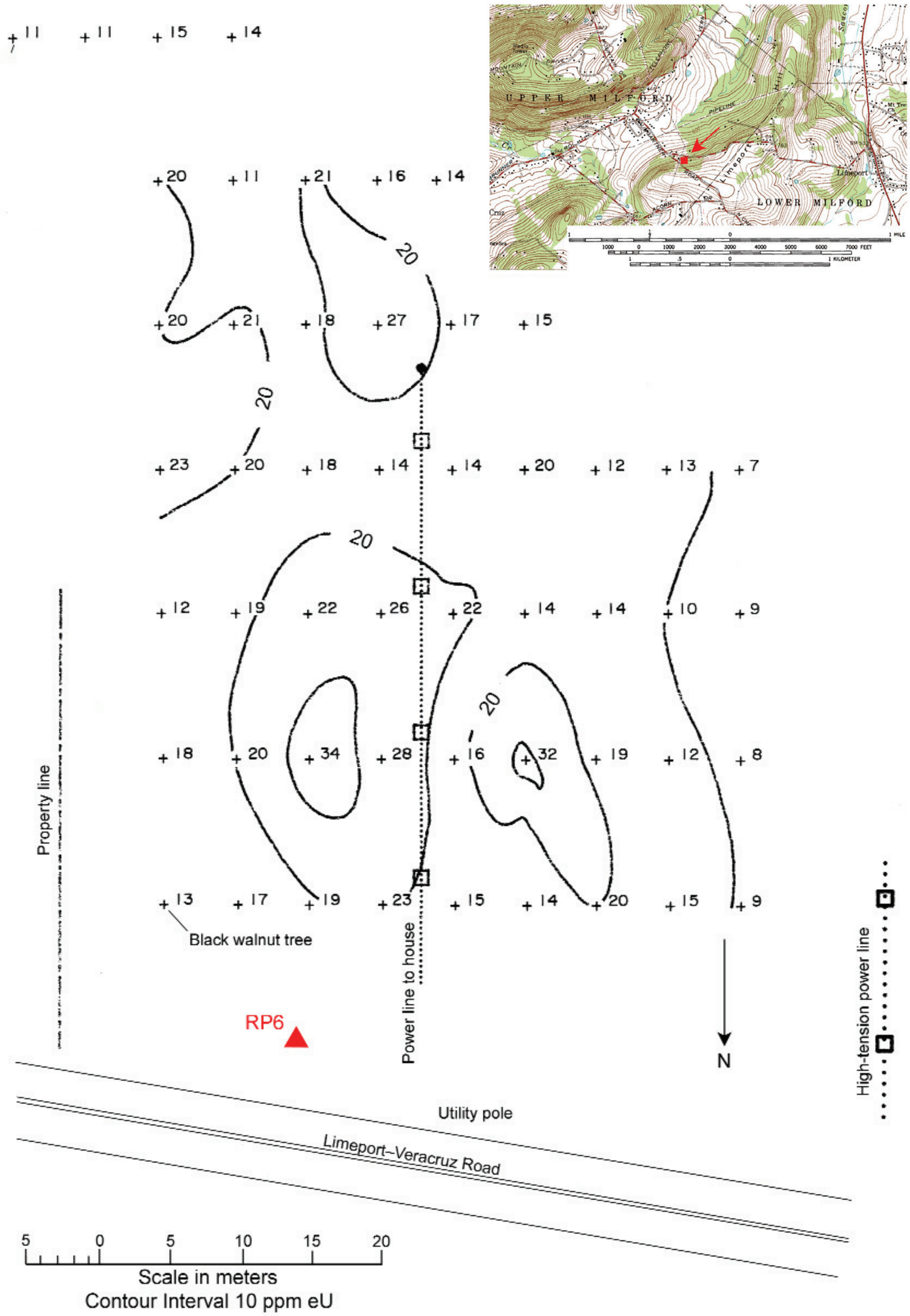


Figure 61. Contour map of radiometric equivalent U in ppm at the Limeport Road anomaly, Upper Milford Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°30'37"N, 75°28'15"W.

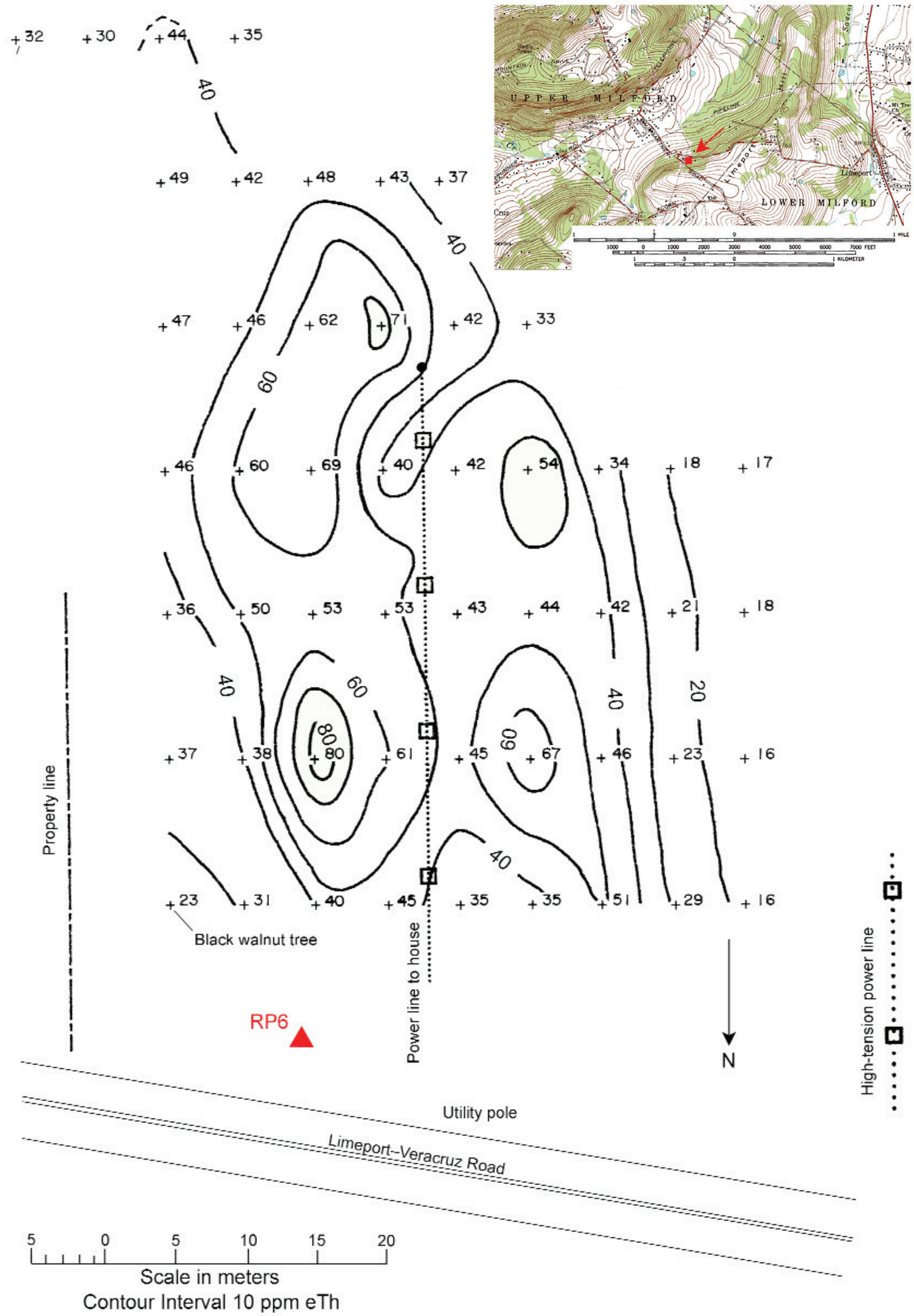


Figure 62. Contour map of radiometric equivalent Th in ppm at the Limeport Road anomaly, Upper Milford Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°30'37"N, 75°28'15"W.

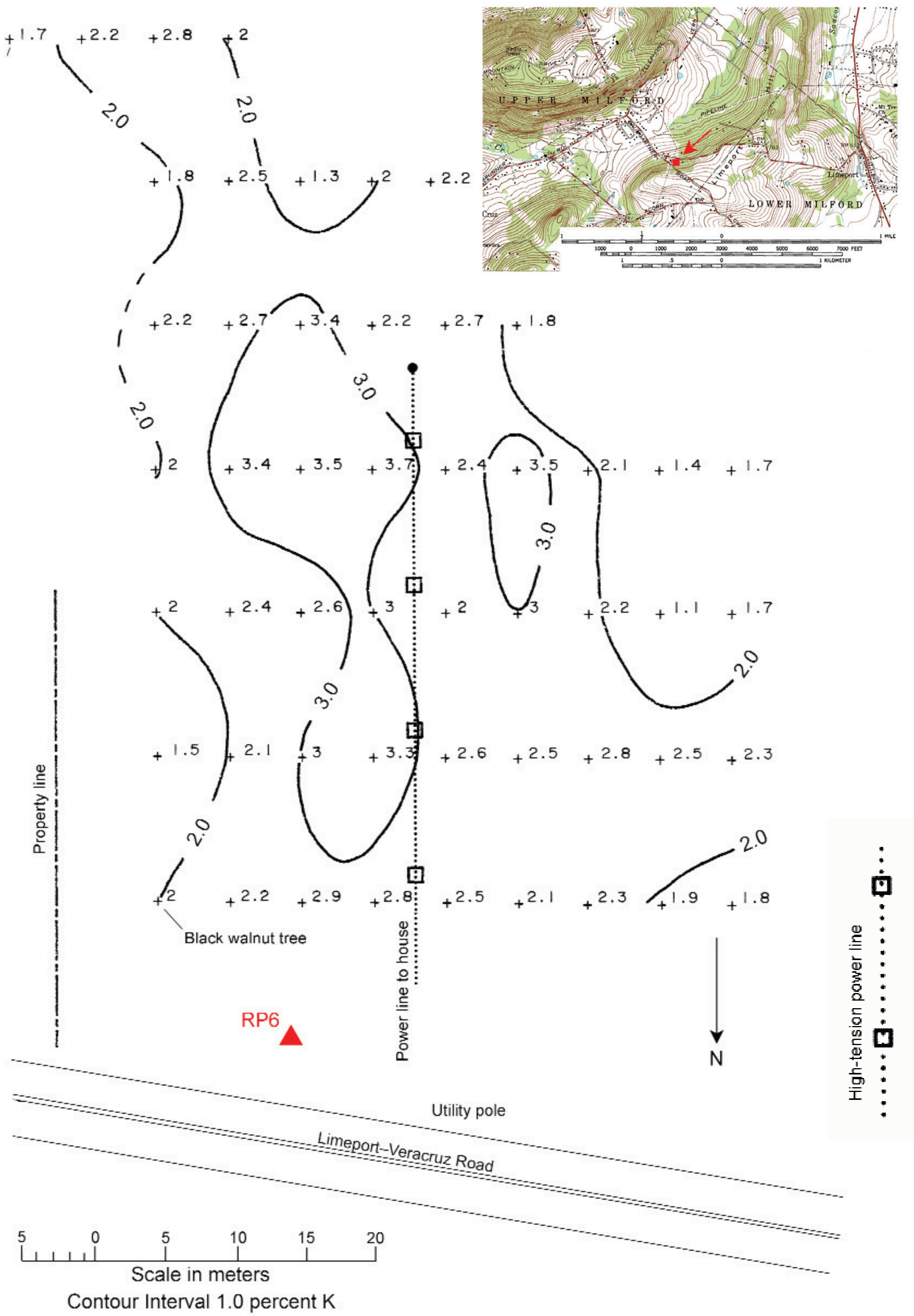


Figure 63. Contour map of radiometric K in percent at the Limeport Road anomaly, Upper Milford Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°30'37"N, 75°28'15"W.

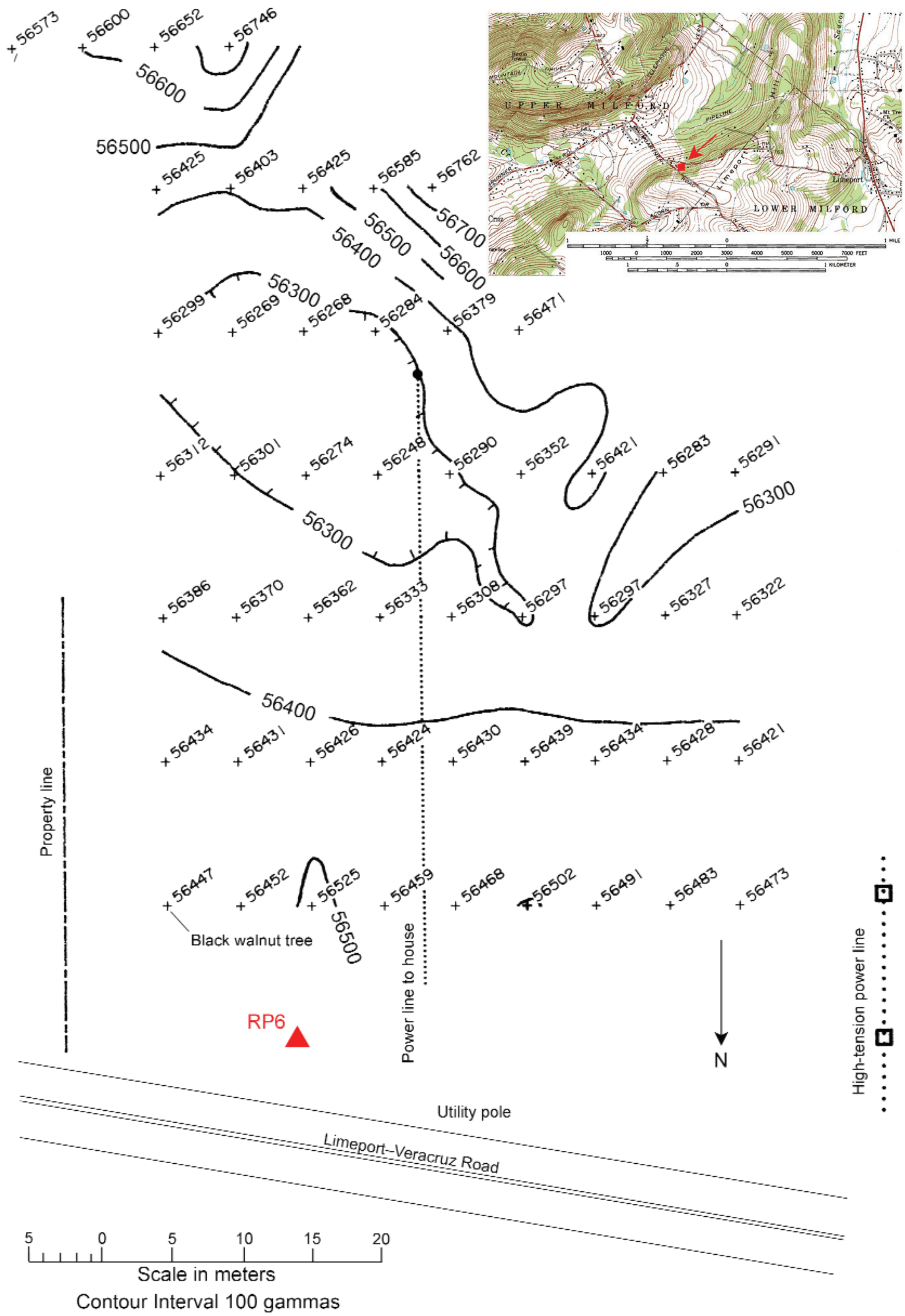


Figure 64. Contour map of total magnetic flux in gammas at the Limeport Road anomaly, Upper Milford Township, Lehigh County. Allentown East 7.5-minute quadrangle; 40°30'37"N, 75°28'15"W.

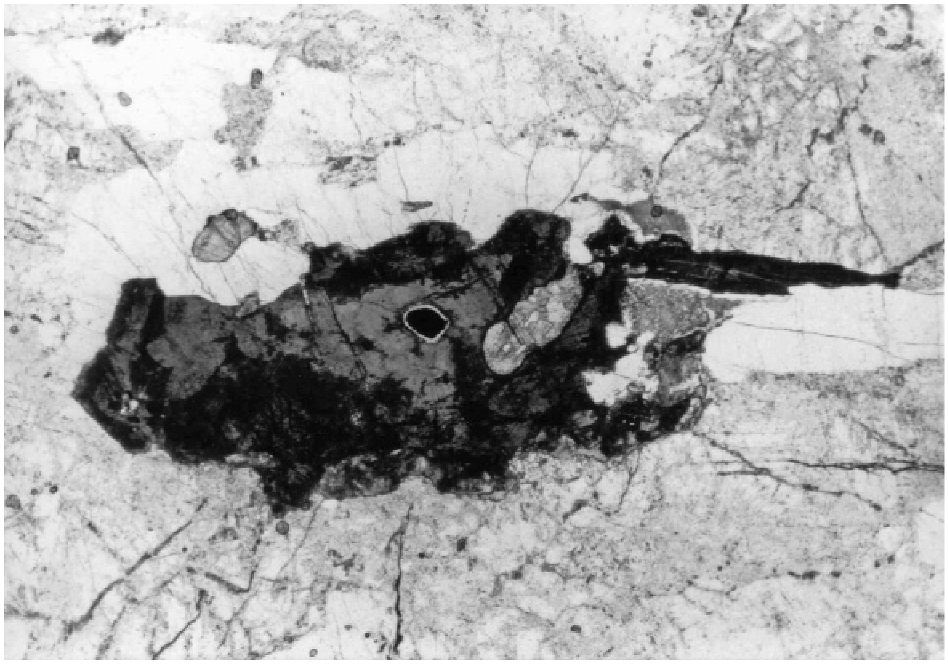


Figure 65. Photomicrograph (31x) of a thin section of sample RP6, from the Limeport Road anomaly, Lehigh County, showing a large dark-brown allanite-(Ce) grain containing an opaque uraninite(?) inclusion having a thin, translucent yellow rim.

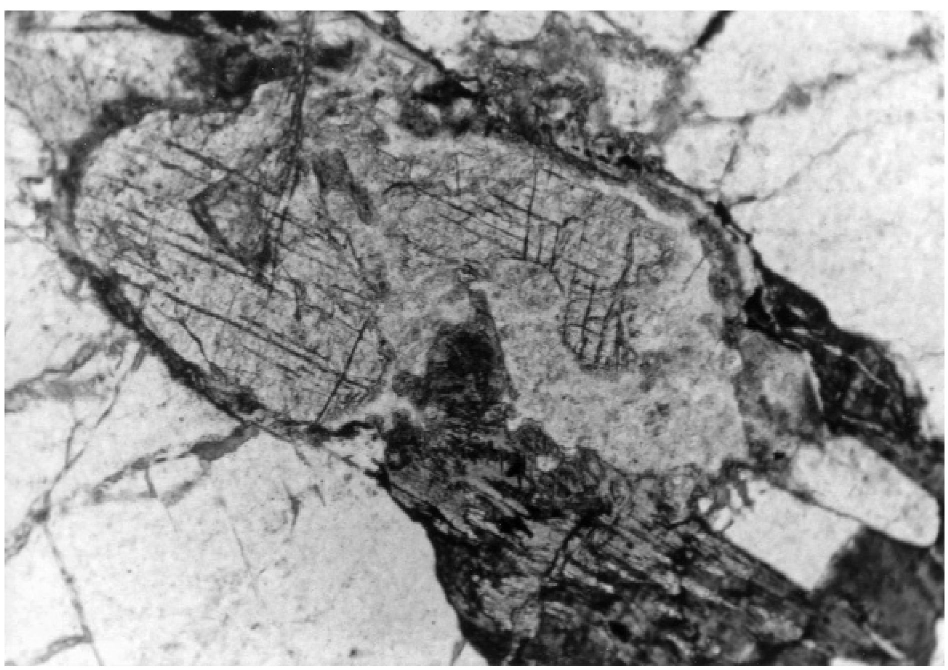


Figure 66. Photomicrograph (123x) of a thin section of sample RP6, from the Limeport Road anomaly, Lehigh County, showing probable xenotime with parting planes.

Name: Oley Road anomaly

Location: Field on the north side of Oley Road at a point 1.05 km (0.65 mi) east of the intersection of Pricetown Road, Oley Road, and Antietam Road at Alsace Manor.

Sample: RP11

7.5-Minute Quadrangle: Fleetwood
Latitude: 40°24'01"N
Longitude: 75°50'56"W
County: Berks
Township: Alsace

Exposure: Gently sloping wooded area and pasture.

Maps: Figures 67–71.

Tectonic setting: North edge of Applebutter nappe, but the choice of faults used as a boundary is somewhat arbitrary.

Petrology: “Byram” granite suite as used herein.

Trend of Mineralization: No apparent trend, perhaps because past agricultural practices redistributed the material.

Comments: The uranium and radon contents in groundwater in the area around Alsace Manor (see location map, Figure 67) are elevated (Rumbaugh, 1983).

Primary “ore” minerals: Uraninite(?) as rounded opaque grains having orange or red rims, zoned zircons, and allanite-(Ce)(?) as tabular metamict grains.

Secondary “ore” minerals: Unidentified golden grains, some pleochroic and fibrous.

Assays: **RP11,** a composite of 11 boulders from a 36-m portion of the bank on the north side of Oley Road, yielded 160 ppm U and 27 ppm Th.

Possible volumes: Unknown, but approximately 200 m^2 of the area studied contains ≥20 ppm eU.

Suggestions for further study: The lack of outcrop and undisturbed soils seems to preclude further studies at this anomaly. Perhaps reconnaissance between this anomaly and the Chapel Hill anomaly, 1.9 km to the south, would be warranted.

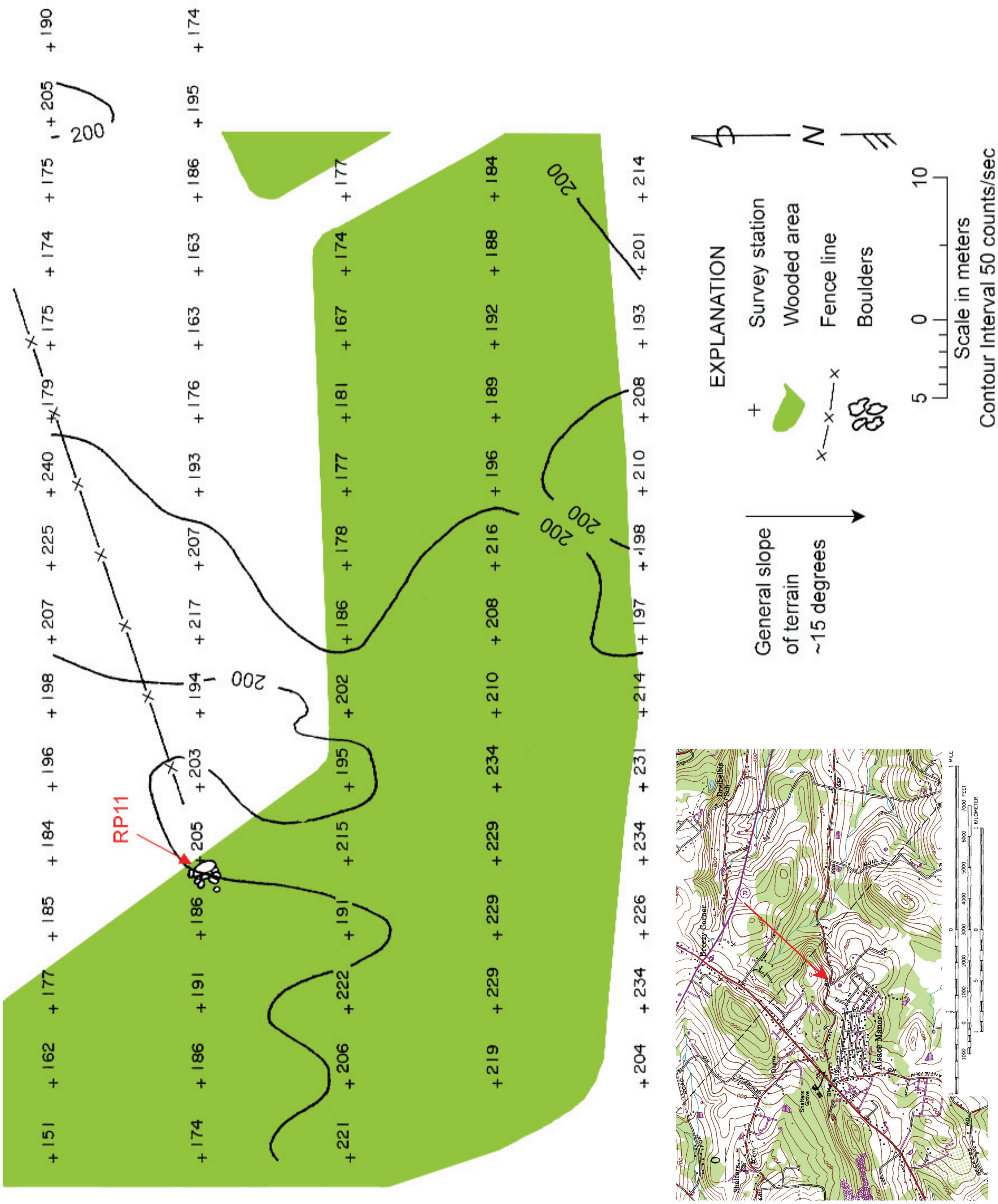


Figure 67. Contour map of total gamma counts per second at the Oley Road anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°24'02"N, 75°50'56"W.

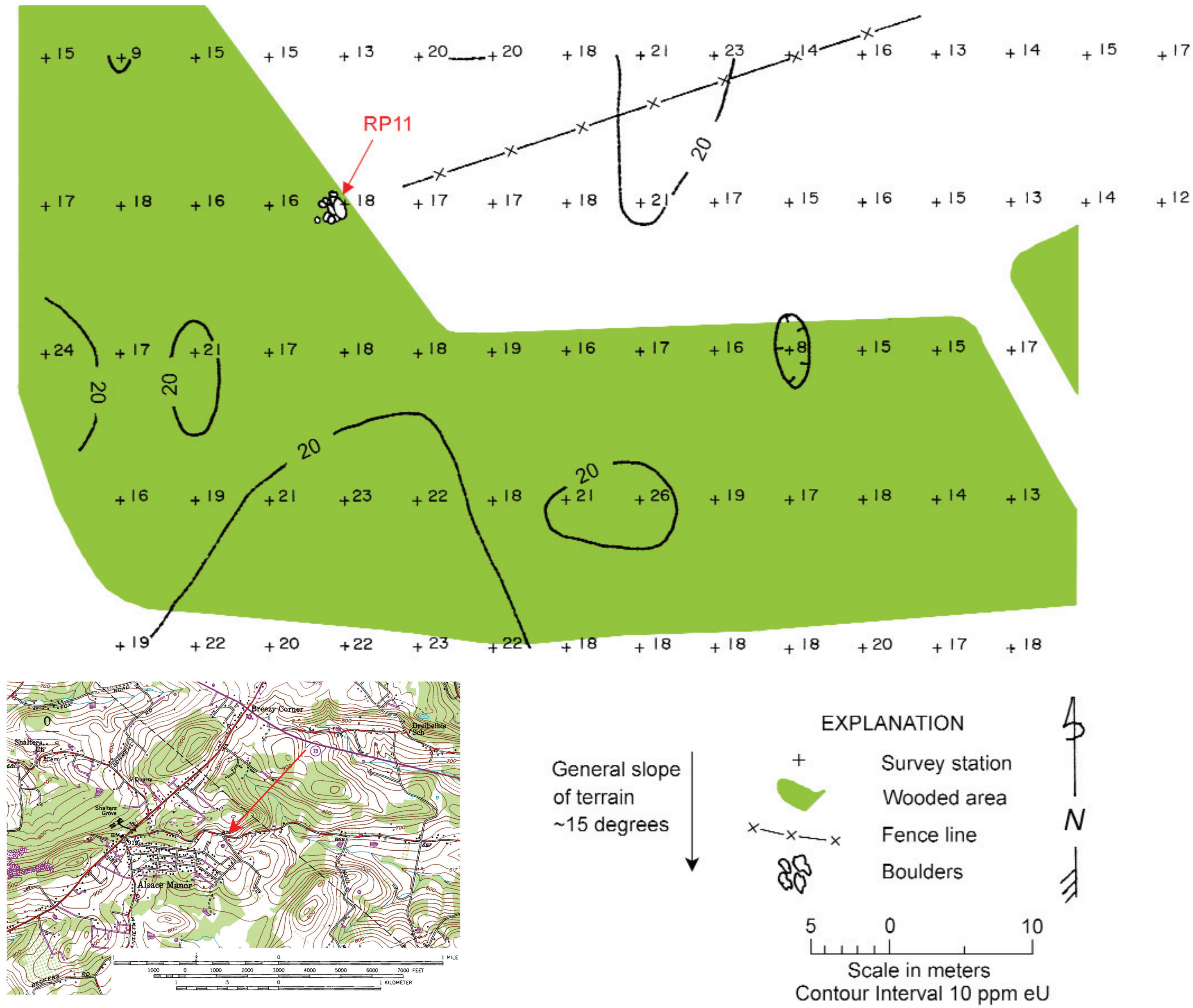


Figure 68. Contour map of radiometric equivalent U in ppm at the Oley Road anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°24'02"N, 75°50'56"W.

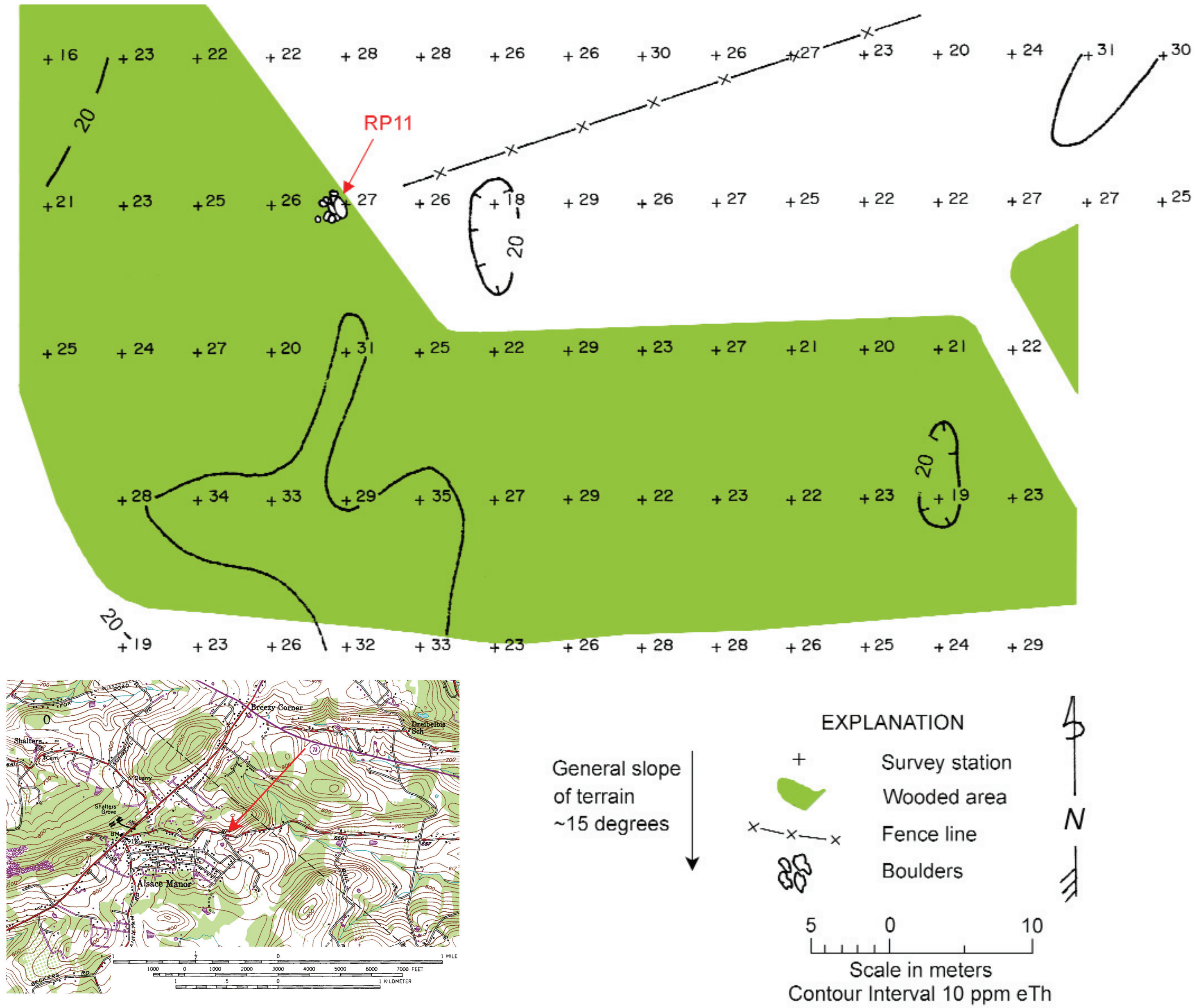


Figure 69. Contour map of radiometric equivalent Th in ppm at the Oley Road anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°24'02"N, 75°50'56"W.

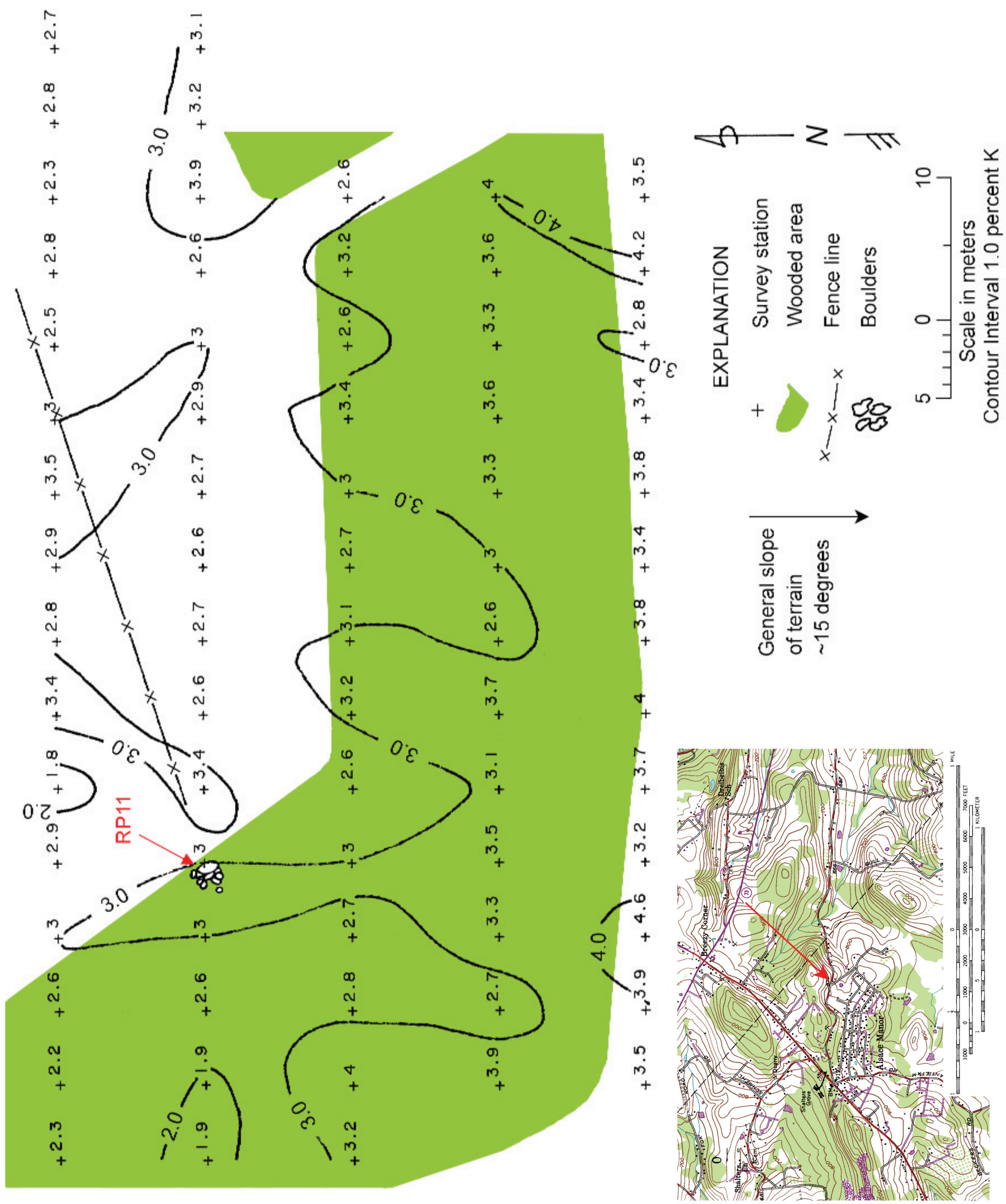


Figure 70. Contour map of radiometric K in percent at the Oley Road anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°24'02"N, 75°50'56"W.

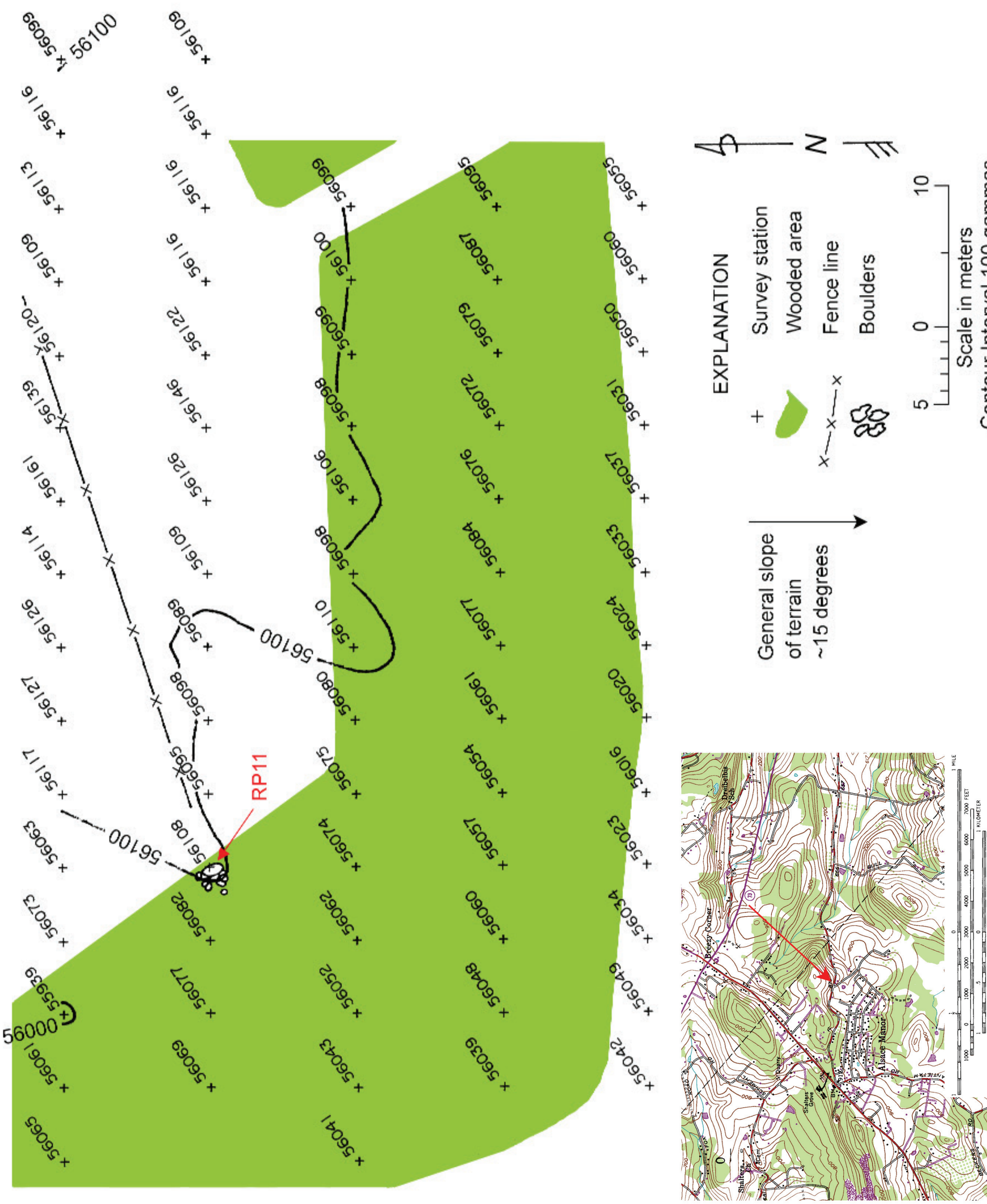


Figure 71. Contour map of total magnetic flux in gammas at the Oley Road anomaly, Alsace Township, Berks County. Fleetwood 7.5-minute quadrangle; 40°24'02"N, 75°50'56"W.

Name: Swoveberg Hill anomaly

Location: Along the north side of Silver Creek Road at a point 1.7 km (1.1 mi) southwest of Wassergass.

Samples: RP52, RP65

7.5-Minute Quadrangle: Hellertown
Latitude: 40°34'29"N
Longitude: 75°18'22"W
County: Northampton
Township: Lower Saucon

Exposure: Natural wooded slope with a few small possible outcrops.

Maps: Figures 72–76.

Geology: Probably in the Musconetcong nappe as defined by Drake (1978), but radiometric data from the carborne survey (Plate 1) suggest that it may be on the northern faulted margin of the eastern end of the Applebutter nappe.

Petrology: "Byram gneiss" as used in the Phase II studies section. The association of magnetite with the uranium is unique amongst the sites studied and suggests a possible affinity with uranium-magnetite occurrences being studied by R. I. Grauch, L. Gunderson-Smoot, and others of the USGS in the Reading Prong of New Jersey and New York.

Trend of Mineralization: Unknown because of the sinister combination of float and slope. Textures of hand samples of float suggest that uraninite follows gneissic foliation. The aeromagnetic map of Bromery, Bennett, and others (1959) suggests that the magnetic grain at Swoveberg Hill trends about N40°E.

Comments: Comparison of the total-count grid (Figure 72) with the eU grid (Figure 73) reveals a moderately good correlation between them. This tends to validate the use of total-gamma-ray surveys for reconnaissance. Either would have led to discovery of the RP65 assay sample that contained nearly 1 percent U. The contour map of eTh (Figure 74), on the other hand, yields broader anomalies and, combined with the uranium map, weakly suggests small ≥20 ppm eU anomalies bordering a ≥30 ppm eTh core.

The contour map of potassium (Figure 75) shows only a faint correlation with total counts. By itself, it tends only to suggest that colluvium moves downslope.

The contour map of the magnetic field, which is certainly "seeing" to a much greater depth than the gamma-ray data, suggests a positive correlation between the east-northeast-trending magnetic highs through the area and the uphill limits of the eU anomalies. This suggests that much of the mineralized colluvium could be originating from bedrock in the area of the magnetic anomalies.

Primary "ore" minerals: Uraninite (Figure 77), some with magnetite, typically as 1- x ≥8-cm rodlike masses and 1-cm-thick sheets. Polished sections suggest a tendency for anhedral magnetite blebs to serve as nuclei for adjacent anhedral uraninite blebs. These latter are surrounded by anastomosing cracks. Rare tiny pyrite blebs occur near uraninite. Euhedral zoned zircons, subhedral monazite, and probable xenotime also occur in uraninite-rich areas.

Secondary "ore" minerals: Uranophane, boltwoodite, and possible kasolite. Unidentified thin, orange, translucent rims of a probable secondary uranium mineral.

Assays: **RP52** from 10 boulders over 15 m yielded 85 ppm U and 16 ppm Th. **RP65** from a 20-cm channel yielded 9,610 ppm U and 2,600 ppm Th.

Possible volumes: Unknown. Within the grid area studied, about one fourth of the area yields concentrations of ≥10 ppm eU. Hand specimens, however, suggest that the chief concentrations might be in one or more 1-cm-wide zone or zones containing on the order of 5 percent U.

Suggestions for further study: Ore microscopy study of uraninite-magnetite-bearing polished sections to determine the paragenesis and origin of the rodlike structures appears warranted. If mineralization appears to be fault-related, gamma-ray and magnetic reconnaissance data should be collected along the possible fault trace/scarp for at least 2.5 km (1.6 mi) to the northeast; that is, to the anomalies along Bergstressor Road. Shallow excavation of the 60,507-gamma magnetic anomaly in the northeast portion of the survey grid appears warranted. Shallow trenches across the area might be helpful.

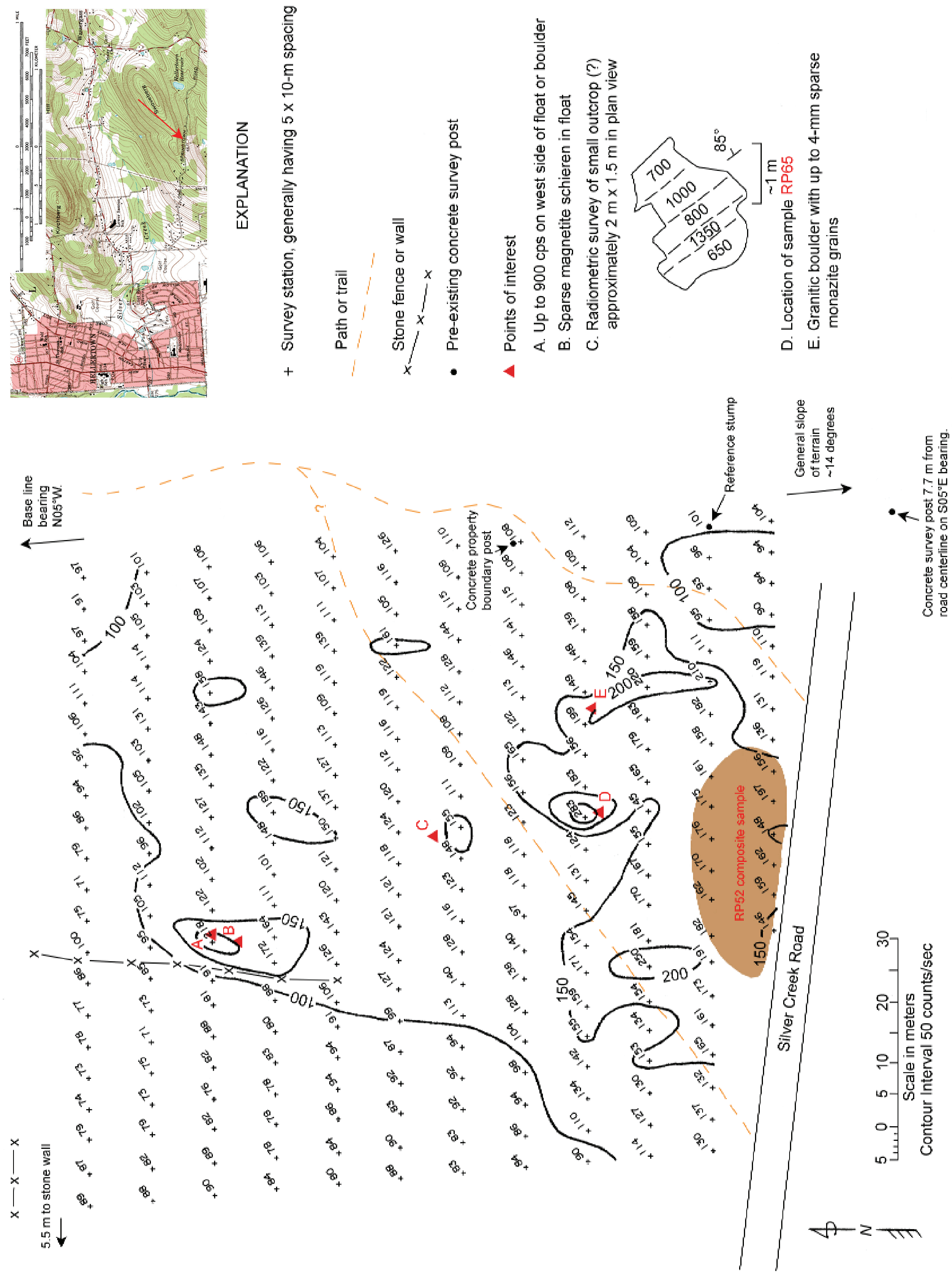


Figure 72. Contour map of total gamma counts per second at the Swoveberg Hill anomaly, Lower Saucon Township, Northampton County. Hellertown 7.5-minute quadrangle; 40°34'29"N, 75°18'22"W.

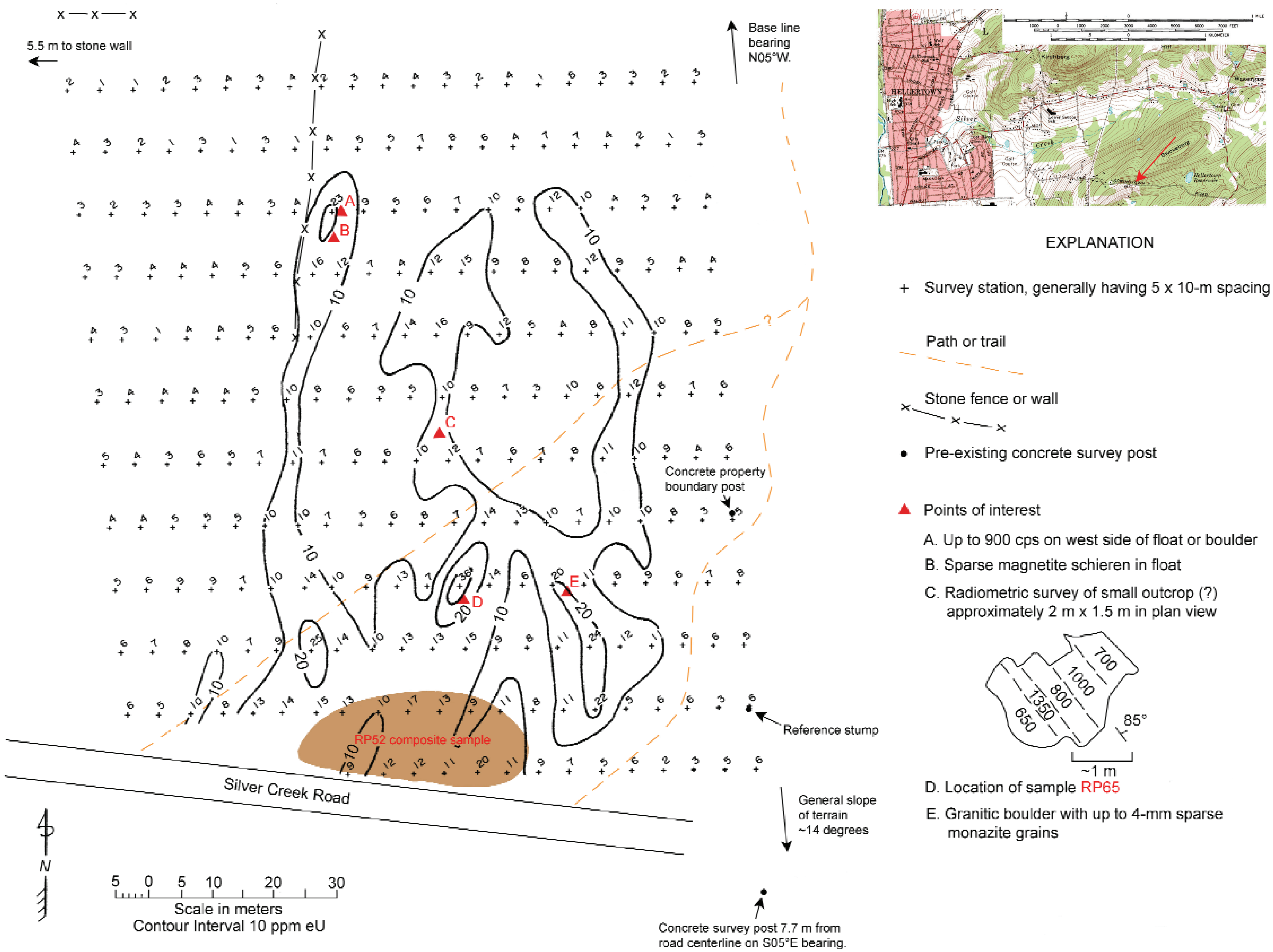


Figure 73. Contour map of radiometric equivalent U in ppm at the Swoveberg Hill anomaly, Lower Saucon Township, Northampton County. Hellertown 7.5-minute quadrangle; 40°34'29"N, 75°18'22"W.

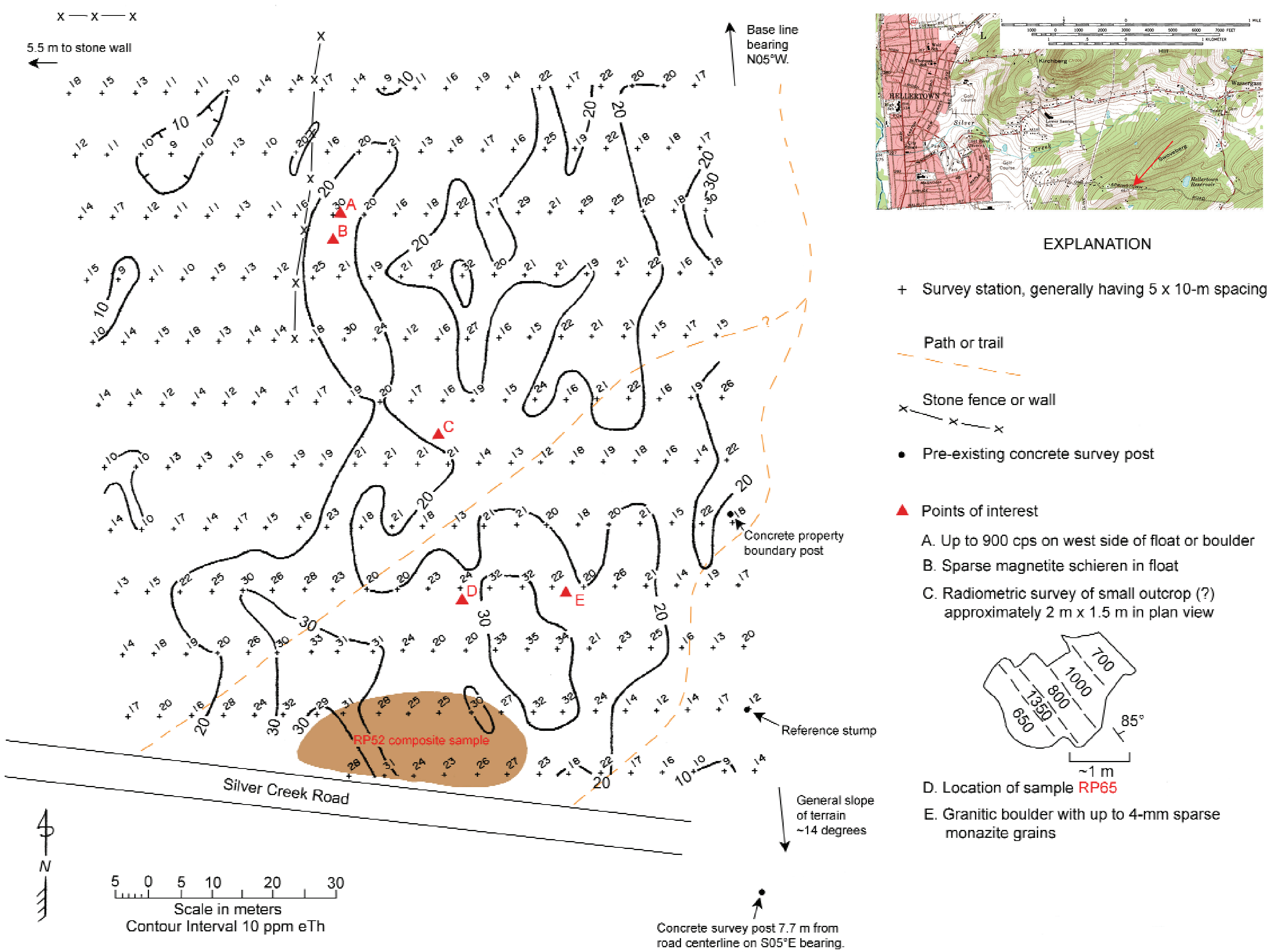


Figure 74. Contour map of radiometric equivalent Th in ppm at the Swoveberg Hill anomaly, Lower Saucon Township, Northampton County. Hellertown 7.5-minute quadrangle; 40°34'29"N, 75°18'22"W.

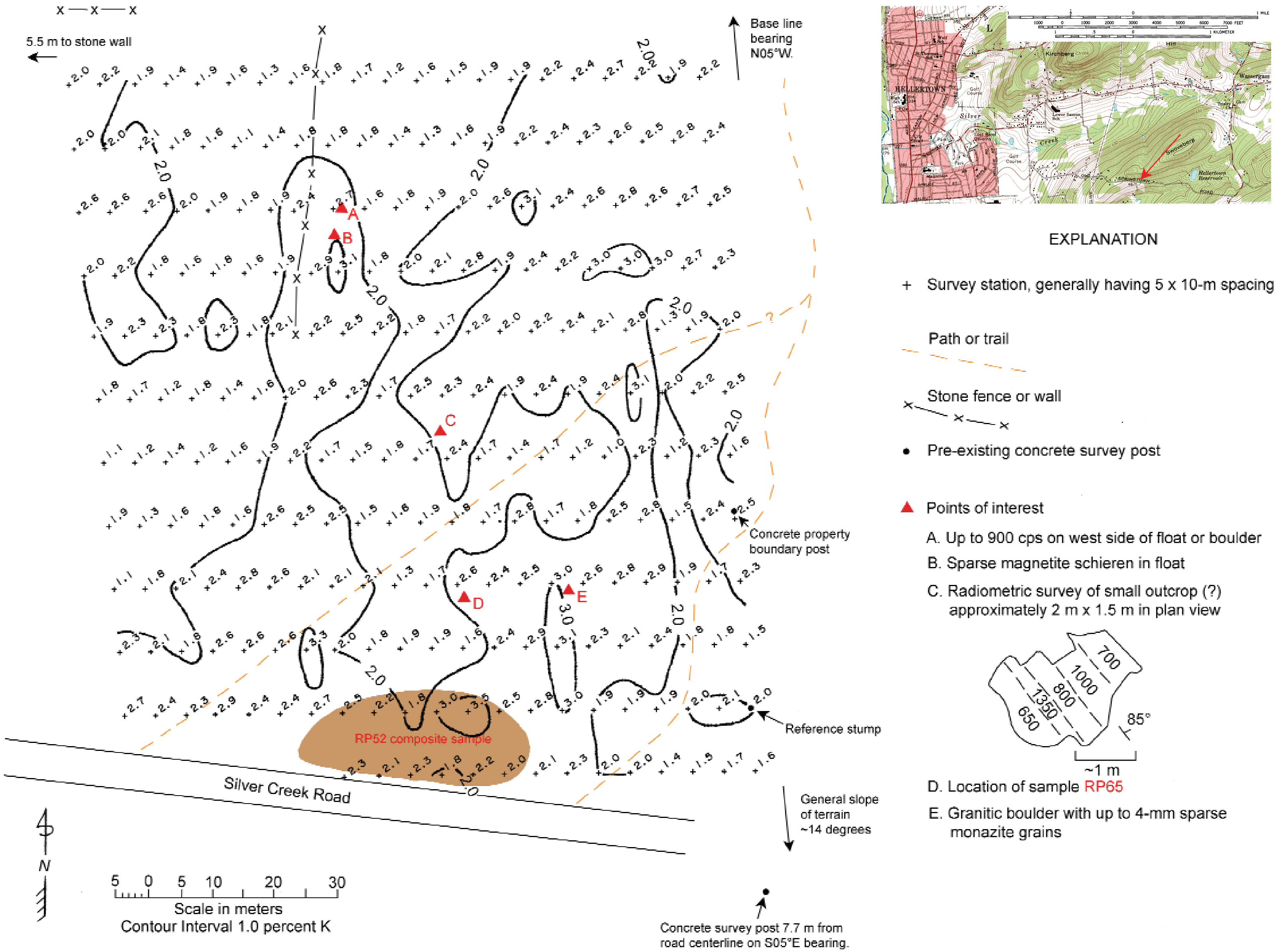


Figure 75. Contour map of radiometric K in percent at the Swoveberg Hill anomaly, Lower Saucon Township, Northampton County. Hellertown 7.5-minute quadrangle; 40°34'29"N, 75°18'22"W.

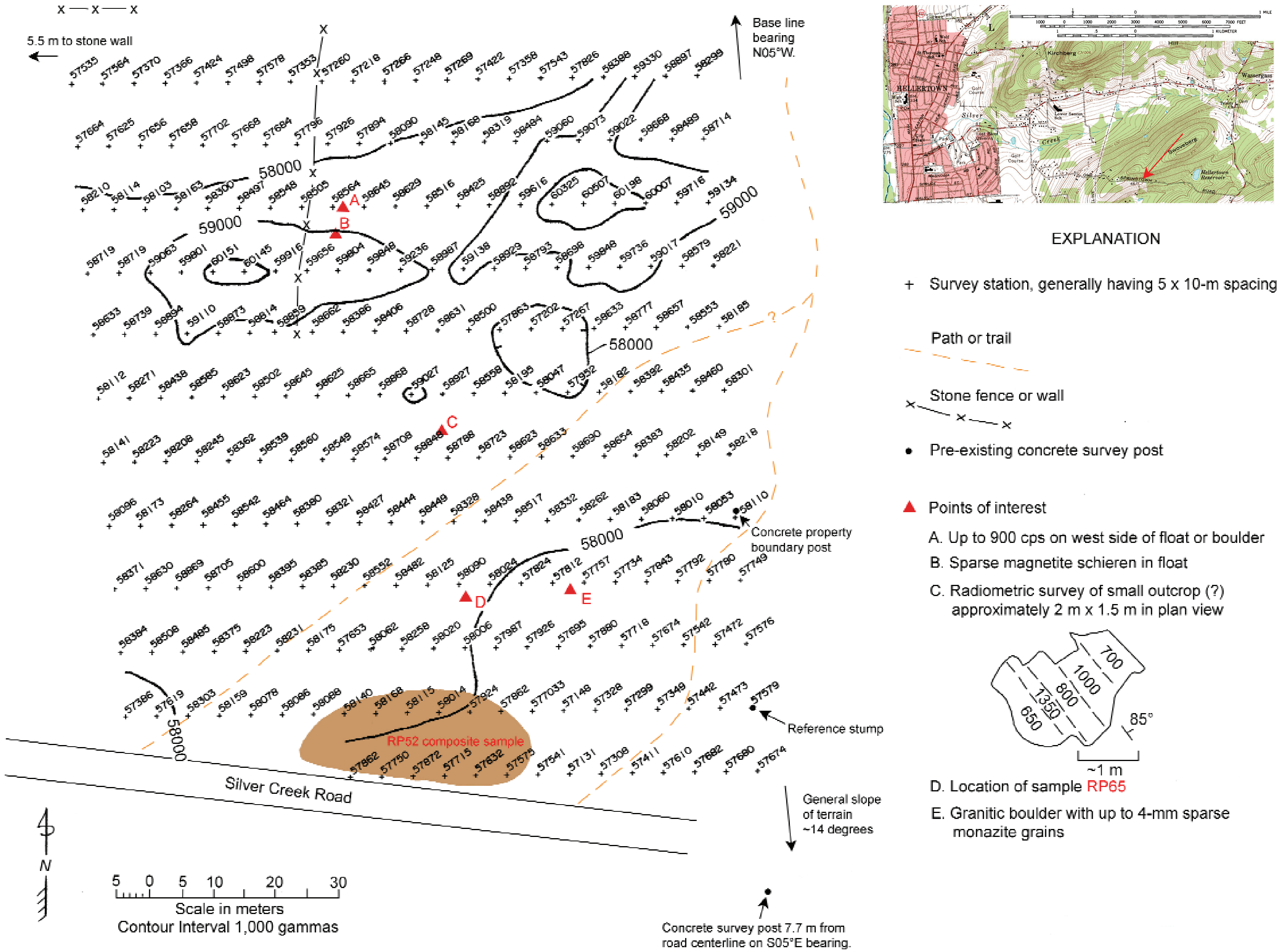


Figure 76. Contour map of total magnetic flux in gammas at the Swoveberg Hill anomaly, Lower Saucon Township, Northampton County. Hellertown 7.5-minute quadrangle; 40°34'29"N, 75°18'22"W.

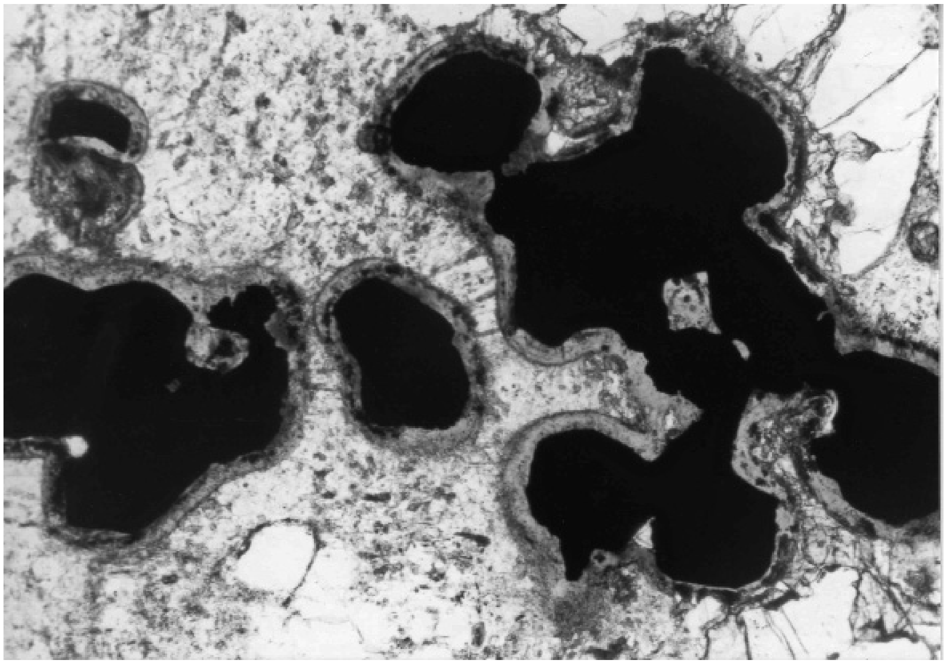


Figure 77. Photomicrograph (123x) of a thin section of sample RP52, from the Swoveberg Hill anomaly, showing opaque, anhedral grains of probable uraninite having thin orange translucent rims of a probable secondary uranium mineral.

SUMMARY AND CONCLUSIONS

1. Portions of the Reading Prong of Pennsylvania are part of a U- and Th-rich province that contains a complex variety of U and Th occurrences. Concentrations as high as 1 percent U were found. The Reading Prong would have contributed anomalous amounts of U to any younger rocks that might have been derived from it.

2. As determined by a carborne gamma-flux survey, 1.5 percent of the road lengths traversed yielded moderate anomalies (80 to 100 counts/sec in vehicle), and 1.2 percent yielded strong anomalies ($>$100 counts/sec in vehicle). Of approximately 75 such moderate and strong anomalies that were field checked, 36 new uranium-thorium occurrences were found and sampled. The median uranium and thorium contents of rock samples from these 36 occurrences are 68 ppm and 180 ppm, respectively. These data compare favorably with median U and Th contents of 58 ppm and 220 ppm, respectively, for 17 rock samples from occurrences that were previously known.

   Although not done so in this study, if a uranium occurrence were to be defined as merely a 100-m^2 (1,076-ft^2) area with rock and soil containing $\geq$10 ppm U, then there are probably hundreds of uranium occurrences in the Reading Prong of Pennsylvania.

3. Examination of maps showing the total gamma-flux carborne data suggests that the Reading Prong of Pennsylvania consists of radiometrically distinct nappes that might represent different lithologic terranes. The Chestnut Hill area north of Easton and the south-southeastern portion of the Reading Prong (Plate 1) tend to yield a higher gamma flux and more uranium occurrences than the northwestern portion.

   Some of the larger and richer occurrences (U$>$200 ppm and/or U/Th$>$0.5) tend to occur in a northeast-southwest-trending zone that corresponds to a possible nappe boundary. Occurrences along the zone include RP65, 64, 6, 10, 33, 37, and 11, from east to west (Plate 1). This vaguely suggests the possibility of structural control of migrating U- and Th-containing ore solutions along the southeast-dipping northern margin of the Applebutter nappe, as that name is used herein. It is possible that radiometric dates could distinguish tectonically controlled mineralization from stratigraphically controlled mineralization, such as appears to be present in Chestnut Hill.

4. Criteria used to select areas for further study from among the RP1 through RP60 samples, with respect to the possibility of identifying significant uranium occurrences, included U concentrations, U/Th ratios, and accessibility. Most sites with U concentrations exceeding 200 ppm and U/Th ratios greater than 2 were further studied. In retrospect, anomalously high ages calculated from total U, Th, and Pb quantitative analyses might have helped to identify samples that had undergone near-surface leaching of uranium. That is, Pb may be a useful pathfinder for U in the granitic rocks.

5. In the Reading Prong of Pennsylvania, Th is a useful pathfinder for U and, with the carborne system used, did not lead to any false (negligible) U occurrences. K was not found to be an indicator of U, and the range of K_2O in typical rocks is small (mostly 3 to 6 percent K_2O) with respect to the variability in U and Th.

6. Five or more petrographic types of U-Th occurrences are known in the Reading Prong. The apparent variation in U, Th, and other elements within each of the populations is very large.

   Analyses of composite rock samples plotted on K_2O–Na_2O–CaO ternary diagrams show that the samples can be divided into the following three gross populations: (a) Hardyston Formation basal samples that plot near the K_2O apex; (b) skarn samples from Chestnut Hill that plot along the K_2O–CaO join; and (c) granitic samples that plot in a more diffuse field extending from near the K_2O–Na_2O join toward the center of the diagram. However, the granitic field in turn appears to include at least three types of occurrences, based, in part, on the presence of detectable boron and/or tourmaline, detectable Mo and/or molybdenite, and major La and/or allanite-(Ce). In the absence of all of these, remaining granitic rocks are classed in a residual "Byram" suite.

7. Basal Hardyston Formation samples have U/Th ratios that range from 0.03 to 0.1 and are high in Fe, Ti, rare earths, and Zr. Their median U content is only 30 ppm, whereas the median Th content is 323 ppm. They do not appear to have the potential for large U occurrences and were not studied further.

8. Skarn samples from Chestnut Hill contain up to about 0.1 percent U over thicknesses of 1.2 m (4 ft) and these have U/Th ratios around 4. The median U content of all sampled skarns is 247

ppm and the median Th content is 250 ppm. The known occurrences are all on Chestnut Hill, Northampton County, a highly populated area. Because of this, the occurrences cannot be exploited and, in fact, are of environmental concern. The areas near samples RP39, 57, and 60 were further studied because of high U contents and high U/Th ratios as well as accessibility. The moderate MgO and K_2O contents suggest that the parent carbonate rocks may have been dolomitic and shaly.

9. The 47 composite rock samples that plot grossly in a granitic field have a median U content of 81 ppm and a median U/Th ratio of approximately 0.5. Many granitic samples are enriched in Mo but not Sn, and most are rather low in V. Meaningful subdivision of these samples, as outlined above, is problematic; the criteria used are believed to be less than satisfactory. Studies of Zr content or zircon morphology might prove useful but were not attempted.

10. The boron-bearing suite of grossly granitic samples are all from Chestnut Hill and have a median U content of 70 ppm and a median Th content of 152 ppm. The boron could have been derived from melting of a sedimentary rock such as shale. The area of RP22 is of environmental concern but was not studied further because of lack of interest by the resident.

11. The Mo-bearing granodiorite suite has a median U content of 87 ppm and a median Th content of 288 ppm. The related Mo-bearing quartz monzonite suite has a median U content of 192 ppm and a median Th content of 75 ppm. Thus, samples from this suite tend to have relatively high U/Th ratios. The high Mo content tends to support an igneous origin for both suites. Copper may be a useful pathfinder for Mo. The areas around samples RP6, 23, 37, and 63 have the potential for moderate-sized U occurrences and were included in the more detailed Phase III study.

12. The three allanite-bearing pegmatites do not constitute a meaningful suite. The area around sample RP8 constitutes the best light-rare-earth target known in the study area.

13. The residual "Byram" granitic suite has a median U content of 54 ppm and a median Th content of 146 ppm. The areas around samples RP9, 11, 16 and 61, 28, 52, and 65 were included in the more-detailed Phase III study. Sample RP65, from Swoveberg Hill, the richest sample found in the entire study, contains about 1 percent U over a 20-cm- (8-in.-) thick interval.

14. The titanite-bearing hybrid skarn zone represented by RP38 and the titanite concentrates RP66, 67, and 68 constitute the best target for heavy rare earths and other rare elements known in the study area. Development in Pennsylvania seems unlikely, but the zone probably continues northeast along Marble Mountain, N.J.

15. Thin-section petrography is of limited use because of the difficulty of obtaining representative samples. The usefulness of X-ray powder diffraction is limited by preferred orientation and other factors discussed in "Mineralogy Estimates and Methods."

16. Gamma-ray spectrometer and magnetometer data gathered from nine sites that were generally chosen based on the criteria mentioned in number 2, above, suggest that downslope movement limits interpretation of spectrometer data to locating the uppermost source of mineralization on a hillside, and magnetometer data are limited to determining the trend of rock units. In this predominantly hilly terrain, with slopes generally greater than 10 percent, trends of mineralization were seldom identified. The lack of outcrop and the presence of boulder colluvium that covers most of the sites studied hinder good evaluation of surface data. Population density suggests that drilling to determine economic potential is unwarranted.

17. Genetic studies were not intended to be a part of this inventory-type study, but many types of uranium and thorium occurrences appear to be present in the Reading Prong of Pennsylvania. Some of these include: (a) skarn-hosted occurrences such as at RP38, 39, 43, 44, 57, and 60; (b) magnetite-associated occurrences, such as RP65; (c) metasedimentary gneiss-associated occurrences, such as RP10, 15, 24, 53, and probably many others; (d) shear-zone hosted occurrences, such as RP3, 4, and especially 59; (e) pegmatite-hosted occurrences, such as RP8, 14, and 50; (f) fossil-placer occurrences, such as RP5, 34, 47, and possibly RP65; (g) those possibly associated with more igneous-appearing bodies, such as RP28. Some of the occurrences may be a combination of types.

18. The apparent primary uranium mineral in the granitic-hosted (inclusive sense) occurrences containing greater than 200 ppm U, as well as in some leaner ones, is uraninite. In the skarn-hosted deposits, the primary mineral is typically

thorian uraninite. Thorite appears to be the predominant Th mineral in the richer occurrences of both types.

The most common secondary uranium minerals are silicates, although phosphates and others have been observed.

The accessory minerals allanite-(Ce), zircon, monazite, titanite, and, less commonly, xenotime may contain much of the U and Th in the leaner granitic occurrences. However, allanite-(Ce) from the richer occurrences tends to contain small, rounded grains of thorite and/or uraninite(?), as may the titanite from RP66, 67, and 68. Similar but less common inclusions may be widespread in leaner occurrences.

SUGGESTIONS FOR ADDITIONAL STUDIES

1. Obtain quantitative trace-element data for the rock samples from this study by instrumental neutron activation and other procedures, and interpret the data. Especially consider the long-noted but little-understood role of Mo.
2. Evaluate the rare-earth, Sn, Nb, and Ta content of the hybrid skarn zones on Chestnut Hill, such as RP38 and the hosts for titanite concentrates RP66, 67, and 68. Scanning electron microprobe studies of the titanites in search of Nb, Sn, and Y minerals are encouraged. Attempt to trace the zones northeast into New Jersey.
3. Measure the gamma-ray dose via thermoluminescent detectors at some of the larger and more intense gamma-flux sites, such as RP6, 11, 22, 28, 41, 52, 57, 59, 64, and 65, and interpret them with respect to environmental concerns.
4. Prepare accurate geologic maps of the Precambrian bedrock in the East Greenville and Milford Square 7.5-minute quadrangles and evaluate the Fe- and As-rich skarn zones for precious-metal and environmental (groundwater) significance. Metasedimentary units in this area have the potential for stratigraphic continuity.
5. Locate and inventory uranium occurrences in the Mesozoic basin to the southeast of the Reading Prong via airborne gamma-ray spectrometry, soil-gas radon (during a drought), and sedimentologic studies. The permissive model assumes that the Reading Prong could have supplied uranium in rock fragments and in solution as uranyl ions and that roll front remobilization down the hydraulic gradient into reduced Mesozoic sedimentary rock was possible.
6. The Quarry L area provides a relatively undisturbed site for research on skarn-hosted occurrences and the Swoveberg, Korn-Stelts, and Chapel Hill anomalies provide excellent sites for study of granitic-hosted occurrences.

   (a) The relationship of the gamma-ray anomaly on the northwest side of Quarry L to the mineralization exposed in the phlogopitic beds should be studied.

   (b) The Swoveberg anomaly should be studied to interpret the downslope movement of colluvium and the relationship between U-Th, rare-earth, and magnetite mineralization.

   (c) The Korn-Stelts site appears to offer the potential to compare the secondary mobility of uranium to thorium and the role of titanite as a primary collector in granitic rocks.
7. Radiometric dates of samples of uraninite from sites other than Chestnut Hill are needed to evaluate the possibility of Taconic or later remobilization of uranium, especially along shear zones and possible nappe boundaries. The most critical samples might be obtained from along the northern edge of the Applebutter nappe.
8. Also consider the suggestions for further study at the end of the discussions of selected anomalies in Phase III.

REFERENCES

Aaron, J. M., 1969, Petrology and origin of the Hardyston Quartzite (Lower Cambrian) in eastern Pennsylvania and western New Jersey, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N. J., Rutgers University Press, p. 51–131.

Abbey, Sydney, 1972, "Standard samples" of silicate rocks and minerals—A review and compilation: Geological Survey of Canada Paper 72–30, 13 p.

_________, 1980, Studies in "standard samples" for use in the general analysis of silicate rocks and minerals, Part 6, 1979 edition of "usable" values: Geological Survey of Canada Paper 80–14, 30 p.

Bromery, R. W., Bennett, B. L., and others, 1959, Aeromagnetic map of the Allentown quadrangle, Northampton, Lehigh, and Bucks Counties, Pennsylvania: U.S. Geological Survey Geophysical Investigations Map GP–213.

Bromery, R. W., and Griscom, Andrew, 1967, Aeromagnetic and generalized geologic map of southeastern Pennsylvania: U.S. Geological Survey Geophysical Investigations Map GP–577.

Bromery, R. W., Zandle, G. L., and others, 1959, Aeromagnetic map of the East Greenville quadrangle, Berks, Lehigh, and Montgomery Counties, Pennsylvania: U.S. Geological Survey Geophysical Investigations Map GP–205.

Buckwalter, T. V., 1959, Geology of the Precambrian rocks and Hardyston Formation of the Boyertown quadrangle: Pennsylvania Geological Survey, 4th ser., Atlas 197.

_________, 1962, The Precambrian geology of the Reading 15' quadrangle: Pennsylvania Geological Survey, 4th ser., Progress Report 161, 49 p.

Chappell, B. W., and White, A. J. R., 1974, Two contrasting granite types: Pacific Geology, v. 8, p. 173–174.

Dallmeyer, R. D., 1974, Tectonic setting of the northeastern Reading Prong: Geological Society of America Bulletin, v. 85, p. 131–134.

d'Invilliers, E. V., 1883, The geology of the South Mountain belt of Berks County: Pennsylvania Geological Survey, 2nd ser., Report D3, v. 2, pt. 1, 441 p.

Drake, A. A., Jr., 1967, Geologic map of the Easton quadrangle, New Jersey-Pennsylvania: U.S. Geological Survey Geologic Quadrangle Map GQ–594.

_________, 1969, Precambrian and lower Paleozoic geology of the Delaware Valley, New Jersey-Pennsylvania, *in* Subitzky, Seymour, ed., Geology of selected areas in New Jersey and eastern Pennsylvania and guidebook of excursions: New Brunswick, N. J., Rutgers University Press, p. 51–131.

_________, 1970, Structural geology of the Reading Prong, *in* Fisher G. W., and others, eds., Studies of Appalachian geology—central and southern: New York, Interscience Publishers, p. 271–291.

_________, 1978, The Lyon Station-Paulins Kill nappe—the frontal structure of the Musconetcong nappe system in eastern Pennsylvania and New Jersey: U.S. Geological Survey Professional Paper 1023, 20 p.

_________, 1980, The Taconides, Acadides, and Alleghenides in the central Appalachians, *in* Wones, D. R., ed., Proceedings of "The Calonides in the USA": Blacksburg, Virginia Polytechnic Institute, Department of Geological Sciences, Memoir 2, p. 179–187.

_________, 1984, The Reading Prong of New Jersey and eastern Pennsylvania—an appraisal of rock relations and chemistry of a major Proterozoic terrane in the Appalachians, *in* Bartholomew, M. J., ed., The Grenville event in the Appalachians and related topics: Geological Society of America Special Paper 194, p. 75–109.

Drake, A. A., Jr., McLaughlin, D. B., and Davis, R. E., 1967, Geologic map of the Riegelsville quadrangle, Pennsylvania-New Jersey: U.S. Geological Survey Geologic Quadrangle Map GQ–593.

Epstein, J. B., D'Agostino, J. P., Drake, A. A., Jr., and Lampiris, Nicholas, 1967, Preliminary log of drill hole near Riegelsville, Pa.: U.S. Geological Survey Open-File Report 67–89, 8 p.

Eyerman, John, 1911, The mineralogy of Pennsylvania—Part 2, Chemical analyses: Easton, Pennsylvania, 25 p.

Faure, Gunter, 1977, Principles of isotope geology: New York, John Wiley and Sons, 464 p.

Fisher, G. W., Higgins, M. W., and Zietz, Isidore, 1979, Geological interpretations of aeromagnetic maps of the crystalline rocks in the Appalachians, northern Virginia to New Jersey: Maryland Geological Survey Report of Investigations 32, 43 p.

Flanagan, F. J., 1970, Sources of geochemical standards, II: Geochimica et Cosmochimica Acta, v. 34, p. 121–125.

Frazier, B. W., 1882, On crystals of axinite from a locality near Bethlehem, Pennsylvania: American Journal of Science, ser. 3, v. 24, p. 439–447.

Frondel, J. W., 1964, Variation of some rare earths in allanite: American Mineralogist, v. 49, p. 1159–1177.

Gault, H. R., and Hamilton, C. L., 1953, Partial log of a deep well, Friedensburg (Oley P.O.), Berks County, Pennsylvania: Pennsylvania Academy of Science, Proceedings, v. 27, p. 146–153.

Genth, F. A., 1855, Contributions to mineralogy—12, Allanite: American Journal of Science, 2nd ser., v. 19, p. 20–22.

_________, 1875, Preliminary report on the mineralogy of Pennsylvania: Pennsylvania Geological Survey, 2nd ser., Report B, 206 p.

Geyer, A. R., Buckwalter, T. V., McLaughlin, D. B., and Gray, Carlyle, 1963, Geology and mineral resources of the Womelsdorf quadrangle: Pennsylvania Geological Survey, 4th ser., Atlas 177c, 96 p.

Geyer, A. R., Smith, R. C., II, and Barnes, J. H., 1976, Mineral collecting in Pennsylvania: Pennsylvania Geological Survey, 4th ser., General Geology Report 33, 260 p.

Gordon, S. G., 1922, The mineralogy of Pennsylvania: Academy of Natural Sciences of Philadelphia Special Publication 1, 255 p.

Grauch, R. I., and Ludwig, K. R., 1979, Uranium mineralization at Easton, Pennsylvania: Pennsylvania Geology, v. 10, no. 5, p. 14–16.

Grauch, R. I., and Zarinski, Katrin, 1976, Generalized descriptions of uranium-bearing veins, pegmatites, and disseminations in non-sedimentary rocks, eastern United States: U.S. Geological Survey Open-File Report 76–582, 114 p.

Gray, Carlyle, Shepps, V. C., Conlin, R. R., and others, compilers and eds., 1960, Geologic map of Pennsylvania: Pennsylvania Geological Survey, 4th ser., Map 1.

Hammond, C. R., 1972, The elements, *in* Weast, R. C., ed., Handbook of chemistry and physics (53rd ed.): Cleveland, Ohio, Chemical Rubber Company, p. B4–B38.

Hedrick, J. B., 1987, Rare-earth minerals and metals, *in* Minerals yearbook 1985, v. 1, Metals and minerals: U.S. Bureau of Mines p. 791–803.

Kratchman, Jack, 1968a, Rohrbach [uranium prospect], *in* U.S. Atomic Energy Commission and U.S. Geological Survey, Preliminary reconnaissance for uranium in Maryland and Pennsylvania, 1953 to 1957: U.S. Atomic Energy Commission, RME–4103, p. 17.

_________, 1968b, Bush No. 1 [uranium prospect], *in* U.S. Atomic Energy Commission and U.S. Geological Survey, Preliminary reconnaissance for uranium in Maryland and Pennsylvania, 1953 to 1957: U.S. Atomic Energy Commission, RME–4103, p. 18.

LKB Resources, 1978, NURE aerial gamma ray and magnetic reconnaissance survey, Thorpe area, Newark NK18–11 quadrangle—Volume II [Data]: U.S. Department of Energy, Report GJBX–16(78), unpaged.

Lyons, P. L., and O'Hara, N. W., chairmen, 1982, Gravity anomaly map of the United States: Society of Exploration Geophysicists, Tulsa, Okla.

MacLachlan, D. B., 1979, Geology and mineral resources of the Temple and Fleetwood quadrangles, Berks County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Atlas 187ab, 71 p.

McCauley, J. F., 1961, Uranium in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 43, 71 p.

McKeown, Frank, and Choquette, P. W., 1968a, Keystone quarry, *in* U.S. Atomic Energy Commission and U.S. Geological Survey, Preliminary reconnaissance for uranium in Maryland and Pennsylvania, 1953 to 1957: U.S. Atomic Energy Commission, RME–4103, p. 49.

_________, 1968b, Rohrbach magnetite-ilmenite prospect, *in* U.S. Atomic Energy Commission and U.S. Geological Survey, Preliminary reconnaissance for uranium in Maryland and Pennsylvania, 1953 to 1957: U.S. Atomic Energy Commission, RME–4103, p. 16.

McKeown, F. A., and Klemic, Harry, 1953, Reconnaissance for radioactive materials in northeastern United States during 1952: U.S. Geological Survey, Trace Elements Investigations Report TEI–317–A, 68 p.

Medlin, J. H., Suhr, N. H., and Bodkin, J. B., 1969, Atomic absorption analysis of silicates employing $LiBO_2$ fusion: Atomic Absorption Newsletter, v. 8, no. 2, p. 25–29.

Millard, H. T., Jr., and Keaten, B. A., 1982, Precision of uranium and thorium determinations by delayed neutron counting: Journal of Radioanalytical Chemistry, v. 72, no. 1–2, p. 489–500.

Miller, B. L, Fraser, D. M., and Miller, R. L., 1939, Northampton County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report 48, 496 p.

Miller, B. L., Fraser, D. M., Miller, R. L., and others, 1941, Lehigh County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., County Report 39, 492 p.

Montgomery, Arthur, 1957, Three occurrences of high-thorian uraninite near Easton, Pennsylvania: American Mineralogist, v. 42, p. 804–820.

_________, 1969, The mineralogy of Pennsylvania, 1922–1965: Academy of Natural Sciences of Philadelphia Special Publication 9, 104 p.

Myers, A. T., Havens, R. G., and Dunton, P. J., 1961, A spectrochemical method for the semiquantitative analysis of rocks, minerals, and ores: U.S. Geological Survey Bulletin 1084–I, p. 207–229.

O'Neill, B. J., Jr., and Barnes, J. H., 1979, Properties and uses of shales and clays, southwestern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 77, 689 p.

Rankama, Kalervo, and Sahama, Th. G., 1950, Geochemistry: University of Chicago Press, 912 p.

Ratcliffe, N. M., and Burton, W. C., 1985, Preliminary results of core drilling of Triassic border faults near Riegelsville, Pennsylvania: U.S. Geological Survey, Open-File Report 85–537, 23 p.

Rogers, H. D., 1858, The geology of Pennsylvania—A government survey: Edinburgh, William Blackwood and Sons [Philadelphia, J. B. Lippincott], v. 2, 1,045 p.

Rose, A. W., Hawkes, H. E., and Webb, J. S., 1979, Geochemistry in mineral exploration (2nd ed.): London, Academic Press, 657 p.

Rose, A. W., Pirc, S., Tole, M. P., and others, 1980, Regional and local anomalies of uranium and thorium in rocks near sandstone-type uranium deposits in Pennsylvania and Colorado: U.S. Department of Energy, National Uranium Resource Evaluation [NURE] Report GJBX–126–80, 140 p. plus appendix, p. A1–A58.

Rumbaugh, J. O., III, 1983, Effect of fracture permeability on radon-222 concentration in ground water on the Reading Prong, Pennsylvania: University Park, Pennsylvania State University, M.S. thesis, 110 p.

Sahama, Th. G., 1946, On the chemistry of the mineral titanite: Bulletin de la Commission Géologique de Finlande, v. 138, p. 88–120.

Smith, R. C., II, 1967, Geochemistry and mineralogy of allanite from the Durham-Reading Hills, Pennsylvania: unpublished research paper, 26 p.

_________, 1974, Uranium in the Hardyston Formation: Pennsylvania Geology, v. 5, no. 3, p. 11–12.

_________, 1975a, New uranium-thorium occurrence in Northampton County: Pennsylvania Geology, v. 6, no. 6, p. 11.

_________, 1975b, New molybdenite occurrence in Berks County: Pennsylvania Geology, v. 6, no. 6, p. 16.

_________, 1977, Zinc and lead occurrences in Pennsylvania: Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 72, 318 p.

_________, 1978a, Uranium near Oley, Berks County: Pennsylvania Geology, v. 9, no. 4, p. 29–31.

_________, 1978b, The mineralogy of Pennsylvania, 1966–1975: Friends of Mineralogy, Pennsylvania Chapter, Special Publication 1, 304 p.

Socolow, A. A., 1974, Geologic interpretation of aeromagnetic maps of southeastern Pennsylvania: Pennsylvania Geological Survey, 4th ser., Information Circular 77, 85 p.

Stewart, R. H., 1951, Radiometric reconnaissance examination in southeastern Pennsylvania and western New Jersey: U.S. Atomic Energy Commission, TEM–255, p. 8–9.

Streckeisen, Albert, 1976, To each plutonic rock its proper name: Earth Science Reviews, v. 12, p. 1–33.

Stromswold, D. C., and Kosanke, K. L., 1978, Calibration and error analysis for spectral radiation detectors: IEEE Transactions on Nuclear Science, v. 25, no. 1, p. 782–786.

Tole, M. P., 1979, The uranium content of zircons from the Catskill Formation, eastern Pennsylvania: University Park, Pennsylvania State University, M.S. thesis, 155 p.

Turekian, K. K., 1977, Geochemical distribution of elements, *in* Encyclopedia of science and technology (4th ed.): New York, McGraw-Hill, p. 627–630.

Virgin, W. W., Jr., 1955, The pegmatite problem at Morgan Hill, Easton, Pennsylvania: Pennsylvania Academy of Science Proceedings, v. 29, p. 199–202.

Ward, S. H., 1981, Gamma-ray spectrometry in geologic mapping and exploration, *in* Skinner, B. J., ed., 75th Anniversary Volume, 1905–1980: Economic Geology, p. 840–849.

Wells, R. C., Fairchild, J. G., and Ross, C. S., 1933, Thorianite from Easton, Pennsylvania: American Journal of Science, 5th ser., v. 26, no. 151, p. 45–54.

Wood, C. R., Flippo, H. N., Jr., Lescinsky, J. B., and Barker, J. L., 1972, Water resources of Lehigh County, Pennsylvania: Pennsylvania Geological Survey, 4th ser., Water Resource Report 31, 263 p.

Young, D. A., 1978, Precambrian salic intrusive rocks of the Reading Prong: Geological Society of America Bulletin, v. 89, p. 1.

FACTORS FOR CONVERTING INTERNATIONAL SYSTEM UNITS (SI) TO INCH-POUND UNITS

Multiply SI units	*By*	*To obtain inch-pound units*
	Length	
centimeter (cm)	0.3937	inch (in.)
meter (m)	3.2808	foot (ft)
dekameter (dam)	32.8084	foot (ft)
kilometer (km)	.6214	mile (mi)
	Area	
square kilometer (km^2)	247.1054	acre (ac)
square kilometer (km^2)	.3861	square mile (mi^2)
	Volume	
milliliter (ml)	.0338	ounce (oz)
	Weight	
gram (g)	.0353	ounce (oz)
kilogram (kg)	2.2046	pound (lb)
	Concentration	
parts per million (ppm)	.0001	percent (%)
parts per million (ppm)	1	milligrams per liter (mg/L)
	Acceleration	
milligal (mGal)	.001	centimeter per second squared (cm/sec^2)
	Temperature	
degree Celsius (°C)	°F = 9/5°C + 32	degree Fahrenheit (°F)
	Pressure and stress	
kilopascal (kPa)	.145	pound per square inch (psi)

APPENDIX 1

LOCATIONS OF SIGNIFICANT GAMMA-RAY ANOMALIES FROM CARBORNE SURVEY

The following table (Table 22) is a list of positive anomalies greater than 80 counts/sec detected in the carborne radiometric survey of the Reading Prong (see "Phase I: Carborne Scintillometer Gamma–Ray Anomaly Survey Methods," p. 19). These anomalies are shown on Plate 1. This table lists anomalies by county, and within each county by traverse number. After each traverse number are listed the name of the road or, if the road name is unknown, some description to facilitate the reader's locating it on a U.S. Geological Survey 7.5-minute topographic quadrangle map; for example, "432–437 Road northwest from Hill Church" or "437–438 Road past Mountain Mary's Grave." If a road was traversed in two directions, a reference is made to the opposite traverse, for example, "1–2 Mexico Road (eastbound) (see 2–1 for westbound traverse)."

Under each traverse are listed the latitude, longitude, and length in kilometers of each traverse segment that registered an intensity of 80 to 100 counts/sec on a Mount Sopris SC–132A scintillometer inside the vehicle, or that registered greater than 100 counts/sec. Those measuring greater than 100 counts/sec are marked by an asterisk. The latitude and longitude are measured at the center of the segment. The 7.5-minute quadrangle in which the segment is located is also listed. In places where a traverse segment measuring less than 100 counts/sec joins one measuring more than 100 counts/sec, separate entries are recorded for each segment, although both may be reflections of the same anomaly.

For some traverses, reference is made to "spikes;" for example, "52–53 Oley Line Road, 1 spike." A spike is an indication on the scintillometer recorder of a measurement briefly exceeding 80 counts/sec. The locations of spikes are not listed because a spike is not considered to be statistically significant and might not be reproducible.

Table 22. *Locations of Significant Gamma-Ray Anomalies From the Carborne Survey*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
			BERKS COUNTY		
		1–2 Mexico Road (eastbound) (see 2–1 for westbound traverse)			
40°23'17"N	75°50'55"W	0.04		—	Fleetwood
40°23'17"N	75°50'54"W	.01	*	—	do.
40°23'16"N	75°50'53"W	.03		—	do.
40°23'16"N	75°50'52"W	.04	*	—	do.
40°23'15"N	75°50'51"W	.02		—	do.
40°23'15"N	75°50'49"W	.07	*	—	do.
40°23'14"N	75°50'48"W	.02		—	do.
40°23'13"N	75°50'45"W	.11	*	RP9	do.
40°23'11"N	75°50'40"W	.20		—	do.
40°23'07"N	75°50'36"W	.01		—	do.
40°23'04"N	75°50'32"W	.03		—	do.
40°22'58"N	75°50'22"W	.09		—	do.
		2–1 Mexico Road (westbound) (see 1–2 for eastbound traverse)			
40°23'12"N	75°50'42"W	0.10		—	Fleetwood
40°23'13"N	75°50'44"W	.03	*	—	do.
40°23'14"N	75°50'48"W	.18		—	do.
		2–3 Basket Road			
40°23'00"N	75°50'16"W	0.10		—	Fleetwood
40°23'00"N	75°50'14"W	.01	*	—	do.
40°23'00"N	75°50'13"W	.06		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		3–4 Summus Road			
40°22'59"N	75°49'34"W	0.01		—	Fleetwood
40°22'58"N	75°49'34"W	.02	*	—	do.
40°22'56"N	75°49'33"W	.07		—	do.
40°22'55"N	75°49'28"W	.09		—	do.
40°22'52"N	75°49'03"W	.04		—	do.
40°22'49"N	75°48'56"W	.08		—	do.
40°22'45"N	75°48'51"W	.11		—	do.
		4–5 Old State Road			
40°23'00"N	75°48'13"W	0.19		—	Fleetwood
		4–26 Old State Road			
40°22'35"N	75°49'00"W	0.02		—	Fleetwood
		5–6 Old State Road			
40°23'03"N	75°48'10"W	0.07		—	Fleetwood
40°23'05"N	75°48'07"W	.13	*	—	do.
40°23'07"N	75°48'05"W	.03		—	do.
		5–7 Road northwest from Old State Road to Basket			
40°23'04"N	75°48'12"W	0.02		—	Fleetwood
40°23'05"N	75°48'13"W	.10	*	RP59	do.
40°23'06"N	75°48'15"W	.01		—	do.
40°23'07"N	75°48'16"W	.04	*	—	do.
40°23'08"N	75°48'18"W	.09		—	do.
40°23'08"N	75°48'23"W	.01		—	do.
40°23'09"N	75°48'24"W	.04	*	—	do.
40°23'09"N	75°48'24"W	.01		—	do.
		9–10 Oley Road, Alsace Manor (westbound) (see 10–9 for eastbound traverse)			
40°24'02"N	75°50'37"W	0.01		—	Fleetwood
40°24'01"N	75°50'42"W	.18		—	do.
40°24'01"N	75°50'47"W	.01	*	—	do.
40°24'01"N	75°50'47"W	.03		—	do.
40°24'00"N	75°50'50"W	.14	*	—	do.
40°24'00"N	75°50'55"W	.10		RP11	do.
		10–9 Oley Road, Alsace Manor (eastbound) (see 9–10 for westbound traverse)			
40°24'00"N	75°50'59"W	0.13		—	Fleetwood
40°23'59"N	75°50'52"W	.16	*	—	do.
40°24'00"N	75°50'49"W	.04		—	do.
40°24'01"N	75°50'48"W	.03	*	—	do.
40°24'01"N	75°50'46"W	.08		—	do.
40°24'01"N	75°50'42"W	.06		—	do.
40°24'02"N	75°50'39"W	.02		—	do.
		10–15 Oley Road and Woodside Avenue, Alsace Manor			
40°23'51"N	75°50'59"W	0.01		—	Fleetwood
40°23'51"N	75°50'59"W	.01	*	—	do.
40°23'51"N	75°50'58"W	.01		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		10–15 Oley Road and Woodside Avenue, Alsace Manor *(Continued)*			
40°23'51"N	75°50'58"W	0.01	*	—	Fleetwood
40°23'52"N	75°50'57"W	.04		—	do.
40°23'53"N	75°50'55"W	.09	*	—	do.
40°23'52"N	75°50'53"W	.03		—	do.
		11–1 Antietam Road			
40°22'58"N	75°51'41"W	0.08		—	Fleetwood
40°23'01"N	75°51'43"W	.07		—	do.
40°23'06"N	75°51'46"W	.03		—	do.
40°23'07"N	75°51'47"W	.03	*	—	do.
40°23'08"N	75°51'47"W	.03		—	do.
		5–16 Driveway at east end of Woodside Avenue, Alsace Manor			
40°23'52"N	75°50'52"W	0.02		—	Fleetwood
40°23'52"N	75°50'50"W	.05	*	—	do.
40°23'53"N	75°50'50"W	.01		—	do.
40°23'54"N	75°50'52"W	.09	*	—	do.
40°23'53"N	75°50'54"W	.02		—	do.
		22–23 Road northwest from Old State Road near Oley			
40°23'19"N	75°48'07"W	0.04		—	Fleetwood
40°23'20"N	75°48'07"W	.01		—	do.
40°23'21"N	75°48'09"W	.10	*	—	do.
40°23'23"N	75°48'10"W	.01		—	do.
40°23'24"N	75°48'10"W	.06	*	—	do.
40°23'26"N	75°48'10"W	.05		RP36	do.
		24–25 Road northwest from road of traverse 5–7			
40°23'08"N	75°48'16"W	0.04	*	—	Fleetwood
40°23'08"N	75°48'17"W	.01		—	do.
40°23'09"N	75°48'18"W	.01		—	do.
40°23'09"N	75°48'19"W	.01		—	do.
40°23'10"N	75°48'21"W	.01		—	do.
40°23'12"N	75°48'24"W	.04		—	do.
40°23'13"N	75°48'26"W	.04		—	do.
40°23'14"N	75°48'28"W	.05		—	do.
40°23'16"N	75°48'30"W	.02		—	do.
40°23'19"N	75°48'32"W	.01		—	do.
		29–30 Road southeast from Basket Road near Mexico Road			
40°22'53"N	75°50'23"W	0.02	*	—	Fleetwood
40°22'52"N	75°50'22"W	.04		—	do.
40°22'52"N	75°50'21"W	.01	*	—	do.
40°22'51"N	75°50'21"W	.02		—	do.
40°22'46"N	75°50'19"W	.02		—	do.
40°22'45"N	75°50'19"W	.03		—	do.
40°22'41"N	75°50'12"W	.01		—	do.
40°22'41"N	75°50'12"W	<.01		—	do.
40°22'41"N	75°50'11"W	.02		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		32–33 Simmons Road			
40°22'02"N	75°51'11"W	0.05		—	Birdsboro
40°22'02"N	75°51'08"W	.02		—	do.
40°22'03"N	75°51'06"W	.03		—	do.
		43–44 Road from Antietam Road to Pricetown Road southwest of Alsace Manor			
40°23'29"N	75°51'43"W	0.02		—	Fleetwood
40°23'29"N	75°51'45"W	.01		—	do.
40°23'29"N	75°51'45"W	.01	*	—	do.
40°23'30"N	75°51'46"W	.02		—	do.
		45–46 Alsace Avenue and Kegerise Drive, Alsace Manor, 1 spike			
		47–48 Kegerise Drive and private drive, Alsace Manor			
40°23'48"N	75°50'57"W	0.02		—	Fleetwood
40°23'48"N	75°50'56"W	.04	*	—	do.
40°23'49"N	75°50'56"W	.02		—	do.
40°23'51"N	75°50'54"W	.10	*	—	do.
40°23'52"N	75°50'52"W	.01		—	do.
40°23'52"N	75°50'50"W	.09	*	—	do.
40°23'52"N	75°50'48"W	.02		—	do.
40°23'44"N	75°50'43"W	.03		—	do.
		51–73 Hartman Road (westbound) (see 73–51 for eastbound traverse)			
40°21'30"N	75°49'27"W	0.04		—	Birdsboro
40°21'30"N	75°49'28"W	.01	*	—	do.
40°21'30"N	75°49'29"W	.06		—	do.
40°21'29"N	75°49'30"W	.03	*	—	do.
40°21'29"N	75°49'31"W	.04		—	do.
40°21'28"N	75°49'33"W	.02		—	do.
40°21'27"N	75°49'34"W	.03	*	—	do.
40°21'27"N	75°49'35"W	.02		—	do.
		52–53 Oley Line Road, 1 spike			
		56–57 Dautrich Road			
40°20'54"N	75°51'03"W	0.04		—	Birdsboro
40°20'53"N	75°51'02"W	.05	*	—	do.
40°20'52"N	75°51'00"W	.05		—	do.
		57–64 Road from Daniel Boone Rod and Gun Club to Church Lane (eastbound) (eastbound) (see 64–57A for westbound traverse)			
40°20'51"N	75°50'55"W	0.06		—	Birdsboro
40°20'50"N	75°50'50"W	.18	*	—	do.
40°20'50"N	75°50'46"W	.04		—	do.
		57A–75 East side of parking lot of Daniel Boone Rod and Gun Club (see 75–57A for west side)			
40°20'54"N	75°50'53"W	0.20	*	RP40	Birdsboro

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		64–57A Road from Daniel Boone Rod and Gun Club to Church Lane (westbound) (see 57–64 for eastbound traverse)			
40°20'49"N	75°50'42"W	0.08		—	Birdsboro
40°20'50"N	75°50'50"W	.28	*	—	do.
		73–51 Hartman Road (eastbound) (see 51–73 for westbound traverse)			
40°21'27"N	75°49'33"W	<0.01	*	—	Birdsboro
40°21'29"N	75°49'30"W	.13		—	do.
		73–74 Road northwest from Hartman Road, 1 spike			
40°21'17"N	75°49'44"W	.12		—	Birdsboro
40°21'20"N	75°49'44"W	.02		—	do.
40°21'21"N	75°49'46"W	.01		—	do.
40°21'22"N	75°49'48"W	.01		—	do.
		75–57A West side of parking lot of Daniel Boone Rod and Gun Club (see 57A–75 for east side)			
40°20'55"N	75°50'56"W	0.21	*	—	Birdsboro
		141–146 Short northwest-southeast road south of Spies Church			
40°22'05"N	75°50'53"W	0.01		—	Birdsboro
40°22'08"N	75°50'55"W	.05		—	do.
		142A–143A Road up southeast side of Church Hill			
40°22'03"N	75°50'10"W	0.02		—	Birdsboro
40°22'04"N	75°50'10"W	.03		—	do.
40°22'05"N	75°50'11"W	.02		—	do.
40°22'06"N	75°50'12"W	.01		—	do.
40°22'07"N	75°50'15"W	.09		—	do.
		144–32 Christmans Road			
40°21'59"N	75°51'33"W	0.03		—	Birdsboro
40°22'00"N	75°51'33"W	.02	*	—	do.
40°22'01"N	75°51'32"W	.03		—	do.
		147–148 Road northwest from Wanshoe Road			
40°21'44"N	75°51'25"W	0.01		—	Birdsboro
40°21'48"N	75°51'31"W	.02		—	do.
40°21'48"N	75°51'32"W	.01	*	—	do.
40°21'47"N	75°51'33"W	.04		—	do.
		149–150 Road north from Old Spies Church Road			
40°21'33"N	75°51'29"W	0.02		—	Birdsboro
40°21'34"N	75°51'29"W	.02		—	do.
40°21'35"N	75°51'30"W	.05		—	do.
		150–151 Road north from Old Spies Church Road			
40°21'36"N	75°51'30"W	0.02		—	Birdsboro
40°21'35"N	75°51'29"W	.03		—	do.
40°21'33"N	75°51'29"W	.05		—	do.
40°21'30"N	75°51'31"W	.05		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		152–153 Road southeast from Christmans Road near Antietam Reservoir			
40°21'40"N	75°51'45"W	0.01		—	Birdsboro
40°21'39"N	75°51'45"W	.03	*	—	do.
40°21'39"N	75°51'44"W	.01		—	do.
40°21'36"N	75°51'40"W	.03		—	do.
		156–157 Road northwest from Christmans Road			
40°21'49"N	75°51'42"W	0.01		—	Birdsboro
		213–214 Road from Shalters Church to Hartz Road, 1 spike			
		213–228 Road past Shalters Church			
40°24'22"N	75°52'21"W	0.01		—	Fleetwood
40°24'24"N	75°52'14"W	.06		—	do.
		224–225 Heckman Road			
40°24'22"N	75°53'16"W	0.01		—	Temple
		281–279 Reider Road			
40°24'46"N	75°47'34"W	0.02		—	Fleetwood
40°24'46"N	75°47'34"W	<.01	*	—	do.
40°24'46"N	75°47'35"W	.02		—	do.
		282–283B Fry Road			
40°24'25"N	75°47'55"W	0.03		—	Fleetwood
		283A–284A Fry Road			
40°24'22"N	75°48'17"W	0.09		—	Fleetwood
40°24'23"N	75°48'08"W	.02		—	do.
40°24'23"N	75°48'06"W	.03		—	do.
40°24'24"N	75°48'00"W	.01		—	do.
		294–297 Kutz Road			
40°27'22"N	75°47'10"W	0.01		—	Fleetwood
40°27'23"N	75°47'09"W	.01	*	—	do.
40°27'23"N	75°47'09"W	.01		—	do.
		304–311 Road between Old State Road and Oley Line Road			
40°21'55"N	75°49'39"W	0.01		—	Birdsboro
		307–306 Short north-south road off Old State Road			
40°22'07"N	75°49'25"W	0.22		—	Birdsboro
		307–308 East-west road north of Old State Road			
40°22'13"N	75°49'27"W	0.06		—	Birdsboro
		307–309 Road through Moore property southeast of Apple Lane			
40°22'14"N	75°49'24"W	0.02		—	Birdsboro
40°22'16"N	75°49'25"W	.02		—	do.
40°22'17"N	75°49'27"W	.03		—	do.
40°22'18"N	75°49'31"W	.25	*	RP12	do.
40°22'20"N	75°49'36"W	.01		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		307–309 Road through Moore property southeast of Apple Lane *(Continued)*			
40°22'23"N	75°49'39"W	0.05		—	Birdsboro
40°22'24"N	75°49'41"W	.01		—	do.
40°22'24"N	75°49'42"W	.01	*	—	do.
40°22'25"N	75°49'42"W	.01		—	do.
40°22'27"N	75°49'45"W	.17		—	do.
40°22'26"N	75°49'50"W	.05	*	—	do.
40°22'25"N	75°49'51"W	.02		—	do.
40°22'25"N	75°49'56"W	.01		—	do.
40°22'25"N	75°49'57"W	.02		—	do.
40°22'26"N	75°49'59"W	.02		—	do.
40°22'27"N	75°50'00"W	.06	*	—	do.
40°22'28"N	75°50'00"W	.01		—	do.
		338–339 Road between Carl's Hill Road and Fredrichsville Road			
40°27'51"N	75°43'54"W	0.02		—	Manatawny
		390–391 Hay Road			
40°24'54"N	75°42'11"W	0.11		RP17	Manatawny
40°24'52"N	75°42'09"W	.04	*	—	do.
40°24'51"N	75°42'07"W	.05		—	do.
40°24'50"N	75°42'06"W	.03	*	—	do.
40°24'49"N	75°42'05"W	.04		—	do.
40°24'47"N	75°42'02"W	.10		—	do.
40°24'42"N	75°41'57"W	.02		—	do.
40°24'41"N	75°41'56"W	.01		—	do.
		391–393 Keim Road			
40°24'44"N	75°41'46"W	0.01		—	Manatawny
40°25'04"N	75°41'30"W	.02		—	do.
40°25'05"N	75°41'28"W	.03		—	do.
40°25'07"N	75°41'27"W	.03		—	do.
40°25'12"N	75°41'20"W	.01		—	do.
40°25'33"N	75°40'52"W	.02		—	do.
		395–390 Mine Road (southbound) (see 396–395 for northbound traverse)			
40°25'03"N	75°42'11"W	0.01		—	Manatawny
		396–395 Mine Road (northbound) (see 395–390 for southbound traverse)			
40°25'07"N	75°42'07"W	0.02		—	Manatawny
40°25'10"N	75°42'03"W	.04		—	do.
40°25'14"N	75°42'00"W	.03		—	do.
		407–410 Woodside Road			
40°23'36"N	75°42'28"W	0.03		—	Manatawny
40°23'35"N	75°42'28"W	.03		—	do.
40°23'33"N	75°42'28"W	.03		—	do.
		409–410 Woodside Road (northbound) (see 410–409 for southbound traverse)			
40°22'39"N	75°42'38"W	0.01		—	Manatawny
40°22'48"N	75°42'44"W	.10		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		409–410 Woodside Road (northbound) (see 410–409 for southbound traverse) *(Continued)*			
40°22'50"N	75°42'45"W	0.02	*	—	Manatawny
40°22'53"N	75°42'44"W	.11		—	do.
40°22'54"N	75°42'43"W	.01	*	—	do.
40°22'55"N	75°42'43"W	.03		—	do.
40°23'02"N	75°42'37"W	.02		—	do.
40°23'14"N	75°42'31"W	.01		—	do.
		409–475 Hill Road, 1 spike			
		410–409 Woodside Road (southbound) (see 409–410 for northbound traverse)			
40°22'59"N	75°42'41"W	0.01		—	Manatawny
40°22'58"N	75°42'41"W	<.01	*	—	do.
40°22'58"N	75°42'41"W	.02		—	do.
40°22'53"N	75°42'44"W	.01		—	do.
40°22'52"N	75°42'44"W	.03		—	do.
40°22'51"N	75°42'44"W	.12		—	do.
40°22'49"N	75°42'44"W	.11		—	do.
40°22'45"N	75°42'44"W	.01		—	do.
40°22'41"N	75°42'41"W	.03		—	do.
		419–420 Bitting Road			
40°27'06"N	75°38'36"W	0.05		—	Manatawny
40°27'04"N	75°38'41"W	.11		—	do.
		432–437 Road northwest from Hill Church			
40°23'15"N	75°40'45"W	0.01		—	Manatawny
40°23'41"N	75°40'43"W	.02		—	do.
40°23'43"N	75°40'43"W	.02		—	do.
		437–438 Road past Mountain Mary's grave			
40°23'41"N	75°41'33"W	0.05		—	Manatawny
40°23'40"N	75°41'35"W	.02		—	do.
40°23'39"N	75°41'36"W	.05	*	—	do.
40°23'38"N	75°41'37"W	.03		—	do.
		441–443 Road north from Hill Church Route to Merkle Road			
40°23'35"N	75°39'27"W	0.02		—	Manatawny
40°23'37"N	75°39'27"W	.01		—	do.
40°23'38"N	75°39'28"W	.01		—	do.
40°23'48"N	75°39'31"W	.01		—	do.
		444–445 East–west road north of Hill Church			
40°23'34"N	75°40'08"W	0.01		—	Manatawny
		464–465 Lenape Road			
40°24'06"N	75°37'57"W	0.01		—	Manatawny
		465–466 Lenape Road			
40°24'01"N	75°37'57"W	0.06		—	Manatawny
40°23'53"N	75°37'56"W	.04		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		476–477 Shenk Road			
40°21'49"N	75°43'07"W	0.01		—	Boyertown
40°21'44"N	75°43'11"W	.02		—	do.
40°21'39"N	75°43'12"W	.32	*	RP7	do.
40°21'34"N	75°43'21"W	.22		—	do.
40°21'32"N	75°43'25"W	.03	*	—	do.
40°21'31"N	75°43'27"W	.06		—	do.
40°21'25"N	75°43'46"W	.06		—	do.
		478–479 Furnace Run Road			
40°21'24"N	75°43'47"W	0.03		—	Boyertown
		480–542 Longview Road			
40°21'08"N	75°42'48"W	0.05		—	Boyertown
40°21'11"N	75°42'47"W	.11		—	do.
40°21'14"N	75°42'48"W	.10	*	—	do.
40°21'16"N	75°42'47"W	.04		—	do.
40°21'18"N	75°42'45"W	.01		—	do.
40°21'20"N	75°42'42"W	.01		—	do.
		480–548 Longview Road, 1 spike			
40°21'05"N	75°42'48"W	0.10		—	Boyertown
40°20'57"N	75°42'50"W	.06		—	do.
		481–482 Mountain Road			
40°21'45"N	75°42'40"W	0.02		—	Boyertown
40°21'46"N	75°42'41"W	.05	*	RP30	do.
40°21'46"N	75°42'42"W	.01		—	do.
40°21'46"N	75°42'44"W	.07	*	—	do.
40°21'47"N	75°42'45"W	.02		—	do.
40°21'47"N	75°42'52"W	.09		—	do.
40°21'50"N	75°42'56"W	.04		—	do.
		481–541 Mountain Road, 2 spikes			
40°21'42"N	75°42'32"W	0.03		—	Boyertown
40°21'40"N	75°42'28"W	.03		—	do.
40°21'36"N	75°42'20"W	.04		—	do.
		502–509 Shady Lane, 2 spikes			
40°22'09"N	75°41'45"W	0.03		—	Boyertown
40°22'05"N	75°41'47"W	.03		—	do.
		515–516 Weisstown Road, 1 spike			
40°21'46"N	75°38'59"W	0.03		—	Boyertown
40°21'41"N	75°38'55"W	.07		—	do.
		519–520 Valley Road, 9 spikes			
40°22'30"N	75°39'48"W	0.02		—	Boyertown
		524–525 "NE Ext." of Hilltop Road to Bechtelsville, 3 spikes			
40°22'16"N	75°37'55"W	0.06		—	Boyertown
40°22'16"N	75°37'59"W	.12	*	RP18	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		524–525 “NE Ext.” of Hilltop Road to Bechtelsville, 3 spikes *(Continued)*			
40°22'16"N	75°38'02"W	0.03		—	Boyertown
40°22'14"N	75°38'11"W	.02		—	do.
40°22'08"N	75°38'21"W	.03		—	do.
40°22'06"N	75°38'23"W	.03		—	do.
		526–527 Hilltop Road, 1 spike			
40°21'51"N	75°38'37"W	0.05		—	Boyertown
40°21'51"N	75°38'39"W	.03		—	do.
40°21'44"N	75°38'42"W	.06		—	do.
40°21'40"N	75°38'48"W	.06		—	do.
		528–526 Ungers Road and unnamed road to north			
40°21'56"N	75°38'22"W	0.03		—	Boyertown
		531–517 Orchard Lane, 1 spike			
		535–516 Weisstown Road			
40°21'00"N	75°38'04"W	0.02		—	Boyertown
		536–537 Funk Road			
40°20'52"N	75°38'39"W	0.10		—	Boyertown
		541–542 Sunset Hill Road, 1 spike			
		542–481 Longview Road			
40°21'23"N	75°42'40"W	0.03		—	Boyertown
40°21'23"N	75°42'40"W	.01	*	—	do.
40°21'25"N	75°42'40"W	.09		—	do.
40°21'27"N	75°42'41"W	.03	*	—	do.
40°21'29"N	75°42'42"W	.10		—	do.
40°21'32"N	75°42'43"W	.14	*	—	do.
40°21'35"N	75°42'45"W	.08		—	do.
40°21'38"N	75°42'46"W	.06		—	do.
40°21'40"N	75°42'45"W	.05		—	do.
40°21'41"N	75°42'45"W	.03		—	do.
40°21'41"N	75°42'44"W	<.01	*	—	do.
40°21'42"N	75°42'43"W	.04		—	do.
40°21'42"N	75°42'42"W	.02	*	—	do.
40°21'43"N	75°42'40"W	.08		—	do.
40°21'43"N	75°42'39"W	.01	*	—	do.
40°21'43"N	75°42'37"W	.08		—	do.
		543–508 Water Street, 5 spikes			
40°21'37"N	75°42'07"W	0.01		—	Boyertown
40°21'37"N	75°42'06"W	<.01	*	—	do.
40°21'37"N	75°42'06"W	.03		—	do.
40°21'38"N	75°42'06"W	<.01	*	—	do.
40°21'39"N	75°42'05"W	.14		—	do.
40°21'44"N	75°42'00"W	.02		—	do.
40°21'46"N	75°41'59"W	.05	*	—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		543–508 Water Street, 5 spikes *(Continued)*			
40°21'47"N	75°41'57"W	0.07		RP8	Boyertown
40°21'48"N	75°41'56"W	.04	*	—	do.
		546–547 Long Lane, 3 spikes			
40°21'04"N	75°42'22"W	0.02		—	Boyertown
		548–549 Longview Road			
40°19'53"W	75°43'28"W	0.07		—	Boyertown
		550–481 Longview Road			
40°21'56"N	75°42'37"W	0.16		—	Boyertown
40°21'45"N	75°42'35"W	.06		—	do.
		553–559 Grims Mill Road, 1 spike			
		555–518 Ironstone Road, 1 spike			
40°21'27"N	75°39'53"W	0.02		—	Boyertown
		567–568 Sunrise Lane			
40°19'40"N	75°40'46"W	0.05		—	Boyertown
40°19'39"N	75°40'48"W	.06		RP48	do.
40°19'38"N	75°40'48"W	<.01	*	—	do.
40°19'36"N	75°40'49"W	.08		—	do.
40°19'35"N	75°40'49"W	<.01	*	—	do.
40°19'34"N	75°40'50"W	.07		—	do.
		571–572 Powder Hollow Road and Powder Mill Road			
40°20'17"N	75°41'32"W	0.06		—	Boyertown
		579–580 Extension of Fancy Hill Road north of Powder Mill Road, 3 spikes			
		580–581 Fancy Hill Road			
40°19'40"N	75°41'53"W	0.01		—	Boyertown
40°19'39"N	75°41'53"W	.03	*	—	do.
40°19'39"N	75°41'52"W	.01		—	do.
40°19'39"N	75°41'50"W	.02		—	do.
40°19'37"N	75°41'49"W	.02	*	—	do.
40°19'37"N	75°41'49"W	.02		—	do.
		583–584 Forgedale Route			
40°24'20"N	75°36'49"W	0.02		—	East Greenville
40°24'21"N	75°36'50"W	.08	*	RP16, RP61	do.
40°24'24"N	75°36'50"W	.12		—	do.
		726–727 Road west from Crow Hill Route, 1 spike			
40°24'30"N	75°35'59"W	0.03		—	East Greenville
40°24'29"N	75°36'02"W	.04		—	do.
40°24'29"N	75°36'03"W	<.01	*	—	do.
40°24'29"N	75°36'03"W	.02		—	do.
40°24'27"N	75°36'04"W	.10		—	do.
40°24'26"N	75°36'06"W	<.01	*	—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BERKS COUNTY *(Continued)*			
		726–727 Road west from Crow Hill Route, 1 spike *(Continued)*			
40°24'26"N	75°36'07"W	0.06		—	East Greenville
40°24'25"N	75°36'08"W	<.01	*	—	do.
40°24'25"N	75°36'09"W	.02		—	do.
40°24'23"N	75°36'16"W	.02		—	do.
40°24'23"N	75°36'17"W	.05		—	do.
40°24'22"N	75°36'17"W	<.01	*	—	do.
40°24'21"N	75°36'17"W	.04		RP51	do.
40°24'20"N	75°36'19"W	.09	*	—	do.
40°24'18"N	75°36'21"W	.01		—	do.
		734–757 Gun Club Road			
40°27'20"N	75°34'58"W	0.07		—	East Greenville
		146–750 Hollyberry Road, 1 spike			
		748–743 Old Mill Road, 6 spikes			
40°27'26"N	75°35'29"W	0.02		—	East Greenville
40°27'25"N	75°35'33"W	.03		—	do.
40°27'24"N	75°35'39"W	.05		—	do.
40°27'23"N	75°35'40"W	<.01	*	—	do.
40°27'22"N	75°35'43"W	.18		—	do.
40°27'16"N	75°36'07"W	.06		—	do.
		748–743 Seisholtzville Road, 1 spike			
40°27'36"N	75°35'28"W	0.06		RP19	East Greenville
40°27'37"N	75°35'29"W	<.01	*	—	do.
40°27'37"N	75°35'31"W	.06		—	do.
		749–748 Five Point Road			
40°27'29"N	75°35'13"W	0.01		—	East Greenville
40°27'29"N	75°35'14"W	<.01	*	—	do.
		764–740 Road from Walker Street to Huff's Church Route, 1 spike			
40°27'14"N	75°37'11"W	0.02		—	East Greenville
		BUCKS COUNTY			
		616–614 County Line Road, 2 spikes (see also Northampton County)			
40°35'31"N	75°14'04"W	0.01		—	Riegelsville
40°35'31"N	75°14'03"W	.01	*	—	do.
40°35'31"N	75°14'03"W	.02		—	do.
		653–654 Dogwood Lane			
40°34'49"N	75°15'40"W	0.03		—	Hellertown
40°34'47"N	75°15'35"W	.12		—	do.
40°34'47"N	75°15'28"W	.20		—	do.
40°34'47"N	75°15'21"W	.02		—	do.
40°34'47"N	75°15'20"W	.03		—	do.
40°34'49"N	75°15'15"W	.20		—	do.
40°34'51"N	75°15'05"W	.27		—	do.
40°34'51"N	75°14'57"W	.07	*	—	Riegelsville

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BUCKS COUNTY *(Continued)*			
		653–654 Dogwood Lane *(Continued)*			
40°34'51"N	75°14'49"W	0.34		—	Riegelsville
40°34'52"N	75°14'40"W	.11	*	RP14	do.
40°34'51"N	75°14'37"W	.03		—	do.
40°34'50"N	75°14'37"W	.01	*	—	do.
40°34'50"N	75°14'36"W	.04		—	do.
40°34'49"N	75°14'36"W	.01	*	—	do.
40°34'47"N	75°14'32"W	.21		—	do.
40°34'43"N	75°14'28"W	.03		—	do.
40°34'43"N	75°14'27"W	.01		—	do.
40°34'44"N	75°14'24"W	.05		—	do.
40°34'43"N	75°14'21"W	.05		—	do.
40°34'40"N	75°14'19"W	.03		—	do.
40°34'39"N	75°14'18"W	.03		—	do.
		654–655 Funk Mill Road			
40°34'35"N	75°14'26"W	0.05		—	Riegelsville
40°34'25"N	75°14'47"W	.01		—	do.
40°34'24"N	75°15'02"W	.05		—	Hellertown
40°34'24"N	75°15'04"W	.07		—	do.
40°34'22"N	75°15'09"W	.04		—	do.
40°34'19"N	75°15'14"W	.05		—	do.
		655–656 Haupts Bridge Road, 3 spikes			
40°34'21"N	75°15'16"W	0.05		—	Hellertown
40°34'23"N	75°15'20"W	.14		—	do.
40°34'23"N	75°15'23"W	.02	*	—	do.
40°34'24"N	75°15'24"W	.04		—	do.
40°34'24"N	75°15'25"W	.01	*	—	do.
40°34'25"N	75°15'28"W	.12		—	do.
40°34'25"N	75°15'32"W	.02		—	do.
40°34'25"N	75°15'34"W	.03		—	do.
40°34'25"N	75°15'36"W	.05		—	do.
40°34'26"N	75°15'39"W	.06		—	do.
40°34'29"N	75°15'42"W	.04		—	do.
40°34'33"N	75°15'42"W	.13		—	do.
40°34'35"N	75°15'44"W	.01	*	—	do.
40°34'35"N	75°15'45"W	.02		—	do.
40°34'34"N	75°15'45"W	.01	*	—	do.
40°34'34"N	75°15'46"W	.06		—	do.
40°34'34"N	75°15'48"W	.01		—	do.
40°34'33"N	75°15'49"W	.01	*	—	do.
40°34'33"N	75°15'50"W	.03		—	do.
40°34'32"N	75°15'54"W	.01		—	do.
40°34'31"N	75°15'56"W	.01		—	do.
40°34'31"N	75°15'59"W	.02		—	do.
40°34'33"N	75°16'00"W	.02		—	do.
		1108–655 Funk Mill Road(?), 5 spikes			
40°34'13"N	75°15'33"W	0.06		—	Hellertown

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		BUCKS COUNTY *(Continued)*			
		1111–1112 East-west road north of Springtown			
40°34'07"N	75°16'49"W	0.05		—	Hellertown
		LEHIGH COUNTY			
		588–589 Constitution Drive			
40°35'44"N	75°26'50"W	0.02		—	Allentown East
40°35'49"N	75°26'47"W	.02		—	do.
40°35'50"N	75°26'45"W	.02		—	do.
40°35'52"N	75°26'41"W	.04		—	do.
40°35'53"N	75°26'37"W	.09		RP5	do.
40°35'54"N	75°26'35"W	.01	*	—	do.
40°35'54"N	75°26'34"W	.05		—	do.
40°36'01"N	75°26'19"W	.11		—	do.
40°36'02"N	75°26'16"W	.02	*	—	do.
40°36'03"N	75°26'14"W	.11		—	do.
40°36'09"N	75°26'03"W	.02		—	do.
40°36'12"N	75°25'59"W	.01		—	do.
40°36'14"N	75°25'56"W	.02		—	do.
40°36'15"N	75°25'54"W	.02		—	do.
40°36'16"N	75°25'52"W	.04		—	do.
40°36'18"N	75°25'50"W	.03		—	do.
40°36'20"N	75°25'45"W	.09		—	do.
		722–722A Fifth Street, Oak Street, and School Lane, 2 spikes			
40°30'14"N	75°36'08"W	0.03		—	Allentown West
40°30'31"N	75°36'07"W	.02		—	do.
		766–767 Chestnut Road, Bachman Road, and Sweetwood Drive			
40°29'28"N	75°33'55"W	0.09		—	East Greenville
		767–794 Apple Lane and Lazor Road, 1 spike			
		770–759 Chestnut Road, 1 spike			
		782–793 St. Peter's Road, 3 spikes			
40°29'28"N	75°32'37"W	0.03		—	East Greenville
		793–794 St. Peter's Road			
40°29'01"N	75°33'32"W	0.28		—	East Greenville
		794–743 St. Peter's Road, 1 spike			
		795–796 Bachman Road			
40°29'27"N	75°33'49"W	0.05		—	East Greenville
40°29'28"N	75°33'49"W	<.01	*	—	do.
40°29'29"N	75°33'49"W	.08		—	do.
		796–797 Road north from Bachman Road and Sweetwood Road			
40°29'32"N	75°33'50"W	0.04	*	—	East Greenville
40°29'34"N	75°33'50"W	.04		—	do.
40°29'35"N	75°33'50"W	<.01	*	—	do.
40°29'35"N	75°33'50"W	.01		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
LEHIGH COUNTY *(Continued)*					
798–793 Macungie Mountain Road and Indian Creek Road					
40°29'23"N	75°33'15"W	0.11		—	East Greenville
40°29'16"N	75°33'17"W	.07		—	do.
40°29'13"N	75°33'18"W	.09	*	—	do.
40°29'11"N	75°33'19"W	.05		—	do.
805–806 Hiestand Road, 1 spike					
809–810 Road northeast from Indian Creek Road					
40°29'23"N	75°33'14"W	0.01	*	—	East Greenville
40°29'24"N	75°33'13"W	.05		—	do.
40°29'25"N	75°33'09"W	.04		—	do.
813–814 Road northwest from St. Peter's Road					
40°29'33"N	75°32'48"W	0.03		—	East Greenville
40°29'33"N	75°32'50"W	.04	*	—	do.
40°29'34"N	75°32'51"W	.02		—	do.
836–853 Churchview Road					
40°29'18"N	75°30'25"W	0.07		—	East Greenville
40°29'17"N	75°30'30"W	.16	*	RP28	do.
40°29'17"N	75°30'34"W	.03		—	do.
40°29'18"N	75°30'45"W	.08		—	do.
844–807 Indian Creek Road					
40°28'55"N	75°32'10"W	0.03		—	East Greenville
852–815 Woodlawn Drive					
40°27'59"N	75°31'49"W	0.02		—	East Greenville
40°27'59"N	75°31'50"W	.05	*	—	do.
40°27'59"N	75°31'52"W	.02		RP27	do.
40°27'59"N	75°31'57"W	.06		—	do.
40°27'57"N	75°32'03"W	.02		—	do.
40°27'57"N	75°32'09"W	.10		—	do.
40°27'56"N	75°32'15"W	.07		—	do.
854–856 Ridge Road					
40°27'59"N	75°32'09"W	0.07		—	East Greenville
40°27'58"N	75°32'10"W	<.01	*	—	do.
40°27'58"N	75°32'10"W	.02		—	do.
856–857 Ridge Road					
40°27'55"N	75°32'11"W	0.03		—	East Greenville
863–864 Buhman Road, 2 spikes					
885–886 Schoolhouse Lane, 4 spikes					
40°28'20"N	75°29'06"W	0.08		—	Milford Square
40°28'13"N	75°29'01"W	.10		—	do.
40°28'10"N	75°29'00"W	.11		—	do.
887–889 Scout Road					
40°27'49"N	75°29'22"W	0.03		—	Milford Square

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		LEHIGH COUNTY *(Continued)*			
		892–893 Bellgate Road			
40°29'27"N	75°27'50"W	0.04		—	Milford Square
		895–952 Baumgartner Road, 1 spike			
		923–924 Liberty Road			
40°31'32"N	75°23'36"W	0.06		—	Allentown East
40°31'32"N	75°23'37"W	<.01	*	—	do.
40°31'32"N	75°23'39"W	.08		—	do.
40°31'32"N	75°23'45"W	.07		—	do.
40°31'32"N	75°23'49"W	.14		—	do.
40°31'32"N	75°23'53"W	.04		—	do.
		930–914 Chestnut Hill Road			
40°31'33"N	75°26'17"W	0.20		RP24	Allentown East
40°31'29"N	75°26'13"W	.09	*	RP23, RP64	do.
40°31'27"N	75°26'11"W	.06		—	do.
40°30'33"N	75°25'55"W	.04		—	do.
40°30'32"N	75°25'55"W	<.01	*	—	do.
		937–938 Chestnut Hill Church Road to Limeport Pike			
40°29'23"N	75°27'01"W	0.07		—	Milford Square
		948–949 Vera Cruz Road			
40°30'37"N	75°27'30"W	0.29		—	Allentown East
40°30'40"N	75°27'35"W	.04	*	—	do.
40°30'41"N	75°27'35"W	.05		—	do.
		949–950 Road running north from Vera Cruz and Limeport Roads			
40°30'47"N	75°27'36"W	0.07		—	Allentown East
40°30'48"N	75°27'36"W	<.01		—	do.
40°30'49"N	75°27'36"W	.02		—	do.
		949–951 Limeport Road (westbound) (see 951–949 for eastbound traverse)			
40°30'39"N	75°27'58"W	0.01		—	Allentown East
40°30'39"N	75°28'01"W	.12	*	—	do.
40°30'38"N	75°28'05"W	.06		—	do.
40°30'37"N	75°28'11"W	.23	*	—	do.
40°30'38"N	75°28'17"W	.08		—	do.
		951–949 Limeport Road (eastbound) (see 949–951 for westbound traverse)			
40°30'38"N	75°28'17"W	0.13		—	Allentown East
40°30'37"N	75°28'07"W	.37	*	RP6	do.
40°30'39"N	75°27'59"W	.03		—	do.
40°30'40"N	75°27'56"W	.04		—	do.
		953–959 Oak Hill Road, 1 spike			
		954–955 Road running south from Kozy Corner Lane up Limeport Hill, 1 spike			
		963–958 Road running southeast from Vera Cruz Road to Limeport Hill			
40°31'13"N	75°27'58"W	0.03		—	Allentown East

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		LEHIGH COUNTY *(Continued)*			
		964–965 Pennsylvania Turnpike, Northeast Extension, southbound lane, 1 spike			
40°30'53"N	75°30'22"W	0.31		—	Allentown West
40°30'47"N	75°30'17"W	.14	*	RP50	do.
40°30'39"N	75°30'12"W	.40		—	do.
40°30'33"N	75°30'10"W	.02	*	—	do.
40°30'32"N	75°30'10"W	.04		—	do.
40°30'29"N	75°30'10"W	.10	*	—	do.
40°30'27"N	75°30'09"W	.07		—	do.
40°30'22"N	75°30'07"W	.08		—	do.
40°30'17"N	75°30'06"W	.08		—	do.
40°30'09"N	75°30'01"W	.06		—	do.
40°29'56"N	75°29'47"W	.21		—	Milford Square
40°29'52"N	75°29'39"W	.26	*	—	do.
40°29'48"N	75°29'30"W	.25		RP10, RP53	do.
40°29'44"N	75°29'09"W	.06		—	do.
40°29'25"N	75°28'11"W	.59		—	do.
40°29'15"N	75°27'58"W	.17		—	do.
40°28'37"N	75°27'31"W	.44		—	do.
40°28'28"W	75°27'24"W	.16		—	do.
		965–964 Pennsylvania Turnpike, Northeast Extension, northbound lane			
40°29'46"N	75°29'20"W	<0.01	*	—	Milford Square
40°29'46"N	75°29'21"W	.02		—	do.
40°29'46"N	75°29'21"W	<.01	*	—	do.
40°29'46"N	75°29'22"W	.02		—	do.
40°29'50"N	75°29'34"W	.12		—	do.
40°30'28"N	75°30'09"W	.08		—	Allentown West
		966–967 Pa. Route 309, 2 spikes			
40°33'39"N	75°27'14"W	0.50		—	Allentown East
40°33'43"N	75°27'36"W	.07		—	do.
40°33'43"N	75°27'41"W	.04		—	do.
40°33'44"N	75°27'46"W	.17	*	—	do.
40º33'44"N	75°27'51"W	.07		RP47	do.
		989–990 North-south road north of Chestnut Hill Road on South Mountain			
40°32'35"N	75°28'25"W	0.14		—	Allentown East
40°32'39"N	75°28'25"W	.08	*	—	do.
40°32'41"N	75°28'26"W	.06		—	do.
		993–995 West Rock Road			
40°33'35"N	75°27'16"W	0.03		—	Allentown East
40°33'34"N	75°27'20"W	.05		—	do.
40°33'34"N	75°27'21"W	<.01	*	—	do.
		995–996 West Rock Road, 1 spike			
40°33'10"N	75°27'56"W	0.03		—	Allentown East
40°33'10"N	75°27'57"W	<.01	*	—	do.
40°33'10"N	75°27'58"W	.03		—	do.
40°33'09"N	75°28'04"W	.01		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		LEHIGH COUNTY *(Continued)*			
		997–998 Road south of West Rock Road on South Mountain			
40°33'34"N	75°27'14"W	0.01		—	Allentown East
40°33'31"N	75°27'15"W	.20	*	RP26	do.
		1009–1010 Road around South Mountain reservoir, 3 spikes			
		1016–1017 Beacon Street and power line service road, 3 spikes			
40°33'49"N	75°27'21"W	0.04		—	Allentown East
40°33'49"N	75°27'22"W	<.01	*	—	do.
40°33'50"N	75°27'23"W	.09		—	do.
40°33'51"N	75°27'25"W	<.01	*	—	do.
40°33'51"N	75°27'25"W	.02		—	do.
40°33'52"N	75°27'28"W	.10	*	—	do.
40°33'52"N	75°27'30"W	<.01		—	do.
40°33'52"N	75°27'31"W	.04	*	—	do.
40°33'52"N	75°27'32"W	.01		—	do.
40°33'50"N	75°27'37"W	.28	*	RP34	do.
40°33'48"N	75°27'41"W	<.01		—	do.
40°33'48"N	75°27'43"W	.06	*	—	do.
40°33'47"N	75°27'44"W	<.01		—	do.
40°33'46"N	75°27'46"W	.12	*	RP45, RP46	do.
		1017–1018 Power line service road and Blackgum Street, 2 spikes			
40°33'47"N	75°27'39"W	0.42	*	—	Allentown East
40°33'49"N	75°27'31"W	<.01		—	do.
40°33'49"N	75°27'29"W	.09	*	—	do.
40°33'50"N	75°27'28"W	<.01		—	do.
40°33'50"N	75°27'27"W	.02	*	—	do.
40°33'50"N	75°27'27"W	<.01		—	do.
40°33'50"N	75°27'27"W	.01	*	—	do.
40°33'51"N	75°27'26"W	.05		—	do.
		1019–1021 Mountain Park Road, 1 spike			
		1021–1020 Mountain Park Road loop			
40°34'17"N	75°26'43"W	0.12		—	Allentown East
		1023–1024 Mountain Road and Johnston Street			
40°34'31"N	75°26'38"W	0.11		—	Allentown East
40°34'29"N	75°26'33"W	.07		—	do.
		1025–1026 North-south road in eastern Mountainville			
40°34'25"N	75°26'52"W	0.01		—	Allentown East
		1033–1034 Black River Road and Evergreen Road, 1 spike			
		1038–1039 Linda, Gail, and Ehrets Streets			
40°35'10"N	75°25'20"W	0.01		—	Allentown East
		1050–588 Constitution Drive			
40°35'35"N	75°27'00"W	0.03		—	Allentown East

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		LEHIGH COUNTY *(Continued)*			
		1055–1056 Lincoln and Skyline Roads, 1 spike			
40°35'33"N	75°26'13"W	0.03		—	Allentown East
		1062–1064 Road from River Road to Uncas Street, north side Lehigh Mountain, 2 spikes			
40°36'44"N	75°23'47"W	0.02		—	Allentown East
		1063–1064 Road from River Road to Uncas Street, north side Lehigh Mountain, 1 spike			
		1074–1075 Weyhill Road, 2 spikes			
40°33'05"N	75°21'37"W	0.04		—	Hellertown
40°33'05"N	75°21'38"W	<.01	*	—	do.
40°33'03"N	75°21'41"W	.17		—	do.
40°33'00"N	75°21'47"W	.23		RP25	do.
40°32'48"N	75°22'16"W	.18		—	do.
		1074–1082 Spring Road, 2 spikes			
40°33'06"N	75°21'34"W	0.01		—	Hellertown
40°33'08"N	75°21'35"W	.12	*	—	do.
40°33'11"N	75°21'42"W	.04		—	do.
40°33'11"N	75°21'45"W	.07	*	—	do.
40°33'10"N	75°21'51"W	.24		—	do.
		1076–1077 Landis Mill Road, 2 spikes			
		1080–1081 Station Road, 1 spike			
		NORTHAMPTON COUNTY			
		607–608 Sunnyside Road, 3 spikes			
40°36'19"N	75°12'25"W	0.01		—	Riegelsville
		616–614 County Line Road, 1 spike (see also Bucks County)			
40°35'12"N	75°14'52"W	0.02		—	Riegelsville
40°35'11"N	75°14'51"W	.01	*	—	do.
40°35'11"N	75°14'50"W	.02		—	do.
		616–652 Ballek Road			
40°35'25"N	75°15'04"W	0.12		—	Hellertown
		616–653 County Line Road			
40°35'03"N	75°15'12"W	0.01		—	Hellertown
40°35'02"N	75°15'14"W	.02		—	do.
40°35'02"N	75°15'15"W	.02	*	—	do.
40°35'02"N	75°15'16"W	.05		—	do.
40°34'57"N	75°15'26"W	.05		—	do.
40°34'56"N	75°15'29"W	.12	*	—	do.
40°34'55"N	75°15'32"W	.06		—	do.
40°34'54"N	75°15'33"W	<.01	*	—	do.
40°34'54"N	75°15'34"W	.05		—	do.
40°34'53"N	75°15'34"W	<.01	*	—	do.
40°34'52"N	75°15'36"W	.08		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		NORTHAMPTON COUNTY *(Continued)*			
		623–624 Pa. Route 611, 1 spike			
		632–633 Moyers Lane			
40°39'42"N	75°12'28"W	0.02		—	Easton
40°39'42"N	75°12'25"W	.02		—	do.
		635–636 Morvale (Morgan Valley) Road			
40°39'26"N	75°13'30"W	0.04		—	Easton
40°39'37"N	75°13'38"W	.16		—	do.
40°39'40"N	75°13'40"W	.01	*	—	do.
40°39'41"N	75°13'41"W	.06		—	do.
40°39'41"N	75°13'42"W	.01	*	—	do.
40º39'41"N	75°13'43"W	.02		—	do.
40°39'42"N	75°13'47"W	.04		—	do.
40°39'42"N	75°13'50"W	.03	*	—	do.
40°39'42"N	75°13'51"W	.04		—	do.
40°39'42"N	75°13'53"W	.02	*	—	do.
		636–637 Industrial Drive			
40°39'43"N	75°13'55"W	0.11	*	—	Easton
40°39'43"N	75°13'59"W	.06		—	do.
40°39'45"N	75°13'59"W	.01	*	—	do.
40°39'45"N	75°13'59"W	.02		—	do.
40°39'47"N	75°13'58"W	.03		—	do.
40°39'50"N	75°13'54"W	.13		—	do.
40°39'52"N	75°13'52"W	.04	*	—	do.
40°39'56"N	75°13'47"W	.29		—	do.
40°40'00"N	75°13'43"W	.02	*	—	do.
40°40'01"N	75°13'42"W	.05		—	do.
40°40'01"N	75°13'41"W	.01	*	—	do.
40°40'02"N	75°13'40"W	.05		—	do.
		630–640 Echo Ridge Girl Scout Camp Road			
40°39'31"N	75°12'22"W	0.02		—	Easton
40°39'33"N	75°12'06"W	.05		—	do.
40°39'32"N	75°12'06"W	.02	*	—	do.
40°39'30"N	75°12'07"W	.06		—	do.
40°39'30"N	75°12'08"W	.02	*	—	do.
40°39'30"N	75°12'08"W	.01		—	do.
40°39'29"N	75°12'09"W	.05	*	—	do.
40°39'27"N	75°12'09"W	.04		—	do.
		649–650 Spring Valley Road			
40°39'50"N	75°12'53"W	0.09		—	Easton
40°39'50"N	75°12'56"W	.01		—	do.
40°39'50"N	75°12'58"W	.04	*	—	do.
40°39'50"N	75°13'00"W	.10		—	do.
		652–617 Ballek Road			
40°35'40"N	75°15'02"W	0.15		—	Hellertown

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
		NORTHAMPTON COUNTY *(Continued)*			
		652–651 Private road and Motil Road			
40°35'39"N	75°15'22"W	0.02		—	Hellertown
40°35'40"N	75°15'25"W	.04		—	do.
40°35'43"N	75°15'27"W	.01		—	do.
		657–651 Wassergass Road			
40°35'27"N	75°15'48"W	0.06		—	Hellertown
40°35'31"N	75°15'43"W	.04		—	do.
		660–659 Park Road			
40°38'43"N	75°15'26"W	0.03		—	Nazareth
40°38'52"N	75°15'17"W	.02		—	do.
40°38'52"N	75°15'16"W	.01		—	do.
40°38'53"N	75°15'15"W	.04		—	do.
40°38'54"N	75°15'14"W	<.01	*	—	do.
40°38'55"N	75°15'12"W	.15		—	do.
40°38'59"N	75°15'05"W	.04		—	do.
		661–660 Park Road			
40°38'21"N	75°15'46"W	0.03		—	Nazareth
40°38'23"N	75°15'43"W	.21		—	do.
40°38'26"N	75°15'40"W	.04		—	do.
40°38'33"N	75°15'34"W	.02		—	do.
40°38'36"N	75°15'32"W	.02		—	do.
40°38'38"W	75°15'29"W	.04		—	do.
		663–661 Park Road			
40°38'05"N	75°16'18"W	0.02		—	Nazareth
		678–677 Hillcrest Drive			
40°42'29"N	75°12'52"W	0.07		—	Easton
40°42'30"N	75°12'50"W	.05	*	—	do.
40°42'30"N	75°12'49"W	.01		—	do.
40°42'32"N	75°12'45"W	.11		—	do.
40°42'33"N	75°12'42"W	.02	*	—	do.
40°42'33"N	75°12'41"W	.06		—	do.
40°42'35"N	75°12'37"W	.18	*	RP21	do.
40°42'37"N	75°12'31"W	.14		—	do.
40°42'42"N	75°12'23"W	.03		—	do.
		679–680 Pennsylvania Avenue			
40°42'31"N	75°12'21"W	0.09		—	Easton
40°42'33"N	75°12'18"W	.05		—	do.
40°42'37"N	75°12'13"W	.03		—	do.
		681–679 Hillside Drive			
40°42'43"N	75°12'10"W	0.03		—	Easton
40°42'43"N	75°12'12"W	.09	*	—	do.
40°42'41"N	75°12'15"W	.15		RP22	do.
40°42'38"N	75°12'19"W	.02		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
NORTHAMPTON COUNTY *(Continued)*					
681–679 Hillside Drive *(Continued)*					
40°42'37"N	75°12'21"W	0.08	*	—	Easton
40°42'36"N	75°12'22"W	.04		—	do.
40°42'35"N	75°12'23"W	.03	*	—	do.
40°42'34"N	75°12'23"W	.04		—	do.
40°42'33"N	75°12'24"W	.02	*	—	do.
40°42'33"N	75°12'23"W	.03		—	do.
40°42'32"N	75°12'23"W	.01	*	—	do.
40°42'32"N	75°12'23"W	.05		—	do.
40°42'30"N	75°12'21"W	.04		—	do.
683–684 Bushkill Drive					
40°42'04"N	75°13'56"W	0.01		—	Easton
40°42'06"N	75°13'57"W	.10	*	RP15	do.
40°42'08"N	75°13'58"W	.01		—	do.
685–688 Road from Ridge Trail to Lafayette Street					
40°42'12"N	75°13'23"W	0.02		—	Easton
40°42'11"N	75°13'21"W	.03		—	do.
40°42'11"N	75°13'18"W	.02		—	do.
40°42'09"N	75°13'16"W	.03		—	do.
687–688 Morrison Street and Paxinosa Street, 1 spike					
40°42'13"N	75°13'23"W	0.03		—	Easton
40°42'12"N	75°13'21"W	.05		—	do.
40°42'15"N	75°13'17"W	.17	*	—	do.
40°42'17"N	75°13'14"W	.01		—	do.
40°42'20"N	75°13'14"W	.04		—	do.
40°42'23"N	75°13'05"W	.02		—	do.
40°42'25"N	75°13'03"W	.01		—	do.
689–682 Knoll Road					
40°42'25"N	75°12'59"W	0.03		RP41	Easton
40°42'24"N	75°12'58"W	.02	*	—	do.
40°42'24"N	75°12'56"W	.08		—	do.
697–698 Santee Mill Road and Altonah Road					
40°39'54"N	75°21'44"W	0.05		—	Nazareth
1111–1114 Lower Saucon Road					
40°34'12"N	75°17'35"W	0.05		—	Hellertown
40°34'19"N	75°17'34"W	.05		—	do.
1113–1114 Banko Lane, 1 spike					
1114–1115 Lower Saucon Road, 1 spike					
1117–1115 Bergstressor Road, 2 spikes					
40°34'58"N	75°16'41"W	0.04		—	Hellertown
40°34'57"N	75°16'37"W	.06		—	do.
40°34'55"N	75°16'33"W	.04		—	do.

Table 22. *(Continued)*

Latitude	Longitude	Length (km)	Intensity[1]	Samples[2]	Quadrangle
NORTHAMPTON COUNTY *(Continued)*					
1134–1135 Reservoir Road					
40°33'57"N	75°19'32"W	0.02		—	Hellertown
40°33'53"N	75°19'32"W	.02		—	do.
1134–1139 Polk Valley Road					
40°34'10"N	75°18'26"W	0.20		—	Hellertown
40°34'12"N	75°18'14"W	.24		—	do.
40°34'14"N	75°17'59"W	.31		—	do.
1140–1141 Silver Creek Road, 1 spike					
40°34'28"N	75°18'12"W	0.05		—	Hellertown
40°34'28"N	75°18'22"W	.10		RP52, RP65	do.

[1]Intensity of the gamma-ray anomaly as detected by the Mount Sopris SC–132A scintillometer inside the vehicle. Those marked by an asterisk (*) registered greater than 100 counts/sec. Those not marked registered between 80 and 100 counts/sec.
[2]Dash, no sample.

APPENDIX 2

SUMMARY OF ROCK-SAMPLING SITES OF PHASE II

Table 23 lists the 67 samples collected for chemical analysis and assay, constituting the second phase of this study (see "Phase II: Anomaly Rock Sampling and Analysis," p. 23). The samples are listed by numerical order for easy reference while reading the main body of the report. It should be noted that one sample number, RP58, is skipped in the sequence, as it was not used for a Reading Prong sample.

The format of each entry is as follows:

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
NUMBER[1] AND NAME OF OCCURRENCE	County	Geiger counter[2]	Assay
Formation name, if known, and lithology	Municipality	Scintillometer[3]	
Weathering	Description of location		
Type of sample	Latitude		
Interval sampled	Longitude		
Weight	Date collected		

[1] Samples marked by an asterisk were located as a result of the carborne gamma-ray survey.
[2] Geiger counter readings are expressed as "milliroentgens per hour" ("mR/hr") even though the beta shield on the Geiger counter was open, meaning that true mR/hr readings were not obtained. This was done to obtain greater reproducibility and sensitivity. Counts per second, another alternative, was not used because it is not comparable from one Geiger counter to another, whereas "mR/hr" is comparable from instrument to instrument.
[3] Counts per second (counts/sec) were obtained with a handheld Mount Sopris SC–132A scintillometer equipped with 1.5- x 1.5-in. (38- x 38-mm) NaI crystal.

Table 23. *Summary of Rock-Sampling Sites*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP1 PENNSYLVANIA URANIUM MINING CORP. DUMPS Disintegrated rock from mineralized part of dump Weathering: soil Type of sample: mostly coarse sand Interval sampled: 25 cm Weight: 3.03 kg	Berks Co. Shanesville 15 m S65ºE of shaft 40º22'20"N 75º42'12"W Collected June 27, 1980	0.60 “mR/hr” 5,000 counts/sec	541
RP2* ANTIETAM RESERVOIR Leuco gneiss with pyrite>pyrrhotite>molybdenite>chalcopyrite Weathering: pristine Type of sample: 38 pieces ≥3 cm Interval sampled: 4.85 m along horizontal Weight: 3.71 kg	Berks Co. Stony Creek Mills 97–102 m S of intersection of Angora and Antietam Rds. 40º21'14"N 75º52'14"W Collected June 27, 1980	0.12 “mR/hr” 900 counts/sec	31
RP3* PA. ROUTE 611 ROADCUT Sheared pink K-feldspar–quartz gneiss with trace zircon and red to orange resinous mineral Weathering: pristine Type of sample: 30 pieces ≥3 cm Interval sampled: 65 cm along base of outcrop Weight: 2.81 kg	Bucks Co. Monroe 110 m NW of creek under road 40º34'25"N 75º11'37"W Collected June 19, 1980	— 450 counts/sec	18
RP4 C. K. WILLIAMS QUARRY Sheared, gray quartz-feldspar gneiss with trace brick-red thorite and pyrite Weathering: fresh Type of sample: 25 pieces ≥3 cm Interval sampled: chips from 12 boulders Weight: 2.86 kg	Northampton Co. Easton Slide area 40º42'46"N 75º11'50"W Collected June 20, 1980	— 2,000 counts/sec	55
RP5 CONSTITUTION DRIVE Hardyston Fm., 6-cm dark, heavy fossil placer with quartz pebbles up to 3.5 cm Weathering: pristine Type of sample: 8.5-cm-wide channel sample Interval sampled: 0–32 cm perpendicular to contact Weight: 3.3 kg	Lehigh Co. Salisbury Twp. 0.16 mile ENE of spring 40º36'00"N 75º26'17"W Collected June 20, 1980	0.12 “mR/hr” —	30

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP6* LIMEPORT ROAD ANOMALY Foliated, gray quartz-feldspar gneiss with uranophane and tan to black resinous mineral Weathering: fresh Type of sample: 12 pieces 2–8 cm Interval sampled: one 20-kg boulder Weight: 2.96 kg	Lehigh Co. Upper Milford Twp. 0.18 km E of intersection of Baumgartner Rd. (Figures 60–64) 40º30'37"N 75º28'15"W Collected June 5, 1980	0.50 "mR/hr" 2,000 counts/sec	1,120
RP7* SHENKEL HILL ROAD ANOMALY Fresh rock was probably coarse pink feldspar-quartz gneiss Weathering: soil Type of sample: Coarse sand and small fragments Interval sampled: 80 cm along horizontal Weight: 2.84 kg	Berks Co. Earl Twp. 0.95 km NE of intersection of Furnace Run Rd. 40º21'40"N 75º43'13"W Collected July 9, 1980	0.12 "mR/hr" 1,050 counts/sec	62
RP8* WATER STREET ANOMALY Pegmatitic pink feldspar-quartz gneiss with major allanite-(Ce) and minor zircon Weathering: fresh Type of sample: 34 pieces 4–6 cm Interval sampled: 10 boulders high-graded for allanite-(Ce) Weight: 3.37 kg	Berks Co. Shanesville 100–135 m SSW of Pa. Route 73, stone fence on E side 40º21'46"N 75º41'57"W Collected July 9, 1980	0.07 "mR/hr" —	14
RP9* MEXICO ROAD ANOMALY Foliated pink to salmon and white feldspar-quartz gneiss Weathering: fresh Type of sample: 32 pieces 4–8 cm Interval sampled: 10 boulders over 50- x 125-m area Weight: 3.03 kg	Berks Co. Alsace Twp. 50 m S of road, 50–175 m W of phone line, 0.45 km NNE of Chapel Hill 40º23'11"N 75º50'46"W Collected July 9, 1980	0.12 "mR/hr" 750 counts/sec	64
RP10 RED FELDSPAR LAYER ANOMALY Very coarse pink feldspar with minor quartz; molybdenite with brown resinous mineral; meta-autunite Weathering: fresh Type of sample: 2 blocks, each with entire layer Interval sampled: 15-cm-thick layer Weight: 2.78 kg	Lehigh Co. Upper Milford Twp. W side of NE Ext. Pa. Turnpike, 0.25 km NW of former Reading Railroad tunnel 40º29'48"N 75º29'34"W Collected June 6, 1980	0.15 "mR/hr" 700 counts/sec	231

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP11* OLEY ROAD ANOMALY Tan to salmon K-feldspar–quartz gneiss with tiny resinous minerals Weathering: fresh Type of sample: 35 pieces ≥3 cm Interval sampled: 11 boulders 36 m along bank Weight: 3.12 kg	Berks Co. Alsace Twp. 1.1 km E of intersection with Pricetown Rd., Alsace Manor (Figures 67–71) 40º24'02"N 75º50'56"W Collected July 15, 1980	0.10 “mR/hr” 450 counts/sec	160
RP12* M. MOORE PROPERTY Pink K-feldspar–off-white plagioclase–quartz gneiss with tiny resinous minerals Weathering: weathered Type of sample: 41 pieces ≥3 cm from 12 rocks Interval sampled: 6 m along 0.6- to 0.9-m bank Weight: 3 kg	Berks Co. Alsace Twp. NW-SE road through farm, 320 m NW of barn, 1.5 km NE of Five Points 40º22'18"N 75º49'32"W Collected July 15, 1980	0.07 “mR/hr” 300 counts/sec	31
RP13* HARTMAN ROAD ANOMALY Fresh rock probably coarse pink feldspar-quartz gneiss Weathering: weathered Type of sample: mostly sand and small fragments Interval sampled: 80 cm along 3-m-high bank Weight: 3.34 kg	Berks Co. Exeter Twp. 110 m N of W. Behn house on E side of road, 1.1 km W of intersection of Oley Line Rd. 40º21'26"N 75º49'37"W Collected July 15, 1980	0.14 “mR/hr” 700 counts/sec	18
RP14* DOGWOOD LANE ANOMALY Pegmatitic pink K-feldspar–greenish plagioclase–quartz gneiss with major allanite-(Ce), trace zircon, biotite, magnetite Weathering: fresh Type of sample: 35 pieces ≥3 cm from 35 boulders Interval sampled: from edge of bank 15 m SW Weight: 2.52 kg	Bucks Co. Durham Twp. S side of road, 1.85 km NW of Durham 40º34'50"N 75º14'39"W Collected June 4, 1980	0.04 “mR/hr” —	35
RP15* BUSHKILL DRIVE ANOMALY Foliated pink K-feldspar–greenish plagioclase–quartz gneiss with trace magnetite-ilmenite and pyrite Weathering: pristine Type of sample: 40 pieces ≥3 cm Interval sampled: 3.7 m along horizontal Weight: 2.86 kg	Northampton Co. Easton E side of road, centered 58 m N of culvert, Chestnut Hill 40º42'04"N 75º13'54"W Collected June 19, 1980	— —	70

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP16* FORGEDALE ROUTE ANOMALY Foliated pink K-feldspar–greenish plagioclase–quartz gneiss with black, red, and yellow metamict minerals, allanite-(Ce), and pyrite Weathering: pristine Type of sample: 15 pieces ≥5 x 10 x 2 cm (=channel) Interval sampled: 80 cm along base of outcrop Weight: 2.72 kg	Berks Co. Washington Twp. 0.95 km SSE of intersection at Dale, on E side of road (Figures 44–47) 40º24'20"N 75º36'50"W Collected July 24, 1980	0.30 “mR/hr” 1,800 counts/sec	130
RP17* HAY ROAD ANOMALY White feldspar-quartz gneiss, one third with pink K-feldspar; red-brown monazite(?), trace allanite-(Ce) Weathering: fresh Type of sample: 25 pieces ≥3 cm from 10 boulders Interval sampled: 30 m of stone fence Weight: 2.84 kg	Berks Co. Pike Twp. J. Theron property, 270 m SE of intersection with Mine Road 40º24'53"N 75º42'10"W Collected July 24, 1980	0.10 “mR/hr” 500 counts/sec	81
RP18* CHERRY STREET WEST Pegmatitic salmon-pink K-feldspar–quartz gneiss with minor altered off-white plagioclase(?) Weathering: fresh Type of sample: 13 pieces ≥5 cm (=channel) Interval sampled: 50 cm E-W along horizontal Weight: 2.95 kg	Berks Co. Bechtelsville Twp. N side of road, 270 m W of intersection with Main Street 40º22'16"N 75º37'58"W Collected July 24, 1980	0.08 “mR/hr” 450 counts/sec	18
RP19* HARLEM ANOMALY Bluish-gray feldspar–elongated quartz gneiss Weathering: fresh Type of sample: 30 pieces ≥3 cm from 10 boulders Interval sampled: 2.5-m-high bank, 26 m long Weight: 3.12 kg	Berks Co. Hereford Twp. NE side of Seisholtzville Rd., 320 m NW of intersection with Five Points Rd. 40º24'53"N 75º42'12"W Collected July 23, 1980	0.07 “mR/hr” 200 counts/sec	26
RP20 CONSTITUTION DRIVE U ALLANITE QUARRY Pegmatitic salmon K-feldspar–greenish plagioclase gneiss with minor allanite-(Ce) and trace titanite Weathering: pristine Type of sample: 88 pieces ≥2 cm Interval sampled: outcrop zone 1 m wide [allanite-(Ce)] Weight: 3.23 kg	Lehigh Co. Salisbury Twp. Uphill from quarry that is 100 m ENE of spring 40º35'57"N 75º26'22"W Collected June 20, 1980	— 600 counts/sec	2.9

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP21 EASTON UPPER RESERVOIR N BANK Pegmatitic bright-pink K-feldspar–quartz gneiss with red thorite in magnetite grains Weathering: weathered Type of sample: 15 pieces ≥5 cm from 10 boulders Interval sampled: 10 x 10 m excavated from reservoir Weight: 2.95 kg	Northampton Co. Forks Twp. S side of Hillcrest Drive 40º42'35"N 75º12'34"W Collected August 7, 1980	0.14 “mR/hr” 900 counts/sec	166
RP22* HILLSIDE AVENUE ANOMALY Pink K-feldspar–greenish plagioclase–quartz gneiss with trace uranophane, thorite, schorl, allanite-(Ce) Weathering: fresh Type of sample: 20 pieces ≥5 cm from 10 boulders Interval sampled: 35- x 45-m area Weight: 3.28 kg	Northampton Co. Forks Twp. 0.37 mi NE of Wayne Ave. 40º42'44"N 75º12'14"W Collected August 7, 1980	0.22 “mR/hr” 1,190 counts/sec	125
RP23* HELLER’S 2 BOULDERS Pink K-feldspar–quartz gneiss with minor greenish plagioclase, trace allanite-(Ce), titanite, thorite(?) Weathering: pristine Type of sample: 7 pieces ≥5 cm from 2 boulders Interval sampled: 2 boulders that are 1 m apart Weight: 3.34 kg	Lehigh Co. Limeport 75 feet SW of SW corner of house, SW side of Chestnut Hill Rd., 1.72 km NE of Limeport 40º31'27"N 75º26'15"W Collected August 6, 1980	0.33 “mR/hr” 2,500 counts/sec	960
RP24* COUTUMAS TRACT Pink to tan K-feldspar–quartz gneiss with epidote layers having trace thorite, rare allanite-(Ce) Weathering: fresh Type of sample: 12 pieces >5 cm from 10 boulders Interval sampled: 30-m length of knoll Weight: 3.06 kg	Lehigh Co. Upper Saucon Twp. 100 m S40ºW of house, SW side of Chestnut Hill Rd., 1.68 km NE of Limeport 40º31'28"N 75º26'19"W Collected August 6, 1980	0.13 “mR/hr” 650 counts/sec	92
RP25* REICHARD TRACT Pink K-feldspar–greenish plagioclase–quartz gneiss with minor magnetite Weathering: weathered Type of sample: 25 pieces >3 cm Interval sampled: 90 cm from channel Weight: 2.82 kg	Lehigh Co. Upper Saucon Twp. Weyhill Rd., 0.39 km SW of Station Rd. intersection 40º33'02"N 75º21'46"W Collected August 6, 1980	0.06 “mR/hr” 320 counts/sec	3.5

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP26* BONASKIEWICH'S ROCK Fine-grained tan K-feldspar–off-white plagioclase–quartz gneiss with trace biotite and magnetite Weathering: fresh Type of sample: 18 pieces >3 cm from 10 layers Interval sampled: 9.5 m across boulder face Weight: 2.92 kg	Lehigh Co. Salisbury Twp. 0.28 km SW of W. Rock Rd. bridge over Pa. Route 309 40º33'29''N 75º27'13''W Collected August 7, 1980	0.10 "mR/hr" 700 counts/sec	22
RP27* LEISTER STONE FENCE Very pale pink K-feldspar–very pale greenish plagioclase–quartz gneiss, trace allanite-(Ce) Weathering: fresh Type of sample: 18 pieces >3 cm from 10 boulders Interval sampled: 10 m along fence Weight: 2.82 kg	Lehigh Co. Upper Milford Twp. N side of Woodlawn Dr., 0.66 km W of Powder Valley 40º28'01''N 75º31'52''W Collected August 5, 1980	0.14 "mR/hr" 550 counts/sec	45
RP28* HOCH-FREDERICK GRANITE QUARRY Pink K-feldspar–greenish plagioclase–quartz gneiss with sparse cm-sized clots of chlorite and garnet Weathering: pristine Type of sample: 62 pieces ≥3 cm Interval sampled: 3.25-m channel one third of the way up the face Weight: 10.64 kg	Lehigh Co. Upper Milford Twp. NE end of quarry N of Churchview Rd., 1.12 km NE of Old Zionsville (Figures 49–53) 40º29'20 ''N 75º30'32''W Collected August 5, 1980	0.15 "mR/hr" 1,300 counts/sec	97
RP29* MARTIN'S LANE ANOMALY Pink K-feldspar–white plagioclase–quartz–magnetite gneiss, trace thorite, two tiny white zircons Weathering: fresh Type of sample: 25 pieces ≥3 cm from 10 boulders Interval sampled: boulders over 30-m interval Weight: 4.14 kg	Lehigh Co. Upper Milford Twp. SW side, 0.38 km NW of St. Peters Rd. 40º29'34''N 75º32'52''W Collected July 30, 1980	0.18 "mR/hr" 650 counts/sec	127
RP30* MOUNTAIN ROAD ANOMALY Tan K-feldspar–quartz–magnetite gneiss with trace molybdenite, apatite, thorite, pyrite, brown resinous mineral Weathering: fresh Type of sample: 18 pieces ≥5 cm from 10 boulders Interval sampled: 20-m N-S line north from iron pipe Weight: 3.77 kg	Berks Co. Earl Twp. Old iron mine 50 m N of road, 0.15 km WNW of Longview Rd. 40º21'47''N 75º42'40''W Collected July 28, 1980	0.15 "mR/hr" 850 counts/sec	121

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP31 JOBST MAGNETITE MINE Actinolite vein rock with chlorite and/or biotite and molybdenite, pyrite, magnetite-ilmenite. See Bromery, Bennett, and others (1959). Weathering: fresh Type of sample: 36 pieces ≥4 cm from 15 boulders Interval sampled: boulders over 27-m interval having molybdenite Weight: 2.98 kg	Lehigh Co. Upper Milford Twp. 120 m NE of Mountain Dr., 2.15 km NE of Vera Cruz 40º31'04"N 75º28'38"W Collected October 20, 1980	0.02 "mR/hr" 60 counts/sec	58
RP32 ROHRBACH PROSPECT CRUSHED Fe-Ti ORE Magnetite-ilmenite ore with biotite-rich gneiss Weathering: fresh Type of sample: silt- to 1-cm-sized particles Interval sampled: 5-m channel sample along NE end Weight: 3.29 kg	Berks Co. Pike Twp. SE of SW end of open cut, 3.3 km NE of Pikeville 40º25'22"N 75º41'49"W Collected October 17, 1980	0.03 "mR/hr" 150 counts/sec	8.6
RP33 ROHRBACH PROSPECT U ORE BOULDERS Gray and white feldspar gneiss with minor biotite and allanite-(Ce), trace zircon, molybdenite, yellow uranium secondary minerals Weathering: fresh Type of sample: 30 pieces ≥4 cm from 10 boulders Interval sampled: boulders along a 150-m line Weight: 2.89 kg	Berks Co. Pike Twp. SE of SW end of open cut, 3.3 km NE of Pikeville 40º25'22"N 75º41'49"W Collected October 17, 1980	0.40 "mR/hr" 2,200 counts/sec	1,210
RP34* SOUTH MOUNTAIN PARK Basal Hardyston Fm. with purple quartz cobbles to 10 cm and thorite to 5 mm Weathering: fresh Type of sample: >100 pieces >1 cm (sand and cobbles) Interval sampled: 10 cm perpendicular to bedding Weight: 2.66 kg	Lehigh Co. Allentown Elevation 12 m below tower, 1.28 km E of Pa. Route 309 bridge over Emaus Ave. 40º33'50"N 75º27'46"W Collected November 24, 1978	0.90 "mR/hr" 580 counts/sec	65

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP35 LARUE DIEHL RANCH Salmon K-feldspar–pale greenish plagioclase–quartz gneiss with minor hornblende, magnetite, allanite-(Ce), trace zircon Weathering: fresh Type of sample: 20 pieces ≥3 cm from 10 boulders Interval sampled: 30 m along and <20 m from fence Weight: 2.78 kg	Lehigh Co. Upper Saucon Twp. Allanite-(Ce)–bearing boulders 25 m SW of the NE pasture corner, 1.5 km NW of Limeport 40º31'20"N 75º27'33"W Collected September 24, 1980	0.06 "mR/hr" 200 counts/sec	8.5
RP36* S. DETURK BORROW PIT TRAIL Pink K-feldspar–gray quartz pegmatitic gneiss with minor magnetite, altered zircon, "leucoxene(?)" Weathering: weathered Type of sample: 14 pieces >4 cm, 36 pieces >2 cm, from 10 boulders Interval sampled: boulders over 15-m interval Weight: 2.66 kg	Berks Co. Oley Twp. E side of trail 0–15 m N of pit, Trails End, 1.0 km W of Oley 40º23'27"N 75º48'11"W Collected October 17, 1980	0.10 "mR/hr" 550 counts/sec	85
RP37 SW CREST CHAPEL HILL Well-foliated salmon K-feldspar–white feldspar–elongated smoky quartz gneiss with garnet, zircon, unidentified resinous mineral Weathering: pristine Type of sample: 12 pieces >6 cm Interval sampled: 65-cm channel perpendicular to foliation Weight: 4.31 kg	Berks Co. Alsace Twp. E. Gottschall tract, 2.07 km SE of Alsace Manor (Figures 38–41) 40º22'58"N 75º51'02"W Collected September 12, 1980	0.30 "mR/hr" 3,000 counts/sec	271
RP38 LEDGE N SCHWEYER'S QUARRY Gray K-feldspar–quartz–green hornblende pegmatitic gneiss with minor epidote, titanite, schorl, trace thorite Weathering: fresh Type of sample: 22 pieces >5 cm Interval sampled: 1.6-m channel perpendicular to foliation Weight: 3.43 kg	Northampton Co. Easton 5 m N of cable anchor, E side of Bushkill Gap 40º42'03"N 75º13'52"W Collected October 22, 1980	0.12 "mR/hr" 1,000 counts/sec	25

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP39 NORTHERN C. K. WILLIAMS QUARRY "SKARN" Green phlogopite with white fibrous tremolite on shears, trace molybdenite, pyrite Weathering: pristine Type of sample: 3 pieces >12 cm Interval sampled: 25-cm channel 1.6 m above floor Weight: 3.26 kg	Northampton Co. Forks Twp. S15ºW-trending face, 2.07 km NNE of confluence of Bushkill Creek and Delaware River (Figures 33–36) 40º42'50"N 75º11'48"W Collected October 10, 1980	0.50 "mR/hr" 3,000 counts/sec	1,080
RP40* BOONE CLUB OPEN PIT Tan and pink K-feldspar–quartz gneiss with minor biotite, trace red resinous mineral Weathering: fresh Type of sample: 17 pieces >5 cm Interval sampled: 10 sites in 10- x 15-m area Weight: 3.29 kg	Berks Co. Exeter Twp. 2.1 km SE of Ohlinger Dam at Antietam reservoir 40º20'52"N 75º50'52"W Collected September 11, 1980	0.16 "mR/hr" 1,050 counts/sec	30
RP41* KNOX AVENUE ANOMALY Fresh rock is probably pink feldspar-quartz gneiss Weathering: soil Type of sample: coarse sand with cm-sized fragments Interval sampled: 3.3 m along horizontal Weight: 2.42 kg	Northampton Co. Forks Twp. SW side, 103–106 m SSE of Paxinosa Rd. W, Chestnut Hill 40º42'26"N 75º13'00"W Collected November 5, 1980	0.12 "mR/hr" 1,050 counts/sec	216
RP42 HACKETT PARK RIDGE NE Brecciated white feldspar-quartz gneiss. Some plagioclase, sparse pink K-feldspar, trace schorl, allanite-(Ce). Weathering: weathered Type of sample: 22 pieces >5 cm Interval sampled: 10 boulders from 4-m length Weight: 3.2 kg	Northampton Co. Wilson Path 12 m W of power line across ridge, 740 m NW of U.S. Route 22 and 13th St. 40º41'58"N 75º14'07"W Collected October 10, 1980	0.07 "mR/hr" 600 counts/sec	6.6
RP43 E LAFAYETTE STREET TALC QUARRY "SKARN" Skarn of talc, phlogopite, and tremolite Weathering: fresh Type of sample: 36 pieces >5 cm Interval sampled: vertical 1.2-m and 0.4-m channels Weight: 4.88 kg	Northampton Co. Easton NE corner of quarry, 0.68 km W of intersection of Cattell and Lafayette Sts. 40º42'16"N 75º12'59"W Collected October 22, 1980	0.10 "mR/hr" 800 counts/sec	30

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP44 W LAFAYETTE STREET TALC QUARRY "SKARN" Skarn of phlogopite, serpentine, and coarse pink to gray calcite with trace pyrite and garnet Weathering: fresh Type of sample: 42 pieces >5 cm Interval sampled: 1.7-m channel perpendicular to bedding Weight: 5.39 kg	Northampton Co. Easton E side cross cut 16 m S of main S wall, 0.87 km WSW of intersection of Cattell and Lafayette Sts. 40º42'14"N 75º13'07"W Collected October 21, 1980	0.10 "mR/hr" 800 counts/sec	63
RP45 PA. ROUTE 309 SAPROLITE GULLY Fresh rock probably pink feldspar-quartz gneiss containing other minerals Weathering: soil Type of sample: coarse sand with cm-sized fragments Interval sampled: 1.85-m and 2.35-m vertical channel Weight: 2.38 kg	Lehigh Co. Allentown N side of Pa. Route 309, 1.08 km E of Emaus Ave. and 16 m above road 40º33'44"N 75º27'50"W Collected September 25, 1980	0.05 "mR/hr" 400 counts/sec	16
RP46* PA. ROUTE 309 PARENT GNEISS Two thirds fine-grained pale pinkish- to greenish-gray feldspar–quartz gneiss and one third pegmatite gneiss, parent to saprolite of RP45 Weathering: pristine Type of sample: 12 pieces >8 cm Interval sampled: 10 places along 1.5-m horizontal Weight: 2.38 kg	Lehigh Co. Allentown N side of Pa. Route 309, 1.08 km E of Emaus Ave. and 5.3 m above road 40º33'44"N 75º27'50"W Collected September 25, 1980	0.07 "mR/hr" 450 counts/sec	22
RP47* PA. ROUTE 309 BASAL HARDYSTON FM. Hardyston Fm. conglomeratic graywacke with major ilmenite, trace weathered thorite Weathering: fresh Type of sample: 20 pieces >5 cm Interval sampled: 45-cm channel perpendicular to bedding Weight: 3.41 kg	Lehigh Co. Allentown S side of Pa. Route 309, 0.97 km E of Emaus Ave. and 2 m above road 40º33'44"N 75º27'54"W Collected September 24, 1980	0.12 "mR/hr" 600 counts/sec	23
RP48* SUNRISE LANE ANOMALY White plagioclase-quartz gneiss with biotite, allanite-(Ce), magnetite-ilmenite, one molybdenite grain Weathering: weathered Type of sample: 22 pieces >5 cm from 10 boulders Interval sampled: 10- x 15-m L-shaped area Weight: 2.46 kg	Berks Co. Douglass Twp. Bank on NW side, 1.63 km NE of intersection with Pa. Route 562 40º19'40"N 75º40'49"W Collected July 23, 1980	0.08 "mR/hr" 200 counts/sec	90

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP49 VERA CRUZ GRANITE QUARRY Gray feldspar-smoky quartz gneiss with accessory magnetite, biotite, trace pyrite, tan metamict mineral Weathering: pristine Type of sample: 14 pieces >8 cm from 10 boulders Interval sampled: 10 boulders on NW dump Weight: 2.75 kg	Lehigh Co. Upper Milford Twp. 0.37 km SW of Acorn Dr. railroad crossing and 1.03 km E of Vera Cruz 40º30'20"N 75º29'05"W Collected September 26, 1980	0.10 “mR/hr” 530 counts/sec	29
RP50* NE EXT. PA. TURNPIKE PEGMATITIC ZONE Pink K-feldspar–gray quartz–hornblende gneiss with common allanite-(Ce), zircon, thorite, bastnaesite Weathering: weathered Type of sample: 1- to 15-cm size Interval sampled: 40-cm channel perpendicular to pegmatite contact Weight: 3.18 kg	Lehigh Co. Upper Milford Twp. SW side of NE Ext. Pa. Turnpike, 1.64 km SE of Chestnut St. 40º30'46"N 75º30'19"W Collected June 5, 1980	0.15 “mR/hr” 1,000 counts/sec	99
RP51* BELLA VISTA ORCHARD LEDGES Pink K-feldspar–gray quartz gneiss with minor greenish plagioclase, rare orange metamict mineral, and allanite-(Ce) Weathering: fresh Type of sample: 20 pieces >5 cm from 10 boulders Interval sampled: 18 m NW-SE along orchard Weight: 3.4 kg	Berks Co. Washington Twp. Saddle between 2 hills, 1.5 km NW of Bally 40º24'20"N 75º36'16"W Collected November 25, 1980	0.11 “mR/hr” 530 counts/sec	12
RP52* SWOVEBERG HILL ANOMALY Pink K-feldspar–pale greenish plagioclase–smoky quartz gneiss, accessory magnetite-ilmenite, uranophane Weathering: fresh Type of sample: 16 pieces >8 cm from 10 boulders Interval sampled: 15-m length <10 m from road Weight: 3.32 kg	Northampton Co. Lower Saucon Twp. N side of Old Springtown Rd., 1.73 km SW of Wassergass (Figures 72–76) 40º34'24"N 75º18'22"W Collected November 26, 1980	0.12 “mR/hr” 700 counts/sec	85
RP53* DILLINGER STATION RAILROAD TUNNEL Gray feldspar-quartz gneiss with minor graphite, rare molybdenite, pyrite, pyrrhotite, gray metamict mineral Weathering: fresh Type of sample: 20 pieces ≥5 cm Interval sampled: 40-cm channel perpendicular to dike contact Weight: 2.46 kg	Lehigh Co. Upper Milford Twp. Outcrop above SE entrance, 2.07 km NNW of Dillingerville 40º29'45"N 75º29'22"W Collected November 28, 1980	0.20 “mR/hr” 1,500 counts/sec	116

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP54 OLAFSEN'S MINE Magnetite-pyrrhotite-hornblende-fayalite gneiss and quartz-almandine-graphite-hornblende gneiss Weathering: pristine Type of sample: 2-cm chips Interval sampled: entire dump Weight: >2 kg	Berks Co. Hereford Twp. 1.5 km NE of Huffs Church 40º27'30"N 75º36'49"W Collected 1976	— —	2.0
RP55 BETHLEHEM PEGMATITE 30-cm-wide dike containing yellowish albite-gray perthitic microcline-quartz-hornblende pegmatite with chevkinite, rare molybdenite, zircon Weathering: pristine Type of sample: 2-cm chips Interval sampled: complete section through 30-cm dike Weight: >2 kg	Northampton Co. Bethlehem W side of Mountain Dr., 3.6 km NW of Hellertown City Hall 40º36'06"N 75º22'28"W Collected 1975	0.03 "mR/hr" 150 counts/sec	0.5
RP56 ANTIETAM RESERVOIR S MOLYBDENITE POD Pyritic, fine-grained granitic gneiss (Smith, 1975b) Weathering: pristine Type of sample: 2-cm chips Interval sampled: few-m-wide Mo-rich zone Weight: >2 kg	Berks Co. Lower Alsace Twp. 185 m SSE of Ohlinger Dam 40º21'14"N 75º52'14"W Collected 1975	— —	89
RP57 QUARRY L, CHANNEL B Phlogopitic serpentine Weathering: fresh Interval sampled: 1.22-m vertical cut Weight: >2 kg	Northampton Co. Wilson 0.8 m N of channel A, 0.6 km NW of U.S. Route 22 bridge over 13th St. (Figures 28–32) 40º41'58"N 75º13'58"W Collected May 22, 1975	0.30 "mR/hr" 4,000 counts/sec	1,130
RP59 MOXON QUARRY FACE COMPOSITE Pegmatitic, salmon-pink albite gneiss; all sheared Weathering: weathered Type of sample: 2-cm chips Interval sampled: 16.8-m and 3.8-m horizontal channel Weight: >2 kg	Berks Co. Oley Twp. 1.14 km SW of Oley 40º23'04"N 75º48'14"W Collected April 14, 1978	0.20 "mR/hr" —	58

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP60 QUARRY L, CHANNEL A Phlogopitic serpentine Weathering: fresh Type of sample: Continuous line of chips Interval sampled: 1.0-m cut Weight: 5 kg	Northampton Co. Wilson 0.8 m S of channel B, 0.6 km NW of U.S. Route 22 bridge over 13th St. (Figures 28–32) 40º41'58"N 75º13'58"W Collected October 3, 1974	0.50 "mR/hr" —	247
RP61 FORGEDALE ROUTE ANOMALY Foliated pink K-feldspar–greenish altered plagioclase–quartz gneiss with chalky red-brown to yellow metamict mineral Weathering: fresh Type of sample: 23 pieces >5 cm Interval sampled: 97-cm channel NE along outcrop Weight: 5.75 kg	Berks Co. Washington Twp. 0.90 km SSE of intersection at Dale, between road and Perkiomen Creek (Figures 44–47) 40º24'22"N 75º36'51"W Collected August 28, 1981	0.12 "mR/hr" 800 counts/sec	51
RP62 LEAKE-ROHRBACH PROSPECT Greenish-gray plagioclase–pinkish-gray K-feldspar–smoky quartz gneiss with minor biotite, trace zircon Weathering: fresh Type of sample: 9 pieces ≥8 cm from 10 boulders Interval sampled: 15- x 15-m area Weight: 3.32 kg	Berks Co. Pike Twp. 25 m SE of tributary to Pine Creek, SE of old crusher 40º25'16"N 75º41'51"W Collected October 7, 1981	0.19 "mR/hr" 1,200 counts/sec	149
RP63 CHAPEL HILL, NW OUTLIER Relatively well-foliated pink K-feldspar–smoky quartz–minor greenish plagioclase gneiss with red-brown metamict mineral Weathering: fresh Type of sample: two 20-cm-long slabs Interval sampled: 30 cm perpendicular to foliation Weight: 4.29 kg	Berks Co. Alsace Twp. E. Gottschall Tract, eastern N-S-trending face of tent-shaped rock (Figures 38–41) 40º23'00"N 75º51'02"W Collected October 9, 1981	0.15 "mR/hr" —	154
RP64* KORN-STELTS ANOMALY Pink K-feldspar–quartz pegmatite with minor leucoxene, abundant yellow metamict mineral, zircon, monazite(?) Weathering: weathered Type of sample: 25 3- to 5-cm chips Interval sampled: <1-m diameter hand-dug hole Weight: 3.44 kg	Lehigh Co. Upper Saucon Twp. 5.5 m NW of reference rock, NW side Applebutter Hill, 1.67 km NE of Limeport (Figures 54–58) 40º31'26"N 75º26'14"W Collected October 9, 1981	0.15 "mR/hr" 1,100 counts/sec	718

Table 23. *(Continued)*

Sample name and description	Sample location	Average radioactivity	Uranium (ppm)
RP65 SWOVEBERG HILL Fine-grained salmon-pink K-feldspar–gray plagioclase–smoky quartz granite with uraninite, magnetite, yellow secondary minerals Weathering: fresh Type of sample: several large blocks Interval sampled: 20 cm E-W perpendicular to joints Weight: 4.14 kg	Northampton Co. Lower Saucon Twp. 5.1 m S79ºE of midmarker in third full row from the south, 1.68 km SW of Wassergass (Figures 72–76, point D) 40º34'28"N 75º18'21"W Collected October 8, 1981	5.00 "mR/hr" 10,000 counts/sec	9,610
RP66 FOOTWALL ZONE BETWEEN QUARRY L AND RAILROAD "SKARN" Host is pink K-feldspar and fibrous green actinolite, with minor calcite, trace schorl, zircon Weathering: fresh Type of sample: titanite separate Interval sampled: 465 in. Weight: >2 kg	Northampton Co. Easton 0.61 km NW of U.S. Route 22 bridge over 13th St., W side Bushkill Gap (Figures 28–32) 40º41'59"N 75º13'57"W Collected November 27, 1981	— —	— —
RP67 FOOTWALL ZONE SCHWEYER'S QUARRY "SKARN" Host is gray feldspar-quartz-actinolite gneiss, minor titanite, trace schorl, epidote Weathering: pristine Type of sample: titanite separate Interval sampled: 127 in. Weight: >2 kg	Northampton Co. Easton 5 m N of cable anchor, E side of Bushkill Gap, 0.64 km NNW of U.S. Route 22 and 13th St. 40º42'03"N 75º13'52"W Collected November 26, 1981	— —	— —
RP68 N RIM C. K. WILLIAMS QUARRY "SKARN" Host is gray K-feldspar–greenish plagioclase–quartz–greenish actinolite, minor titanite Weathering: fresh Type of sample: titanite separate Interval sampled: 168 in. Weight: >2 kg	Northampton Co. Easton Elevation 300 ft, 2.77 km NE of square in Easton 40º42'51"N 75º11'47"W Collected October 8, 1981	— —	— —

APPENDIX 3

ANALYTICAL PROCEDURES

Atomic Absorption and Flame Emission

Major and minor oxides and the trace elements Rb, Sr, and Ba in samples RP1 through RP65 were determined by flame atomic absorption or flame emission, using a procedure based on that of Medlin and others (1969) with minor modifications suggested by N. H. Suhr (personal communication, 1976).

All glassware and plasticware were cleaned in a chromic acid solution. Splits of the nominally minus-200-mesh powdered sample and $LiBO_2$ were heated to 115°C for one hour, then stored in a desiccator. A 0.2000-g aliquot of each sample was thoroughly mixed with 0.8000 g of $LiBO_2$ using an agate mortar and pestle for 10 minutes, then transferred to a pre-ignited graphite crucible. The mixture was fused in a muffle furnace at 1,000°C for 12 minutes, then transferred, while still molten, into 40 ml of 4 percent HNO_3. This was stirred in a polypropylene beaker for 30 minutes using a magnetic stirrer, then this "stock solution" was stored in a polypropylene bottle.

Two dilutions were prepared from the stock solution. One was a dilution of 4 ml of stock with 40 ml of the "lanthanum solution A" of Medlin and others (1969, p. 25), which is prepared from lanthanum nitrate and distilled-deionized water and has a La concentration of 10,680 mg/ml, or approximately 1 percent. The other dilution was prepared by diluting 1 ml of stock with 60 ml of distilled-deionized water.

All standards were prepared in the same manner as the samples. The standards chosen are international reference samples which have been repeatedly analyzed by many laboratories. The values assumed for this study are, in most cases, the average of the values reported by Flanagan (1970) and Abbey (1972) (Table 24).

Samples were analyzed in groups of approximately 7, using the parameters listed in Table 25, with alternation between aspiration of samples and standards. All runs were immediately repeated in reverse order to compensate for drift, and the two readings averaged. Concentrations were determined by hand-plotting absorbance versus concentration of the standards. A new calibration curve was plotted for each group of 7 samples.

The procedure used is the same as that developed for the shale and clay study of O'Neill and Barnes (1979). As a part of that study, complete or partial analyses were performed on 22 international reference rock samples to test the procedure. The results were compared with the commonly accepted values reported by Flanagan (1970) and Abbey (1972) and generally showed good agreement (O'Neill and Barnes, 1979, Table 15).

The precision of the analyses, taken as one standard deviation of the scatter of the standard data points plotted on each side of the calibration curve, is typically as follows: SiO_2, 1.25 percent; TiO_2, 0.02; Al_2O_3, 0.23; total Fe as "Fe_2O_3", 0.03; MnO, 0.006; MgO, 0.01; CaO, 0.07; Na_2O, 0.03; K_2O, 0.04 (all percentages); Rb, 23 ppm; Sr, 6 ppm; and Ba, 13 ppm.

Semiquantitative X-Ray Diffraction

Samples RP1 through RP65 were subjected to a semiquantitative X-ray diffraction procedure in order to determine the approximate percentages of chlorite, mica, potassium feldspar, plagioclase feldspar, quartz, and amphibole. The species of chlorite, mica, feldspar, and amphibole were not differentiated. The potassium feldspar and plagioclase feldspar are taken as microcline and albite, respectively.

The samples were run as pressed 31-mm-diameter pellets, using methyl cellulose as a binder. This method was chosen as it allows a uniformity of packing pressure not obtainable in using standard hand-packed sample holders. The pellets were prepared by mixing a 1.0000-g aliquot of minus-200-mesh sample with 0.2000 g of methyl cellulose for 10 minutes in an agate mortar and pestle. The mixture was placed in the bottom of a 31-mm stainless steel die, with a small margin left around the edge. Five grams of methyl cellulose was then used to fill in the margin and to fill most of the remaining volume of the die. To produce the pellet, the die was placed under pressure in two stages, first to 7,280 lb/in^2 (50,200 kPa), which was held for 10 seconds, then to 36,400 lb/in^2 (251,000 kPa), which was held for 20 seconds. The pressure was released gradually over a 10- to 15-second period.

X-ray data were collected using a diffractometer equipped with a Cu diffraction tube, graphite monochromator, and sealed proportional detector. The data were collected by step-scanning selected 2-theta ranges for each mineral of interest, using a 0.02° stepping increment (Table 26). At each step, a 1-second count was taken and the data transferred to an online microcomputer that stored the data. Later, while offline, the data were recalled from disk and displayed graphically on a CRT. Using an analog input device, the background intensity was determined and nearby peaks were subtracted. The computer then totaled the

Table 24. *Values Assumed for International Reference Samples Used as Standards for Atomic Absorption and Flame Emission*[1]

Element	AGV–1	BCR–1	G–2	GA	GH	GSP–1	JG–1	Mica-Fe	Mica-Mg	NIM–G	NIM–L	PCC–1	T–1	W–1
							Percentages							
SiO_2	59.61	—	69.22	—	75.85	67.32	72.36	34.55	—	75.70	—	42.10	62.70	52.72
TiO_2	1.06	2.26	.48	0.38	.08	.66	.27	2.51	—	—	—	—	—	1.07
Al_2O_3	17.19	—	15.40	14.51	12.51	—	14.20	19.58	—	12.08	—	.73	16.69	15.02
"Fe_2O_3"	—	—	2.67	2.83	1.34	4.28	2.17	25.76	9.49	2.04	—	—	5.91	—
MnO	.096	.180	.034	.083	—	.037	.063	.35	.26?	.018	0.77	—	—	.17
MgO	1.52	3.48	.75	—	.03	.97	.76	4.57	20.46?	.06?	—	43.50	1.89	6.63
CaO	—	6.97	1.96	2.45	.69	—	2.17	—	—	.78	—	—	5.08	10.98
Na_2O	—	—	4.06	3.55	3.85	2.81	—	—	—	3.36	—	—	4.39	—
K_2O	2.92	—	4.46	4.03	4.76	5.51	3.96	8.79	10.03?	4.99	5.51	—	1.24	—
							Parts per million							
Rb	67	—	170	—	390	250	—	2,200	1,300?	—	—	—	—	—
Sr	660	—	480	310	—	240	185	—	—	—	—	—	—	—
Ba	—	—	1,900	850	22	1,300	460	—	—	120?	—	—	—	—

[1] Values derived in part from Abbey (1972, 1980) and Flanagan (1970). Not all standards were used for each element for each sample. See Table 25 for a list of those normally used for each.

Table 25. *Analytical Conditions for Atomic Absorption and Flame Emission*

Element	Method	Lambda (nm)	Flame	Dilution	Standards used[1]
SiO_2	Absorption	251.6	Acetylene-N_2O	1:10 (La "A")	GH, NIM–G, JG–1, G–2, GSP–1, T–1, AGV–1
TiO_2[2]	do.	365.3	do.	do.	AGV–1, GSP–1, G–2, GA, JG–1, GH, blank
Al_2O_3[2]	do.	309.3	do.	do.	AGV–1, T–1, G–2, GA, JG–1, GH, NIM–G
"Fe_2O_3"	do.	248.3	Acetylene-air	do.	T–1, GSP–1, GA, G–2, JG–1, GH
MnO	do.	279.5	do.	do.	AGV–1, GA, JG–1, GSP–1, G–2, NIM–G, blank
MgO	do.	285.2	do.	do.	T–1, AGV–1, GSP–1, G–2, GH, blank
CaO	do.	422.7	do.	do.	T–1, GA, JG–1, G–2, NIM–G, GH, blank
Na_2O	Emission	589	do.	1:60 (H_2O)	T–1, G–2, GH, GA, NIM–G, GSP–1, blank
K_2O	do.	766.5	do.	do.	Mica-Fe, GSP–1, NIM–G, GH, G–2, GA, AGV–1, T–1, blank
Rb[3,4]	do.	780.0	do.	1:10 (La "A")	Mica-Fe, Mica-Mg, GH, GSP–1, G–2, AGV–1, blank
Sr[5]	do.	460.7	Acetylene-N_2O	Stock	AGV–1, G–2, GA, GSP–1, JG–1, blank
Ba	do.	533.6	do.	do.	G–2, GSP–1, GA, JG–1, NIM–G, GH

[1] Additional standards were used when concentrations in samples were beyond the range of these standards. See Table 12.
[2] Preheated burner if possible when analyzing for TiO_2 and Al_2O_3.
[3] Analyzed with wide slit, but fine-tuned wavelength with narrower slit for Rb.
[4] Shielded instrument from indirect sunlight as much as possible when analyzing for Rb.
[5] Cleaned burner head thoroughly with 4 percent HNO_3 before and after analysis for Sr.

Table 26. *X-Ray Diffraction Peaks Used for Semiquantitative Mineralogical Analyses*[1]

Mineral	d (Å)	hkl	2θ scanned
Chlorite group	7.07	002	11.00–13.50°
Mica group	10.1	001	7.00–10.00°
Amphibole group	8.52	110	9.00–12.00°
Quartz	4.26	110	20.00–22.00°
K-feldspar group	2.161	060	41.00–42.50°
Plagioclase feldspar group	3.196	002	26.50–29.50°

[1]Listed d spacings and hkl from the following patterns of the JCPDS-International Centre for Diffraction Data:
chlorite group: clinochlore, pattern 12-242;
mica group: biotite 1M, pattern 2-45;
amphibole group: hornblende, pattern 29-1258;
quartz: quartz, low, pattern 5-490;
potassium feldspar group: microcline, intermediate, pattern 19-932;
plagioclase feldspar group: albite, low, pattern 9-466.
Observed d spacings of Reading Prong samples could vary slightly from these because of differences in chemistry or crystal polytype.

counts recorded for each step, subtracted the counts deemed by the operator to be background or interfering peaks, and arrived at an integrated intensity of the diffraction peak of interest. This intensity was compared with calibration curves to obtain approximate percentages for each mineral.

The standards were 10 mixtures prepared from the materials listed in Table 27. These materials were selected because of similarity with materials observed in rocks of the Reading Prong and because of their relative purity. Table 27 lists the contaminants found in each and the amount of each contaminant, estimated by comparison with a diagnostic diffraction peak in the "pure" standard for the contaminating mineral.

The ranges covered by the standards were selected to approximate the compositions of rock types observed in the Reading Prong by Drake (1969). Table 28 lists the means of the modal compositions observed by Drake and the standard mixture that was prepared to approximate each and still retain a good distribution for the preparation of calibration curves, taking into account the impurities identified in the standard minerals.

The standards were prepared by hand-grinding the pure minerals using a mortar and pestle. The biotite was abraded with a file before the mortar-and-pestle grinding. The mixtures were prepared by weighing on an analytical balance and mixing with an agate mortar and pestle for 15 minutes. Each mixture was then quartered, each quarter ground for 10 minutes in an agate mortar and pestle, and the four quarters were reblended. The total weight of each mixture was 10 g.

Table 26 lists the 2-theta ranges that were utilized for each mineral. These were selected after detailed examination of complete diffraction scans of each mineral under consideration and examination of additional diffraction patterns for these minerals published by the JCPDS-International Centre for Diffraction Data. JCPDS-ICDD patterns for garnet, magnetite, ilmenite, zircon, apatite, and epidote, all considered possible accessory minerals in the Reading Prong, were also checked. Because of the probable presence of iron-bearing accessory minerals, each standard included 1 percent magnetite-ilmenite. This was done not only because of the possibility of interference with diagnostic diffraction peaks, but because of the selective absorption of CuKα radiation by Fe and Mn.

Two of the standard mixtures, number 1 and number 7, were run as unknowns at the beginning and end of the project (Table 29). The results of these runs show approximate agreement with the actual contents of these mixtures.

This method, at best, provides only an estimate of the mineralogical content of the samples. Errors that enter into the procedure include preferred orientation of minerals having good cleavage, which can both enhance the intensity of the oriented mineral and

Table 27. *Materials Used in Standard Mixtures for Semiquantitative X-Ray Diffraction*

Mineral	Material used	Location	Source	Contaminants
Chlorite group	Clinochlore	Cedar Hill, Pa.	R. C. Smith, II[1]	—
Mica group[2]	Biotite	Florissant, Colo.	Ward's[3]	0.6 percent K-feldspar
Mica group[2]	Illite	Fithian, Ill.	do.	4 percent quartz
Amphibole group	Hornblende	Oley, Pa.	RMC527[4]	1 percent chlorite
Quartz	Quartz	Hot Springs, Ark.	Ward's[3]	—
K-feldspar group	Microcline	Amelia, Va.	M1718[5]	2 percent albite
Plagioclase group	Albite	Cedar Hill, Pa.	R. C. Smith, II[1]	5 percent microcline
Magnetite	Magnetite	Fulton Twp., Pa.	do.	~50 percent ilmenite

[1]Personal collection.
[2]Equal quantities of biotite and illite were used for the mica group.
[3]Ward's Natural Science Establishment, Rochester, N. Y.
[4]Pennsylvania Geological Survey, Reference Mineral Collection.
[5]State Museum of Pennsylvania.

decrease the intensity of other minerals by masking. Other errors include sampling errors and variations in mineral crystallinity, polytype, and chemistry.

Table 30 shows the result of a reproducibility test consisting of 10 runs of sample RP6, which is a quartz-feldspar gneiss from the Limeport Road anomaly, Upper Milford Township, Lehigh County. The reproducibility of this sample is better than that of the two runs each of the two standard mixtures, probably reflecting the preferred orientation still present in the mixtures prepared from pure specimens of minerals exhibiting perfect cleavage. The elimination of preferred orientation of micaceous minerals is particularly difficult.

Another measure of precision, the standard deviation of the scatter of the standard mixture data points, is as follows: chlorite, 0.1 percent; mica, 0.3; amphibole, 0.5; quartz, 1.0; potassium feldspar, 2.1; and plagioclase feldspar, 2.4.

Table 28. *Standard Mixtures Used in Calibration*

(Quantities are

	1 Amphibolite		2 Pyroxene gneiss		3 Biotite-quartz-plagioclase gneiss		4 K-feldspar gneiss		5 Oligoclase-quartz gneiss	
	Drake[1]	Mixture[2]	Drake[3]	Mixture	Drake	Mixture	Drake	Mixture	Drake	Mixture
Chlorite group	tr.[4]	5.3	—	3.0	0.5	0.5	—	0.2	—	0.0
Mica group	—	3.9	—	2.0	10.5	10.2	0.5	.5	—	.0
Amphibole group	28.0	29.7	—	5.0	—	.0	—	1.3	1.5	1.0
Quartz	—	.1	1.5	14.0	43.5	43.2	45.5	47.0	25.5	23.0
K-feldspar group	—	3.0	—	22.4	1.5	4.1	50.5	49.0	—	3.8
Plagioclase group	53.0	57.0	55.0	52.6	43.0	40.9	.5	1.0	74.5	71.2
Magnetite[5]	—	1.0	—	1.0	—	1.0	—	1.0	—	1.0

[1] Means of modal compositions observed by Drake (1969) for each rock type.
[2] Mixtures prepared from "pure" minerals to approximate the compositions observed by Drake.
[3] This rock type also contained 28 percent pyroxene, not included in the mixture.
[4] Tr., trace.
[5] Magnetite includes ~50 percent ilmenite.

of Semiquantitative X-Ray Diffraction

in percent)

6 Hornblende granite		7 Biotite granite		8 Alaskite		9 Albite-oligoclase granite		10 Charnokite-quartz diorite	
Drake	Mixture	Drake	Mixture	Drake	Mixture	Drake	Mixture	Drake	Mixture
—	2.1	tr.	1.0	—	0.0	—	1.5	—	0.1
—	1.0	6.5	5.9	—	1.5	—	2.4	0.5	.7
9.5	9.9	tr.	2.0	0.5	1.5	1.0	1.0	.5	.2
24.5	25.0	31.0	31.1	32.5	36.0	27.5	28.0	28.0	20.0
41.0	41.2	37.5	33.6	47.5	47.6	1.0	4.2	—	11.3
18.0	19.8	26.5	25.4	11.5	12.4	63.0	61.8	65.5	66.7
—	1.0	—	1.0	—	1.0	—	1.0	—	1.0

Table 29. *Test of Accuracy of Semiquantitative X-Ray Diffraction Method Using Standards as Unknowns*

(Quantities are in percent)

	Standard 1			Standard 7		
	Test 1	Test 2	Actual	Test 1	Test 2	Actual
Chlorite group	4.9	3.3	5.3	0.8	0.6	1.0
Mica group	2.4	1.5	3.9	5.5	4.6	5.9
Amphibole group	22.6	17.6	29.7	2.0	1.0	2.0
Quartz	.0	.0	.1	40.2	27.7	31.1
K-feldspar group	9.5	11.6	3.0	36.1	22.1	33.6
Plagioclase group	42.2	45.1	57.0	26.3	23.5	25.4
Total	81.6	79.1	[1]99.0	110.9	79.5	99.0

[1]Standards also contain 1 percent total magnetite and ilmenite.

Table 30. *Test of Precision of Semiquantitative X-Ray Diffraction Method Using Sample RP6*

(Quantities are in percent)

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7	Run 8	Run 9	Run 10	Standard deviation
Chlorite group	1.5	1.8	1.9	2.4	2.2	2.0	2.0	2.6	1.6	1.7	0.33
Mica group	.9	.8	1.1	1.2	1.5	.9	.7	.8	1.2	1.0	.23
Amphibole group	.0	.5	.0	.0	.0	.0	.0	.0	.0	.0	.15
Quartz	34.2	35.7	28.3	33.2	31.6	37.2	30.9	34.4	33.2	30.1	2.55
K-feldspar group	21.0	23.7	20.9	21.3	20.9	23.5	21.4	23.3	21.1	19.7	1.27
Plagioclase group	14.8	15.2	14.7	14.3	14.2	15.7	14.7	15.4	15.2	14.3	.48
Total	72.4	77.7	66.9	72.4	70.4	79.3	69.7	76.5	72.3	66.8	

APPENDIX 4

RARE ELEMENTS IN TITANITE FROM CHESTNUT HILL, NORTHAMPTION COUNTY

Introduction

Based on analyses of titanite-bearing rock sample RP38 that indicated approximately 100 ppm Nb, 30 ppm Sn, 700 ppm Y, 25 ppm U_3O_8, and 243 ppm Th, and the report that some titanites from New Jersey contained uraninite inclusions (F. Markewicz, personal communication, 1981), titanite concentrates from three localities were prepared and analyzed. This was done both in search of enrichments of rare elements such as Nb, Sn, and Ta, and to help interpret the role of titanite in the geochemistry of U and Th in the Reading Prong.

The original sample (RP38) consisted of a 1.6-m (5.2-ft) channel sample composite cut perpendicular to foliation. Hand-sample examination of RP38 suggests that it is a gray K-feldspar–quartz–actinolite gneiss with minor epidote, titanite, and black tourmaline, as well as trace red thorite (Figure 78). Its location between the serpentine-phlogopite footwall of Schweyer's quarry and granitic gneiss and the presence of the Ca-rich mineral epidote suggests that it is a hybrid skarn.

Atomic absorption analyses of RP38 indicated 0.28 percent TiO_2, equivalent to a maximum of 0.7 percent titanite, $CaTiSiO_5$, in the bulk rock. This suggests that if titanite were the host mineral for the rare elements, then pure titanite might be enriched by a factor of 100/0.7, or approximately 140, relative to the bulk rock. This would yield titanites with 1.4 percent Nb, 0.4 percent Sn, 10 percent Y and 0.35 percent U_3O_8, not inconsistent with the known ability of titanite from other localities to concentrate such elements (Sahama, 1946).

Samples

Samples of titanite-bearing hybrid contact rocks were collected from three abandoned serpentine quarries along strike on Chestnut Hill, Northampton County, as follows:

1. RP66, from the footwall zone between Quarry L and the railroad cut on the west side of Bushkill Gap, 0.61 km (0.38 mile) northwest of the U.S. Route 22 bridge over Thirteenth Street, Easton, latitude 40°41'59"N; longitude 75°13'57"W (Figures 28–32). Hand samples of the bulk rock appear to consist of pink K-feldspar–fibrous green actinolite gneiss with minor calcite and titanite and trace quartz, black tourmaline, and zircon.

2. RP67, from the footwall zone north of Schweyer's quarry about 5 miles north of the cable anchor, east side of Bushkill Gap, 0.64 km (0.40 mile) north-northwest of the U.S. Route 22 bridge over Thirteenth Street, Easton, latitude 40°42'03"N; longitude 75°13'52"W. This is the exact site from which RP38 was cut. Hand specimens of the bulk rock appear to consist of gray feldspar-quartz-actinolite gneiss with minor titanite and trace tourmaline, epidote, and allanite (Figure 78).

3. RP68, from the north rim of the C. K. Williams quarry, Forks Township, 2.77 km (1.72 mile) northeast of the square in downtown Easton, latitude 40°42'51"N; longitude 75°18'47"W (Figures 33–36). Hand specimens of the bulk rock appear to consist of gray K-feldspar–greenish plagioclase–quartz–greenish actinolite gneiss with minor coarse titanite.

Separation and Analyses

Titanite concentrates from each locality were prepared by hand sorting, panning, tetrabromethane and methylene iodide heavy-liquid separation, and magnetic separation using a Frantz Isodynamic Magnetic Separator. The resulting fractions are summarized in Table 31.

Various titanite fractions obtained by differences in magnetic susceptibility with the magnetic separator were scanned by X-ray fluorescence using a W tube at 50 kV and 45 mA, an LiF(220) crystal, scintillation counter, fine collimator, and scan rate of 1°2θ per minute. Based on the scans of the seven splits for which adequate material was available, the contents of Nb, Sn, U, and Y are believed to be relatively constant in the various magnetic fractions from a given locality.

The titanite concentrates from the magnetic fractions separated using the Frantz at 1.0 ampere were further handpicked and submitted to the USGS for acid digestions and ICP trace-element determinations and delayed neutron activation analyses for Th and U. The analyses are summarized in Table 32.

Discussion

Titanite indeed appears to be the carrier for several of the trace elements, but the high Th/U ratio is such that the recovery of U from these titanites would be inefficient, producing excessive Th waste. Nota-

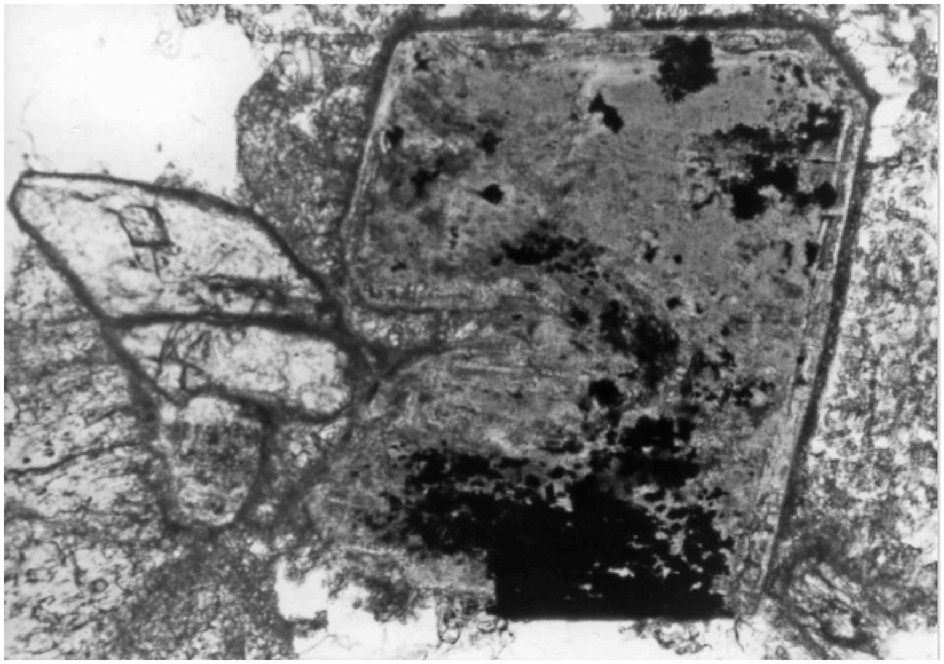


Figure 78. Photomicrograph (123x) of a thin section of sample RP38, from Schweyer's quarry, Northampton County, showing euhedral allanite and titanite.

Table 31. *Summary of Titanite Concentrates Prepared From Three Locations Along Chestnut Hill, Northampton County*

Sample	Titanite color	Amphibole color	Titanite fractions	Fraction at 1.5 A[1]
RP66	Dark brown	Medium dark grayish green	Coarse, hand picked; magnetic at 1.0 A, magnetic at 1.5 A	Bicolor brown and tan zircons and rare smoky white sphalerite
RP67	Light brown	Medium bluish green	Magnetic at 1.0 A, magnetic at 1.5 A	Honey-tan titanite and rare colorless sphalerite
RP68	Medium brown	Dark greenish black	Magnetic at 0.6 A, magnetic at 0.8 A, magnetic at 1.0 A, magnetic at 1.5 A	Pyrite and rare molybdenite

[1] A, ampere.

ble median trace-element contents in the 1-ampere titanite fractions from the three localities are: Nb, 1.4 percent; Pb, 0.24; Sn, 0.27; Ta, 0.30; Y, 0.96; Th, 0.06; and U, 0.02. Comparison with the trace-element contents predicted from the bulk rock composition and estimate of the percent titanite suggest that titanite is the carrier for practically all of the Nb and Sn in these rocks. Based on its geochemical similarity to Nb, the Ta is also probably enriched into the titanite. The low observed Y and U contents of the titanite indicate that these elements are carried in other phases. Y, for example, might be strongly enriched in a rare-earth-bearing epidote tending toward allanite-(Ce), and U might be present in a uranoan thorite in addition to small amounts in zircon, apatite, and other accessory minerals.

Further studies of titanite from marble-gneiss contact zones in the Reading Prong, and especially Chestnut Hill, appear warranted for Nb, Sn, and Ta, but not U. Microscopic inclusions of minerals such as cassiterite, columbite, and ixiolite also may be present within the titanite.

Table 32. *Analyses of 1.0-Ampere Magnetic Fraction Titanite Concentrates From Three Locations Along Chestnut Hill, Northampton County*[1]

Element	RP66	RP67	RP68
Values in percentages			
Al	0.88	1.9	1.6
Fe	1.7	2.2	1.8
Mg	.06	.18	.04
Ca	17	17	18
Na	.07	.03	.07
K	<.3	<.3	<.3
Ti	19	16	18
P	<.03	.03	.03
Values in parts per million			
As	70	<50	80
Au	<40	40	<40
Ba	47	15	21
Be	8	9	9
Ce	2,300	1,800	1,700
Co	50	39	51
Cr	<5	8	8
Cu	100	79	60
La	790	440	450
Mn	750	950	840
Mo	50	170	110
Nb	14,000	14,000	14,000
Ni	10	20	20
Pb	2,500	2,400	2,400
Sc	20	30	50
Sn	2,700	2,500	2,900
Sr	260	170	170
Ta	3,100	2,500	3,000
V	270	150	120
Y	8,800	13,000	9,600
Pr	510	490	450
Nd	2,700	2,700	2,600
Sm	1,100	1,300	1,200
Eu	30	20	30
Gd	4,300	4,800	4,500
Tb	400	500	400
Dy	1,900	2,500	2,100
Ho	350	480	380
Er	940	1,300	1,000
Yb	760	1,200	870
Th	4,250	567	475
U	465	127	168

[1]Moderate Zr detected in each sample by X-ray fluorescence.

APPENDIX 5

MINERAL SPECIES

Table 33. *Some Mineral Species From the Reading Prong Identified by X-Ray Powder Diffraction*

Mineral	Formula	Comment	Sample number
Albite	$NaAlSi_3O_8$	Jobst magnetite mine dump, Lehigh Co.	RP31
Allanite-(Ce)	$(Ce,Ca,Y)_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$	Dogwood Lane anomaly, Bucks Co.	RP14
		Forgedale Route, Berks Co.	near RP16
		Hackett Park Ridge NE, Northampton Co.	RP42
		Limeport Road anomaly, Lehigh Co.	RP6
		NE Ext. Pa. Turnpike pegmatitic zone, Lehigh Co.	RP50
		Rohrbach prospect, Berks Co.	near RP33
Anatase	TiO_2	Cotumas tract, Lehigh Co.	near RP24
Arsenopyrite	FeAsS	Old Zionsville iron mine dump, Lehigh Co. location 281 of Miller (1941)	—
Arsenuranylite	$Ca(UO_2)_4(AsO_4)_2(OH)_4\cdot 6H_2O$	Swoveberg Hill, Northampton Co. thin bright-yellow coating	RP65
Barite	$BaSO_4$	C. K. Williams quarry, Northampton Co.	near RP39
Bastnaesite	$(La,Ce)(CO_3)F$	NE Ext. Pa. Turnpike pegmatitic zone, Lehigh Co.	RP50
Beta-uranophane	$(H_3O)_2Ca(UO_2)_2(SiO_4)_2\cdot 3H_2O$	Hillside Avenue anomaly, Northampton Co.	RP22
		Rohrbach prospect, Berks Co.	RP33
Biotite	$K(Mg,Fe^{+2})_3(Al,Fe^{+3})Si_3O_{10}(OH,F)_2$	Limeport Road anomaly, Lehigh Co.	RP6
		Rohrbach prospect, Berks Co.	RP33
Boltwoodite	$(H_3O)K(UO_2)(SiO_4)$	C. K. Williams quarry (N part), Northampton Co.	near RP39
		Chapel Hill, NW outlier, Berks Co. yellow powder	RP63
		Swoveberg Hill, Northampton Co.	RP52
Carbonate hydroxylapatite(?)	$Ca_5(PO_4,CO_3)_3(OH)$	Jobst magnetite mine dump, Lehigh Co. transparent crystals in actinolite	RP31
Chevkinite(?)	$(Ca,Ce,Th)_4(Fe^{+2},Mg)_2(Ti,Fe^{+3})_3Si_4O_{22}$	Red feldspar layer anomaly, Lehigh Co.	RP10
Chlorite group	$(Fe^{+2},Mg)_5Al(Si_3Al)O_{10}(OH)_8$	Jobst magnetite mine dump, Lehigh Co.	RP31
		Limeport Road anomaly, Lehigh Co.	RP6
		Rohrbach crushed Fe-Ti ore, Berks Co.	RP32

Table 33. *(Continued)*

Mineral	Formula	Comment	Sample number
Diopside	$CaMgSi_2O_6$	Schweyer's quarry, Northampton Co.	RP38
Epidote group	$Ca_2(Al,Fe^{+3})_3(SiO_4)_3(OH)$	Dogwood Lane anomaly, Bucks Co.	RP14
		St. Anthony's Nose, Easton, Northampton Co. east end of Chestnut Hill massive, bluish green, on feldspar and hornblende	—
Ferrimolybdenite	$Fe^{+3}{}_2(MoO_4)_3 \cdot 8H_2O$(?)	Jobst magnetite mine dump, Lehigh Co.	RP31
Ferrohornblende(?)	$Ca_2(Fe^{+2},Mg)_4Al(Si_7Al)O_{22}(OH,F)_2$	Jobst magnetite mine dump, Lehigh Co.	RP31
		Rohrbach crushed Fe-Ti ore, Berks Co.	RP32
Fluorapatite	$Ca_5(PO_4)_3F$	Vera Cruz granite quarry, Lehigh Co.	RP49
Garnet group	$(Fe^{+2},Mg,Mn)_3Al_2(SiO_4)_3$	Chapel Hill, SW crest, Berks Co. a = 11.58Å	RP37
		Dogwood Lane, Bucks Co. a = 11.58Å	near RP14
		Hoch-Frederick granite quarry, Lehigh Co. a = 11.57Å	RP28
		Vera Cruz granite quarry, Lehigh Co.	near RP49
Goethite	$Fe^{+3}O(OH)$	Water Street anomaly, Berks Co.	RP8
Hydroxylapatite	$Ca_5(PO_4)_3(OH)$	Mountain Road anomaly, Berks Co.	RP30
		Schweyer's quarry, Northampton Co.	RP38
		Vera Cruz granite quarry, Lehigh Co.	RP49
Ilmenite	$Fe^{+2}TiO_3$	Jobst magnetite mine dump, Lehigh Co.	RP31
		Rohrbach crushed Fe-Ti ore, Berks Co.	RP32
		Constitution Dr., Salisbury Twp., Lehigh Co. Hardyston Formation	RP5
Jarosite	$KFe^{+3}{}_3(SO_4)_2(OH)_6$	Outcrop above Dillinger Station, Lehigh Co.	near RP53
Lizardite	$Mg_3Si_2O_5(OH)_4$	C. K. Williams quarry, Northampton Co.	near RP39
Maghemite(?)	Fe_2O_3	Forgedale Route anomaly, Berks Co.	RP16
Magnetite	$Fe^{+2}Fe^{+3}{}_2O_4$	Forgedale Route anomaly, Berks Co.	RP16
		Jobst magnetite mine dump, Lehigh Co.	RP31
		Rohrbach crushed Fe-Ti ore, Berks Co.	RP32
		Swoveberg Hill, Northampton Co.	RP52

Table 33. *(Continued)*

Mineral	Formula	Comment	Sample number
Molybdenite	MoS_2	Jobst magnetite mine dump, Lehigh Co.	RP31
		Limeport Road anomaly, Lehigh Co. rare, trace	RP6
Monazite-(Ce)	$(Ce,La,Nd,Th)PO_4$	Moyer Farm, Berks Co.	near RP36
		Stream parallel to Dogwood Lane, Bucks Co.	near RP14
		Swoveberg Hill, Northampton Co. red brown, resinous, with magnetite, uranophane	near RP65
Muscovite	$KAl_2(Si_3Al)O_{10}(OH,F)_2$	Jobst magnetite mine dump, Lehigh Co.	RP31
		Rohrbach crushed Fe-Ti ore, Berks Co.	RP32
Phurcalite	$Ca_2(UO_2)_3(PO_4)_2(OH)_4 \cdot 4H_2O$	Chapel Hill, NW outlier, Berks Co. bright golden coating, rare	RP63
Pyrite	FeS_2	Jobst magnetite mine dump, Lehigh Co.	RP31
Rutile	TiO_2	S. DeTurk borrow pit, Berks Co.	RP36
Thorite	$ThSiO_4$	Forgedale Route anomaly, Berks Co.	RP16
		South Mountain Park, Allentown, Lehigh Co. Hardyston Formation	RP34
		NE Ext. Pa. Turnpike pegmatitic zone, Lehigh Co.	RP50
		Constitution Drive, Salisbury Twp., Lehigh Co. Hardyston Formation	RP5
		Schweyer's quarry, Northampton Co.	RP38
Unknown	Poorly crystalline to noncrystalline	Dillinger Station RR tunnel, Lehigh Co. chalky, cream-colored alteration	RP53
		Dogwood Lane anomaly, Bucks Co. earthy-brown weathering rind on allanite	RP14
		Forgedale Route anomaly, Berks Co. yellow to golden grains with high resinous luster and conchoidal fracture	RP16
		Forgedale Route anomaly, Berks Co. with magnetite, maghemite(?), has subconchoidal fracture, resinous luster	RP16
		Heller's 2 boulders, Lehigh Co. honey-yellow, amorphous, resinous grains	RP23

Table 33. *(Continued)*

Mineral	Formula	Comment	Sample number
Unknown *(Continued)*	Poorly crystalline to noncrystalline	Jobst magnetite mine dump, Lehigh Co. tan oxidation coating with molybdenite and pyrite	RP31
		Limeport Road, float in woods, Lehigh Co. dark grains with conchoidal fracture	RP6
		Pa. Route 611 roadcut, Monroe, Bucks Co. golden brown (Fe-stained[?]) flaky coating	RP3
		Red feldspar layer anomaly, Lehigh Co. tan to yellow with resinous luster and conchoidal fracture	RP10
		Red feldspar layer anomaly, Lehigh Co. brown resinous grains with high luster and conchoidal fracture	RP10
		South Mountain Park, Allentown, Lehigh Co. Hardyston Formation waxy, yellowish-greenish coating on fractures near thorite	RP34
		Vera Cruz granite quarry, Lehigh Co. white micaceous overgrowth on biotite	near RP49
		Vera Cruz granite quarry, Lehigh Co. thin, translucent, red-brown coating on molybdenite	near RP49
Uraninite	UO_2	Swoveberg Hill, Northampton Co.	RP52
	$UO_{2.25}$	Vera Cruz granite quarry, Lehigh Co. a=5.45Å	RP49
Uranophane	$(H_3O)_2Ca(UO_2)_2(SiO_4)_2 \cdot 3H_2O$	C. K. Williams quarry, Northampton Co.	near RP39
		Limeport Road anomaly, Lehigh Co.	RP6
		Swoveberg Hill, Northampton Co.	RP52
Weeksite	$K_2(UO_2)_2Si_6O_{15} \cdot 4H_2O$	C. K. Williams quarry, Northampton Co.	near RP39
Wolsendorfite	$(PbCa)U_2O_7 \cdot 2H_2O$	C. K. Williams quarry, Northampton Co.	near RP39
Xenotime	YPO_4	Echo Ridge Run, Northampton Co., SE side of Morgan Hill, Williams Twp. rare placer grains	—
		Limeport Road anomaly(?)	RP6