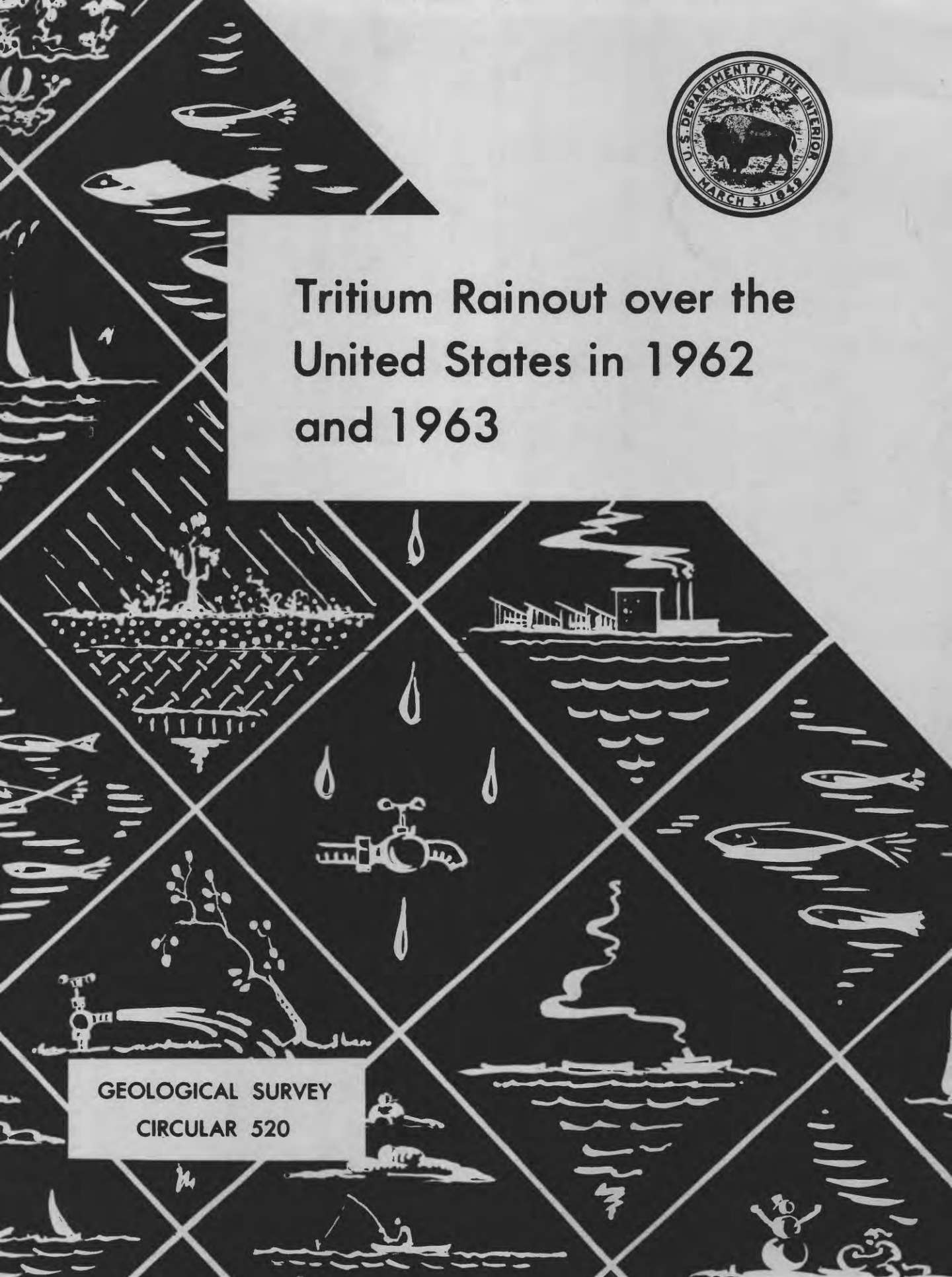
Tritium Rainout over the United States in 1962 and 1963



GEOLOGICAL SURVEY
CIRCULAR 520

Tritium Rainout over the United States in 1962 and 1963

By G. L. Stewart and C. M. Hoffman

Geological Survey Circular 520

Washington 1966

United States Department of the Interior

STEWART L. UDALL, *Secretary*

Geological Survey

William T. Pecora, *Director*

Free on application to the U.S. Geological Survey, Washington, D.C. 20242

CONTENTS

ILLUSTRATIONS

TABLES

Tritium Rainout over the United States in 1962 and 1963

By G. L. Stewart and C. M. Hoffman

ABSTRACT

This report describes the tritium sampling network established by the U.S. Geological Survey. Tritium rainout data are included for 1962 and 1963 precipitation collected at 15 stations in the United States and Puerto Rico.

These data are presented graphically to show seasonal variations and geographic distribution patterns for 1963 tritium rainout. Total tritium rainout during 1963 was considerably higher than it was in previous years. Peak tritium concentrations in late spring or early summer of 1963 were higher by a factor of three or more over concentrations measured in 1962.

INTRODUCTION

In recent years, because of the similarity of its physical and chemical properties with water, tritiated water (HTO) has proved of great value in water dating and tracer applications. Radioactive isotopes are advantageous as water tracers because they can be detected in relatively small concentrations compared to nonradioactive tracers. Tritium, a radioactive isotope of hydrogen, is probably the best radioactive tracer for water because it is incorporated directly into the water molecule, and its 12.26 years half life permits its use in both short- and relatively long-term experiments.

Small quantities of tritium are produced naturally by cosmic radiation in the atmosphere. This tritium eventually becomes oxidized, and it is carried to the earth in the form of rain or snow. The tritium production rate is considered to be quite constant and is the basis for water dating, because the tritium concentration in water is proportional to its age. Various estimates of natural tritium activity in precipitation have been made; these range from 2 to 10 TU[1], the concentration depending upon location with respect to oceanic influences and other meteorologic phenomenon (Kaufman and Libby, 1954, p. 1337; Libby, 1961; Thatcher, 1962).

Since 1952, natural tritium in precipitation has been masked by synthetic tritium placed in the atmosphere by thermonuclear bomb explosions and by nuclear facilities. This synthetic production has resulted in large quantities of tritium being added to the hydrologic environment and has thus produced a tritium pulse valuable for present and future hydrologic investigations.

Since tritium was first introduced as a water tracer (Kaufman and Libby, 1954, p. 1337) in analysis relating to hydrologic problems, several investigations dealing with tritium circulation in the atmosphere and in surface and ground waters have been conducted. In general, these investigations have been quite satisfactory and have further established the potential usefulness of both natural and artificial tritium tracer in hydrologic and meteorologic investigations.

TRITIUM RAINOUT NETWORK

Based upon the premises given above, the U.S. Geological Survey initiated a program in 1958 to measure fluctuating tritium activities in precipitation, which subsequently provides a tag for surface and ground waters. Since that time, precipitation waters have been monitored systematically for tritium activity

[1] 1 TU = 1 tritium atom/10^{18} hydrogen atoms $\cong$ 3.2 pico curies per liter.

by the Survey. Initially, three collection stations were established to monitor tritium on a regular basis, and supplemental data for other locations were provided as required. The observation network was expanded to include 9 stations after the U.S.S.R. broke the 3-year moratorium and resumed nuclear testing in September 1961. To obtain more complete information about tritium rainout patterns and to document tritium data for future work, the network was again revised and expanded in January 1963. It presently includes 15 stations collecting biweekly samples at the following cities: Albuquerque, N. Mex.; Baton Rouge, La.; Bismarck, N. Dak.; Boston, Mass.; Denver, Colo.; Lincoln, Nebr.; Madison, Wis.; Palmer, Alaska; Menlo Park, Calif.; Ocala, Fla.; Portland, Oreg.; St. Louis, Mo.; Salt Lake City, Utah; San Juan, Puerto Rico; and Washington, D.C.

Tritium rainout data reported herein covers a time period from July 1962 to December 31, 1963. These data are almost complete except for a few samples that are missing because of a short discontinuance of sampling during part of July 1962 through March 1963. In March 1963 the station at Albany, N.Y., was discontinued in favor of a station at Boston, which would be more representative of storms originating in the ocean or along the coast.

Precipitation samples were collected in a standard 8-inch U.S. Weather Bureau rain gage. The total amount of precipitation falling during the collection period was measured in the rain gage at the end of the collection period and recorded on the sample container at the time of collection. The network is operated by U.S. Geological Survey personnel of the various district offices. Each precipitation sample represents a biweekly composite of precipitation for the particular region. Precipitation collected in the rain gage is poured into polyethylene containers and shipped to the U.S. Geological Survey tritium laboratory for analysis.

U.S. Geological Survey tritium rainout data before July 1962 are listed in previous reports (Thatcher, 1962; Thatcher and Hoffman, 1963, p. 5899–5901).

ANALYTICAL METHODS

All analytical work was done by the U.S. Geological Survey tritium laboratory in Washington, D.C. Where direct measurement of samples was not feasible, the samples were enriched in electrolysis cells. Most precipitation samples collected during the time period covered in this report were of sufficient tritium activity that electrolytic enrichment was not necessary. In general, higher activity samples were counted directly with a liquid scintillation spectrometer and low activity by a gas-phase counting system employing Geiger-Müller detectors. Counting and electrolytic enrichment methods, except for a few refinements, are the same as those reported earlier (Hoffman and Stewart, 1966).

The statistical counting error was $\pm$ 5 percent or less; the maximum probable analytical error was generally less than $\pm$ 10 percent.

DATA INTERPRETATION

The spring rise and late spring-early summer peak observed in previous years was also characteristic of 1963 precipitation. The two curves on figure 1 are representative of the 1963 tritium rainout pattern. Peak tritium concentrations for areas included in the network were three or more times greater than in 1962. Complete tritium rainout data are not available for 1962 precipitation; therefore, only general comparisons between 1962 and 1963 data can be made. The highest tritium concentration measured for 1963 precipitation waters was 12,950 TU for a sample collected at Denver, Colo. during May 5–18. Salt Lake City, Utah, precipitation for June 2–9 and June 16–30 contained tritium concentrations of 11,450 TU and 10,440 TU, respectively. If individual storms had been monitored for tritium activity, peak values would probably be higher than those reported here.

It is the total tritium rainout, calculated by multiplying the tritium concentration by the amount of precipitation, that is of greatest hydrologic significance. This product gives the total rainout of tritium radioactivity for a given time and ground-surface area in the vicinity of the collecting station (that is, 1 Tu-cm per unit time $\cong 3.2 \times 10^{-3}$ pico curies per cm^2 per unit time). For meteorologic interpretations of tritium rainout data, tritium concentration in individual storms is important. Data for tritium rainout during 1963 for the various stations and 1962 data not previously reported are listed in tables 1 and 2. The "TU-cm" column represents

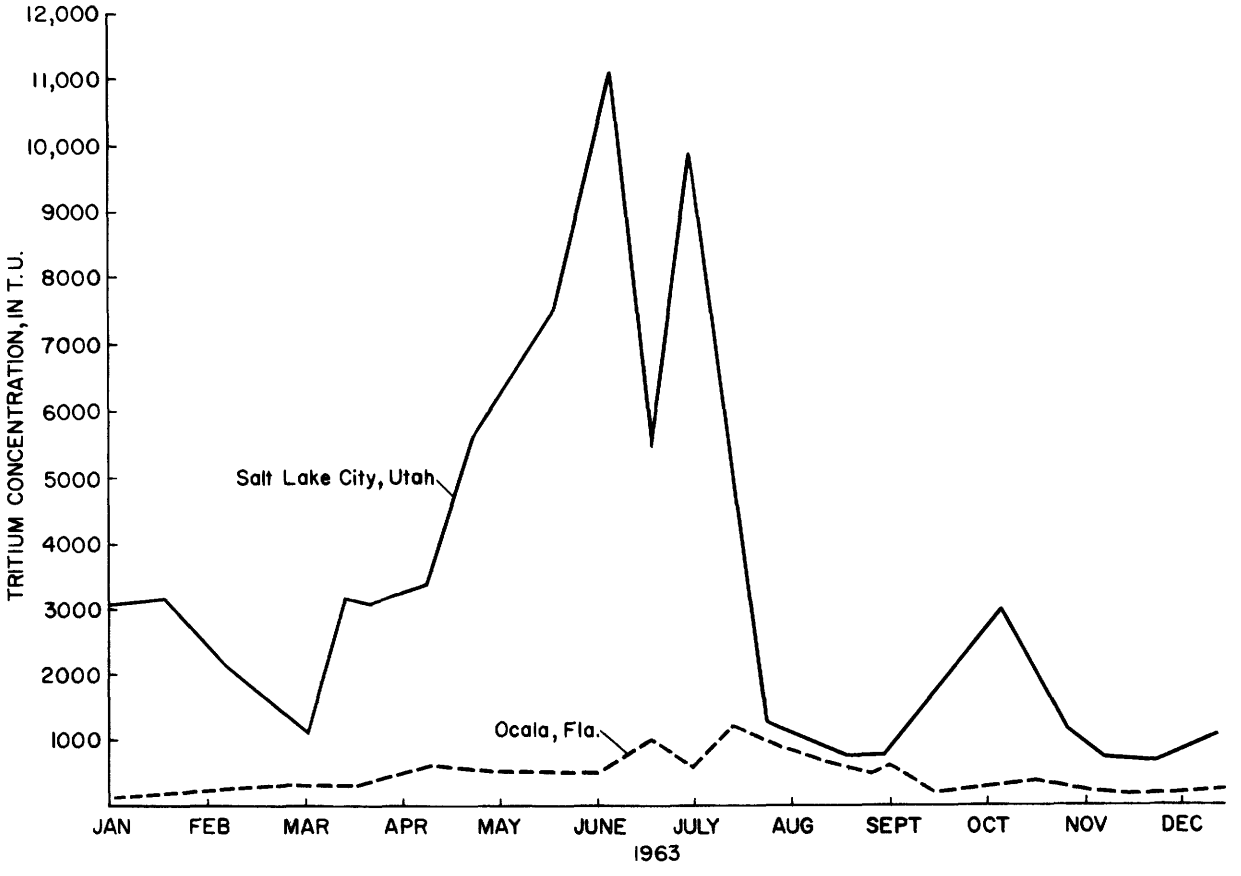


Figure 1.—Tritium concentrations in 1963 precipitation at Salt Lake City, Utah, and Ocala, Fla.

the total tritium rainout per cm^2 of ground-surface area for the collection period specified. For comparison, the 1963 total rainout is given for each location. Where sample collection was not complete, particularly during parts of January and February for a few stations, estimates of tritium rainout were made. These estimates were based upon available tritium data for the location and trends observed at other stations. Because tritium concentrations in precipitation were low during the time when samples are missing, the error introduced by estimating tritium concentrations and amount of precipitation is insignificant when total 1963 rainout weighted-average tritium concentrations are considered. Precipitation amounts for the missing data and for the Denver, Colo., station were estimated from Weather Bureau records. All other precipitation amounts were taken directly from rain gage readings at the collection site. Samples from Denver, Colo., were collected at the Denver Federal Center where precipitation amounts were not recorded but were estimated from Weather Bureau records for the Denver airport about 10 miles away. This introduces an error into computations of total tritium rainout and weighted-average tritium concentration.

The geographic distribution of tritium rainout for 1963 is shown on figures 2 and 3. Because of oceanic influences and other meteorologic phenomena, the tritium concentration in midcontinent precipitation is generally higher than that falling near coastal regions. Weighted-average tritium concentration increases with latitude going from south to north. The relatively low values for total tritium rainout and weighted-average tritium concentrations for Menlo Park are probably due to low rainfall during late spring and early summer when the atmosphere is normally high in tritium. Only 0.08 inch of rain was recorded during May 11 to September 11. Total tritium rainout for Denver and Albuquerque is also lower than expected and is due to low precipitation during the time when tritium in the atmosphere is high. Generally, the data indicate an inverse relationship between the tritium concentration of

Figure 2.—Weighted-average tritium concentration (TU) calculated by dividing the total 1963 tritium rainout (total TU-cm, table 2), by the total amount of precipitation.

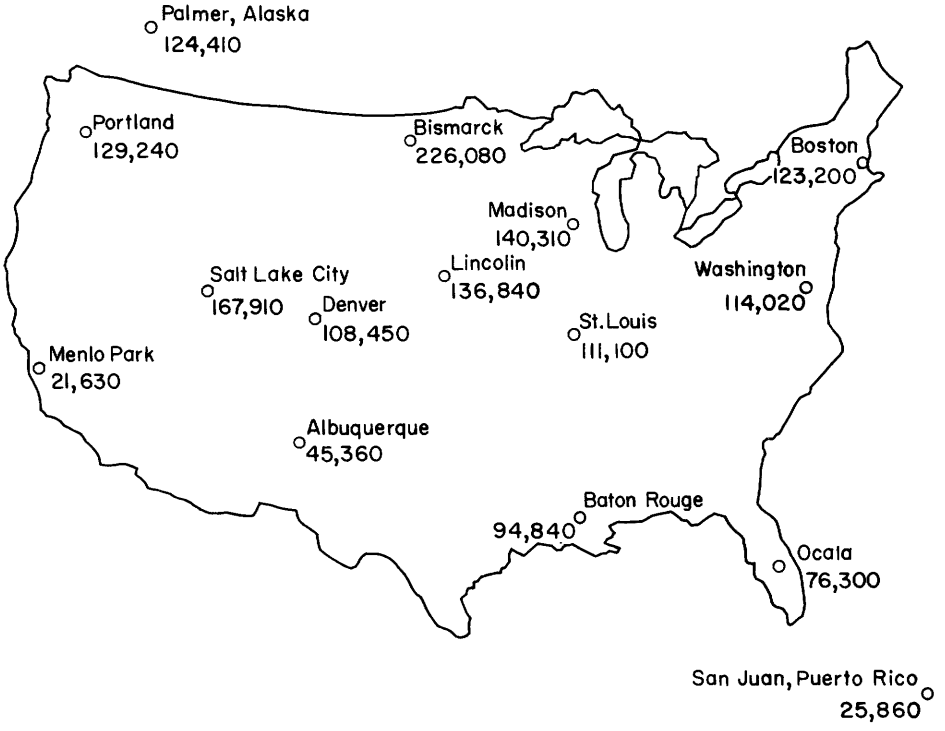


Figure 3.—Total tritium rainout (in TU-cm) during 1963.

precipitation and the amount of precipitation. However, biweekly composites were collected, and this generalization does not always hold because individual storms were not monitored and the precipitation rate of deposition is important.

Although Portland, Oreg., Bismark, N. D., and Boston, Mass., are at about the same latitude, the total tritium rainout at Bismarck is considerably greater than at the other two locations because oceanic influences are not as great and precipitation patterns are different. The relatively low tritium rainout at Palmer, Alaska, is probably due to oceanic influences.

The primary purpose of this report is to document tritium rainout data and to discuss general observations. Subsequent reports will go into more detail on meteorologic influences causing these observed patterns and the hydrologic implications of tritium rainout.

SUMMARY

Locations for 15 sampling stations, collecting biweekly samples for tritium analysis, are listed. Stations in the network were geographically selected to provide representative tritium data for the continental United States, Alaska, and Puerto Rico.

Observations for 1963 tritium rainout are characteristic of previous patterns. A spring rise and late spring-early summer peak was observed for all stations, and the total 1963 tritium rainout was considerably higher than it had been in previous years. Peak tritium concentrations were up by a factor of three or more over 1962 reported values. It was also observed that total tritium rainout and weighted-average tritium concentration increase with northern latitude and that mid-continent values are greater than coastal regions where oceanic influences are important. In some places low tritium rainout is related to low precipitation during times when atmospheric tritium is high.

REFERENCES

Hoffman, C. M., and Stewart, G. L., 1966, Quantative determination of tritium in natural waters: U.S. Geol. Survey Water-Supply Paper 1696-D (in press).

Kaufman, S., and Libby, W. F., 1954, The natural distribution of tritium: Phys. Rev., v. 93, p. 1337.

Libby, W. F., 1961, Tritium geophysics: Recent data and results—a symposium in Vienna, Austria, May 3-10, 1961: Tritium in the Phys. and Biol. Sci., v. 1, International Atomic Energy Agency.

Thatcher, L. L., 1962, The distribution of tritium fallout in precipitation over North America: Internat. Assoc. Sci. Hydrol. Bull., v. 7, no. 2, p. 48.

Thatcher, L. L., and Hoffman, C. M., 1963, Tritium fallout over North America from the Soviet tests in 1961: Jour. Geophys. Research, v. 68, no. 20, p. 5899–5901.

Table 1.—*Tritium rainout data for 1962*

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Albany, N. Y.							
June 26–July 3	0.28	1,240	350	Aug. 29–Sept. 4	3.33	450	1,500
July 4–10	2.62	790	2,070	Sept. 11–18	.81	600	490
July 24	1.52	1,640	2,490	Oct. 2–30	9.73	250	2,430
July 31	1.57	1,160	1,820	Oct. 31–Nov. 28	8.79	370	3,250
Aug. 7–14	3.99	790	3,150	Dec. 4–18	4.77	220	1,050
Aug. 15–21	1.67	1,070	1,790	Dec. 19–26	1.50	1,250	1,870
Albuquerque, N. Mex.							
July 1–29	2.90	570	1,650	Sept. 30–Oct. 27	5.44	300	1,630
July 30–Aug. 4	2.16	560	1,210	Nov. 12–Dec. 2	2.11	390	820
Sept. 9–29	2.46	190	470	Dec. 16–29	1.14	530	600

Table 1.—*Tritium rainout data for 1962*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Lincoln, Neb.							
July 3–30	15.98	1,350	21,570	Oct. 1–31	7.96	400	3,180
Aug. 2–31	13.33	410	5,470	Nov. 1–27	1.75	590	1,030
Sept. 3–30	8.99	380	3,420	Dec. 4–24	1.27	990	1,260
Menlo Park, Calif.							
Oct. 12–14	8.43	70	560	Dec. 3–17	1.55	160	250
Nov. 19–27	.91	190	170				
Ocala, Fla.							
June 28–July 4	3.68	550	2,020	Oct. 4–31	4.17	90	390
July 5–Aug. 1	25.58	400	10,230	Nov. 1–Dec. 5	5.87	200	1,170
Aug. 2–Sept. 5	9.27	160	1,480	Dec. 6–31	3.23	120	390
Sept. 6–Oct. 3	13.69	90	1,230				
Palmer, Alaska							
July 8–Aug. 4	2.24	910	2,040	Oct. 15–29	3.40	340	1,160
Aug. 5–Sept. 2	6.17	560	3,460	Nov. 19	.25	850	220
Sept. 3–30	3.18	540	1,720	Dec. 2–23	1.39	440	610
Portland, Oreg.							
Aug. 6–13	1.96	360	710	Sept. 10	0.38	170	650
Salt Lake City, Utah							
Mar. 7	0.51	1,690	860	May 20	1.90	2,260	4,290
Mar. 10	2.03	1,660	3,370	May 27	3.15	2,460	7,750
Mar. 23	3.00	1,110	3,330	June 3	1.55	2,480	3,840
Apr. 22	--------	3,010	--------	June 10	1.27	2,030	2,580
Apr. 29	2.39	1,040	2,490	June 11–24	.89	4,070	3,620
May 13	.30	1,860	560				
Washington, D.C.							
July 3–25	--------	1,150	--------	Sept. 4	--------	390	-------
Aug. 27	--------	190	--------				

Table 2.—*Tritium rainout data for 1963*

[Items marked with an asterisk (*) indicate no sample collected. Tritium concentration estimated and amount of precipitation taken from Weather Bureau records]

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Albany, N.Y.							
Jan. 1–15	2.70	930	2,510	Jan. 30–Feb. 13	2.95	450	1,330
Jan. 16–22	.41	660	270	Feb. 14–Mar. 4	2.82	1,510	4,260
Jan. 23–29	3.86	1,350	5,210		12.74		13,580
Boston, Mass.							
Mar. 5–18	6.96	620	4,320	Sept. 3–Oct. 16	7.87	1,080	8,500
Mar. 19–30	1.42	1,600	2,270	Oct. 25–Dec. 2	22.71	470	10,670
Apr. 3–11	.91	870	790	Dec. 3–31	9.25	1,280	11,840
Apr. 16–May 13	6.71	2,170	14,560		74.57		109,620
May 14–June 12	5.13	2,590	13,290	Total, Albany			
June 13–July 1	5.00	3,320	16,600	and Boston	87.31		123,200
July 2–Sept. 2	8.61	3,110	26,780				
Albuquerque, N. Mex.							
Jan. 1–5	0.23	1,420	330	July 1–15	1.19	2,520	3,000
Jan. 6–12	.05	1,200	60	July 16–31	1.68	2,140	3,590
Jan. 13–19	.51	2,080	1,060	Aug. 1–15	8.46	2,180	18,440
Feb. 1–15	.74	1,480	1,100	Aug. 16–22	.89	2,410	2,150
Feb. 16–28	.30	2,120	640	Aug. 25–Sept. 5	2.18	1,310	2,860
Mar. 1–15	1.12	1,590	1,780	Sept. 16–30	1.40	1,060	1,480
Mar. 16–31	.96	2,370	2,280	Oct. 16–31	2.41	770	1,860
Apr. 1–15	.68	2,920	1,990	Nov. 1–15	1.12	1,600	1,790
May 15–31	.03	3,690	110		24.23		45,360
June 1–30*	*.28	*3,000	*840				
Baton Rouge, La.							
Jan. 1–Apr. 6	*21.00	*450	*9,450	Aug. 26–Sept. 15	2.51	790	1,980
Apr. 7–June 7	5.23	920	4,810	Sept. 16–22	4.57	380	1,740
June 8–23	9.24	980	9,060	Sept. 23–29	.78	570	440
June 24–July 7	8.53	1,960	16,720	Nov. 4–10	9.73	330	3,210
July 8–13	5.13	930	4,770	Nov. 25–Dec. 1	8.28	190	1,570
July 22–28	12.95	1,980	25,640	Dec. 9–15	10.49	250	2,620
July 29–Aug. 11	7.72	880	6,790		113.80		94,840
Aug. 12–25	9.44	640	6,040				
Bismarck, N. D.							
Jan. 1–Feb. 9	*0.33	*1,000.	*330	Apr. 2–15	3.35	3,690	12,360
Feb. 10–19	.15	1,070	160	Apr. 16–29	1.24	4,400	5,460
Feb. 20–Mar. 3	.91	1,350	1,230	Apr. 30–May 13	*3.18	*4,500	*14,310
Mar. 4–Apr. 1	.99	3,480	3,450	May 14–28	2.49	6,210	15,460

Table 2.—*Tritium rainout data for 1963*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Bismarck, N. D.—Continued							
May 29–June 9	6.86	6,790	46,580	Sept. 2–29	1.42	1,630	2,320
June 10–23	7.85	6,950	54,560	Sept. 30–Oct. 27	3.33	780	2,600
June 24–July 7	5.26	3,740	19,670	Oct. 28–Dec. 8	1.02	1,030	1,050
July 8–20	3.73	3,590	13,390	Dec. 9–22	.76	2,150	1,630
July 21–Aug. 4	5.13	3,930	20,160	Dec. 23–31	.08	1,240	100
Aug. 5–18	2.59	3,450	8,940		51.79		226,080
Aug. 19–Sept. 1	1.12	2,070	2,320				
Denver, Colo.							
Jan. 1–Feb. 9	*1.07	*1,500	*1,610	Aug. 4	1.75	1,520	2,660
Feb. 10–19	1.02	2,060	2,100	Aug. 12–26	4.24	1,490	6,320
Mar. 3–4	1.91	2,220	4,240	Aug. 27–Sept. 8	1.35	1,020	1,380
Mar. 12	2.29	2,840	6,500	Sept. 9–23	2.03	970	1,970
May 5–18	.51	12,950	6,600	Oct. 7–21	2.79	1,210	3,380
May 19–31	1.14	8,130	9,270	Oct. 22–Nov. 4	.41	1,430	590
June 1–14	2.29	5,160	11,820	Nov. 5–18	1.22	1,020	1,240
June 15–16	7.75	5,400	41,850	Nov. 19–Dec. 13	.33	1,490	490
July 8–22	.33	3,380	1,120	Dec. 14–29	.74	2,130	1,580
June 23–Aug. 3	1.24	2,150	2,670		34.82		108,450
Aug. 5–12	.41	2,580	1,060				
Lincoln, Nebr.							
Jan. 1–30	1.63	1,200	1,960	July 2–12	3.63	1,790	6,500
Feb. 10–24	.51	1,520	770	July 16–Aug. 1	3.63	2,520	9,150
Feb. 27–Mar. 12	4.93	1,070	5,280	Aug. 5–12	2.16	1,720	3,720
Mar. 18–25	1.75	1,250	2,190	Aug. 16–27	3.51	2,470	8,670
Apr. 2–10	.84	3,490	2,930	Sept. 1–10	5.89	1,540	9,070
Apr. 15–28	1.68	2,090	3,510	Sept. 16–24	2.99	1,650	4,930
May 4–15	5.92	2,080	12,310	Oct. 16–31	1.83	1,440	2,640
May 16–27	.51	3,460	1,760	Nov. 11–31	.51	1,110	570
June 1–16	1.32	4,150	5,480	Dec. 1–17	.84	1,960	1,650
June 19–26	15.95	3,370	53,750		60.03		136,840
Madison, Wis.							
Jan. 1–Feb. 26	*2.31	*1,500	*3,470	Aug. 1–15	3.48	3,510	12,220
Feb. 27	.71	1,550	1,100	Aug. 16–31	3.17	3,100	9,830
Mar. 1–7	2.36	2,210	5,220	Sept. 1–15	5.56	2,260	12,570
Mar. 8–14	.27	1,680	450	Sept. 16–30	2.57	1,900	4,880
Mar. 15–31	3.28	1,490	4,890	Oct. 1–15	.58	1,450	840
Apr. 1–15	.84	3,690	3,100	Oct. 16–31	.86	1,540	1,320
Apr. 16–30	4.70	2,240	10,530	Nov. 1–15	.91	1,310	1,190
May 1–15	2.06	2,100	4,330	Nov. 16–30	3.96	540	2,140
May 16–31	1.85	4,620	8,550	Dec. 1–15	.68	1,870	1,270
June 1–15	4.80	2,320	11,140	Dec. 16–31	.63	3,140	1,980
June 16–30	4.37	2,550	11,140		55.94		140,310
July 1–18	5.99	4,700	28,150				

Table 2.—*Tritium rainout data for 1963*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
Menlo Park, Calif.							
Jan. 29–Feb. 1	10.52	130	1,370	Sept. 12	0.63	410	260
Feb. 9–16	5.69	410	2,330	Sept. 17	.13	970	130
Mar. 14–31	6.10	870	5,310	Sept. 30–Oct. 14	1.98	290	570
Apr. 10–15	7.31	700	5,120	Oct. 15–28	.81	650	530
Apr. 19–25	1.88	800	1,500	Oct. 29–Nov. 11	1.85	360	670
May 8–10	1.22	1,540	1,880	Nov. 12–25	6.50	280	1,820
July 9	.08	1,770	140		44.70		21,630
Ocala, Fla.							
Jan. 3–30	4.90	140	690	July 18–31	12.95	1,090	14,120
Jan. 31–Feb. 13	9.93	310	3,080	Aug. 1–14	5.05	900	4,550
Feb. 14–27	4.60	170	780	Aug. 15–28	8.51	640	5,450
Feb. 28–Mar. 13	5.05	280	1,410	Aug. 29–Sept. 11	5.49	880	4,830
Mar. 14–27	2.44	250	610	Sept. 12–25	9.65	360	3,400
Mar. 28–Apr. 10	2.64	710	1,870	Sept. 26–Oct. 9	1.47	370	540
Apr. 25–May 8	7.29	660	4,810	Oct. 10–23	.23	510	120
May 9–22	6.32	660	4,170	Oct. 24–Nov. 6	.96	270	260
May 23–June 5	3.99	680	2,710	Nov. 7–20	5.72	180	1,030
June 6–19	4.14	1,420	5,880	Nov. 21–Dec. 4	1.29	310	400
June 20–July 4	6.04	870	5,250	Dec. 19–31	7.59	220	1,670
July 5–17	6.15	1,410	8,670		122.40		76,300
Portland, Oreg.							
Jan. 1–Feb. 3	*12.88	*400	*5,120	Aug. 5–19	0.36	2,750	990
Feb. 4–18	2.62	820	2,150	Aug. 20–Sept. 3	2.08	1,820	3,790
Feb. 19–Mar. 4	2.28	770	1,760	Sept. 4–16	1.65	820	1,350
Mar. 5–18	1.73	1,480	2,560	Sept. 17–Oct. 1	.84	1,280	1,080
Mar. 19–Apr. 1	13.00	1,010	13,130	Oct. 2–15	1.12	840	940
Apr. 2–15	6.57	2,100	13,800	Oct. 16–29	5.03	560	2,820
Apr. 16–29	3.84	1,620	6,220	Oct. 30–Nov. 12	8.84	660	5,830
Apr. 30–May 16	9.39	2,340	21,970	Nov. 13–26	8.56	730	6,250
May 27–June 10	1.09	1,270	1,380	Nov. 27–Dec. 10	4.39	490	2,150
June 11–24	3.63	1,950	7,080	Dec. 11–24	3.94	950	3,740
June 25–July 8	3.96	4,220	16,710	Dec. 25–31	1.95	590	1,150
July 9–22	2.06	3,530	7,270		101.81		129,240
San Juan, Puerto Rico							
Feb. 11–25	3.05	90	270	June 23–30	8.89	420	3,730
Feb. 26–Mar. 14	3.05	200	610	July 2–18	1.42	190	270
Mar. 15–Apr. 1	10.52	200	2,100	July 21–Aug. 1	2.87	170	490
Apr. 2–15	7.23	190	1,380	Aug. 5–22	4.65	170	790
Apr. 16–29	2.24	210	470	Aug. 23–Sept. 5	9.12	220	2,010
Apr. 30–May 13	7.14	220	1,570	Sept. 6–23	5.51	230	1,270
May 14–29	14.35	330	4,740	Sept. 24–Oct. 4	4.90	220	1,080
May 30–June 22	1.90	430	820	Oct. 5–18	4.11	260	1,070

Table 2.—*Tritium rainout data for 1963*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
San Juan, Puerto Rico—Continued							
Oct. 25–Nov. 1	6.65	200	1,350	Dec. 16–31	2.36	190	450
Nov. 2–18	4.88	150	730		109.56		25,860
Dec. 1–15	4.72	140	660				
Salt Lake City, Utah							
Jan. 1–12	*0.20	*2,000	*400	June 16–30	0.20	10,440	2,090
Jan. 13–Feb. 3	2.08	3,100	6,450	July 29–Aug. 4	.53	1,840	980
Feb. 17–24	1.45	2,040	2,960	Aug. 5–11	1.37	1,250	1,710
Feb. 25–Mar. 3	.66	1,090	720	Aug. 19–25	1.42	780	1,110
Mar. 10–17	3.99	3,310	13,210	Aug. 23–Sept. 8	2.82	960	2,710
Mar. 18–24	.25	3,260	820	Oct. 6–13	1.04	3,600	3,740
Mar. 25–31	1.29	3,310	4,270	Oct. 19–27	.94	1,490	1,400
Apr. 1–14	5.77	3,500	20,200	Oct. 28–Nov. 10	3.45	830	2,860
Apr. 15–30	7.34	5,850	42,940	Nov. 11–24	2.57	850	2,180
May 4–12	.58	7,980	4,630	Dec. 8–22	1.57	2,210	3,470
June 2–9	2.84	11,450	32,520	Dec. 23–31	.71	1,430	1,020
June 7–15	2.64	5,880	15,520		45.71		167,910
Palmer, Alaska							
Jan. 1–21	4.57	970	4,430	July 1–15	1.07	7,130	7,630
Feb. 4–14	4.17	1,300	5,410	July 16–22	3.33	6,610	22,000
Mar. 4–12	.56	1,440	810	July 23–29	2.13	4,780	10,180
Mar. 13–18	.25	1,650	410	July 30–Aug. 5	1.12	5,000	5,600
Mar. 19–25	.25	3,130	780	Aug. 12–19	5.33	3,260	17,390
Apr. 8–15	1.47	1,290	1,900	Aug. 20–26	3.76	2,170	8,160
Apr. 16–23	.76	3,640	2,770	Sept. 15–30	1.32	1,300	1,720
Apr. 24–May 13	1.14	3,170	3,610	Oct. 1–7	.81	1,700	1,380
May 14–27	.66	2,980	1,970	Oct. 8–Nov. 13	1.78	1,430	2,550
May 28–June 17	.81	6,210	5,030	Nov. 26–Dec. 9	1.02	1,360	1,390
June 18–24	3.05	3,690	11,250	Dec. 10–23	1.02	980	1,000
June 25–30	1.73	4,070	7,040		42.11		124,410
St. Louis, Mo.							
Jan. 1–Feb. 19	*1.19	*500	*600	Aug. 9–12	2.39	1,420	3,390
Feb. 20–Mar. 7	4.60	640	2,940	Aug. 18–29	4.01	2,450	9,820
Mar. 8–18	3.81	1,490	5,680	Sept. 1–15	2.87	1,660	4,760
Mar. 25–31	5.43	610	3,310	Oct. 1–15	1.68	1,170	1,970
Apr. 13–29	5.03	1,680	8,450	Oct. 16–31	5.56	1,080	6,000
May 1–15	3.81	1,030	3,920	Nov. 1–15	.38	1,070	410
May 16–31	8.30	2,530	21,000	Nov. 16–30	6.99	870	6,080
June 10–13	5.59	1,680	9,390	Dec. 7–11	1.50	840	1,260
June 15–20	4.24	4,200	17,810	Dec. 17–18	.20	3,560	710
July 2–13	1.75	990	1,730		71.06		111,100
July 17–28	1.73	1,080	1,870				

Table 2.—*Tritium rainout data for 1963*—Continued

Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)	Collection period	Amount precipitation (cm)	Tritium concentration (TU)	Tritium rainout (TU-cm)
			Washington, D.C.				
Jan. 1–Feb. 1	*4.83	*500	*2,410	July 4–16	1.52	4,800	7,300
Feb. 2–21	5.84	620	3,620	July 17–Aug. 7	3.43	3,490	11,970
Feb. 22–Mar. 9	3.30	640	2,110	Aug. 8–Sept. 10	15.75	1,500	23,630
Mar. 10–24	9.91	920	9,120	Sept. 11–26	3.05	1,730	5,280
Mar. 25–Apr. 6	2.54	1,100	2,790	Sept. 27–Oct. 9	4.83	540	2,610
Apr. 7–14	.51	2,520	1,290	Oct. 10–Nov. 15	10.80	680	7,340
Apr. 15–30	.89	2,130	1,900	Nov. 16–Dec. 5	9.14	510	4,660
May 1–15	1.27	1,190	1,510	Dec. 6–31	8.38	750	6,290
May 16–June 5	11.22	850	9,540		100.51		113,770
June 6–July 3	3.30	3,150	10,400				

☆ U. S. GOVERNMENT PRINTING OFFICE : 1966 O - 213-782

GEOLOGICAL SURVEY CIRCULAR 521

Mineral Resources of the Grandfather Mountain Window and Vicinity North Carolina

Mineral Resources of the Grandfather Mountain Window and Vicinity North Carolina

By Bruce Bryant and John C. Reed, Jr.

GEOLOGICAL SURVEY CIRCULAR 521

Washington 1966

United States Department of the Interior

STEWART L. UDALL, *Secretary*

Geological Survey

William T. Pecora, *Director*

First printing 1966

Second printing 1967

Free on application to the U.S. Geological Survey, Washington, D.C. 20242

CONTENTS

ILLUSTRATIONS

TABLES

Mineral Resources of the Grandfather Mountain Window and Vicinity, North Carolina

By Bruce Bryant and John C. Reed, Jr.

ABSTRACT

The most valuable and largest mineral resources presently known in the Grandfather Mountain area are gravel, sand, road metal, and building stone. Mica, feldspar, kaolin, iron, titanium, and asbestos have been produced, and additional resources may be available in modest amounts. Uranium, lead, zinc, manganese, gold, and copper occur in small amounts, but no deposits minable under present economic conditions are known.

INTRODUCTION

This circular summarizes the information collected on mineral deposits during a study of the Grandfather Mountain window and vicinity in northwestern North Carolina and presents these data independently of the description and interpretation of the general geology of this large and complex area. The Grandfather Mountain area comprises the Linville, Linville Falls, Lenoir, and Blowing Rock 15-minute quadrangles and parts of the Marion 15-minute quadrangel and the Little Switzerland and Marion East $7\frac{1}{2}$-minute quadrangles. Geologic information on the area is in published geologic maps (Bryant, 1963, 1965; Reed, 1964a, b) and in the open-file map (Reed and Bryant, 1964). Information in this report pertaining to the Linville and Linville Falls quadrangles has previously been published (Bryant, 1962; Reed, 1964b). The specific localities mentioned in this report can be found on the published quadrangles, for many of the geographic features are too small to be shown on figure 1.

SUMMARY OF GEOLOGY

From northwest to southeast the area is composed of the following tectonic units: the Mountain City window, the Blue Ridge thrust sheet, the Grandfather Mountain window, the Brevard fault zone, and the Inner Piedmont (fig. 1).

In the Mountain City window, weakly metamorphosed Lower Cambrian rocks of the Rome Formation, the Shady Dolomite, and the Chilhowee Group are exposed.

The Blue Ridge thrust sheet consists of upper Precambrian schist, gneiss, amphibolite, migmatite, and granitic rock formed during a metamorphic-plutonic event 1,000–1,100 million years ago and intruded by ultramafic rock of early Paleozoic(?) age and leucogranodiorite and pegmatite of early or middle Paleozoic age. These rocks have been metamorphosed one or more times during the Paleozoic. In late Paleozoic time the Blue Ridge thrust sheet moved relatively northwestward at least 35 miles over Precambrian granitic rocks and migmatite and a thick sequence of upper Precambrian sedimentary and volcanic rocks that are now exposed in the Grandfather Mountain window. An intermediate thrust sheet, the Tablerock thrust sheet, occurs above the autochthonous rocks and beneath the Blue Ridge thrust sheet in the southern part of the window. The Tablerock thrust sheet is composed of the Shady Dolomite and rocks of the Chilhowee Group. The rocks in the window and the thrust sheet were pervasively metamorphosed at low grade during the Paleozoic.

The Brevard fault zone, a strike-slip fault of regional extent, truncates the Grandfather Mountain window and the Blue Ridge thrust sheet to the southeast. The fault zone contains slices of exotic rock, and the zone and adjacent rocks showing structural and metamorphic effects related to the faulting form a belt 5 miles wide. Right-lateral movement along the Brevard fault took place in late Paleozoic and early Mesozoic time and may

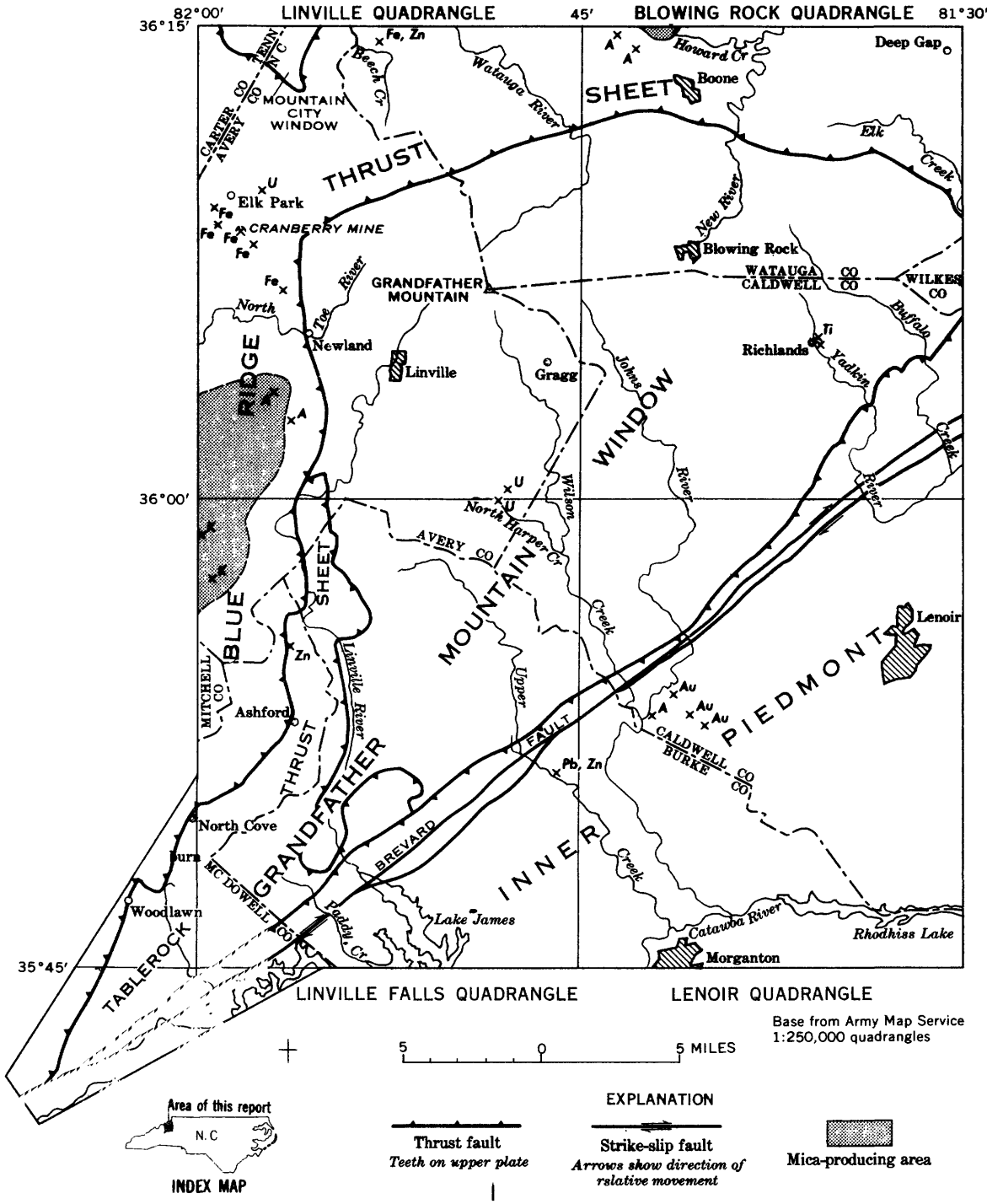


Figure 1.—Generalized map of the Grandfather Mountain area showing location of some of the mineral resources: A, asbestos; Au, gold; Fe, iron; K, kaolin; Pb, lead; Ti, titanium; U, uranium; Zn, zinc.

have been closely related to the northwestward transport of the Blue Ridge thrust sheet.

In the inner Piedmont, which is southeast of the Brevard fault, layered biotite and biotite-amphibole gneiss, mica, and sillimanite schist and concordant bodies of cataclastic augen gneiss of Precambrian or early Paleozoic age have been invaded by granitic rocks of early or middle Paleozoic age and by ultramafic rocks of early Paleozoic(?) age. These rocks were subjected to one or more episodes of metamorphism during the Paleozoic.

METALLIC RESOURCES

IRON

Historically, iron has been an important mineral resource of the Grandfather Mountain area. A belt of iron prospects and mines in the Linville quadrangle extends northwestward from near Newland through Cranberry and about 6 miles west into Tennessee. The principal producing mine in this belt was the Cranberry mine at Cranberry, N.C.

The first published description of the Cranberry deposit, including several analyses of the ore, was written by Kerr (1875) before any extensive mining had been done. Bayley (1923) gave a rather complete review of the literature on Cranberry mine. During the present survey the underground workings at Cranberry were only partly accessible; most of the description, therefore, is summarized from the literature.

The ore mineral is magnetite; the gangue minerals are, principally, pyroxene, amphibole, epidote, quartz, feldspar, and, subordinately, garnet, and calcite. According to Ross (1935), the country rock contains augite and the ore deposits hedenbergite. Other minerals in the gangue include biotite, pyrite, pyrrhotite, sphalerite, and chalcopyrite. The ore is nontitaniferous and low in phosphorus. The iron content is 30–35 percent.

Keith (1903) recognized that the ore occurs in separate lenses peneconcordant with the foliation of the Cranberry Gneiss; he believed that the ore was postmetamorphic. However, Bayley (1923, p. 67, pl. 4) found that the ore and gangue at the Cranberry deposit were sheared, indicating that the mineralization occurred before or during the latest metamorphism. Goldich and Wedow (1943) considered the ore bodies as discus-shaped tectonic lenses. The lenses mined ranged in thickness from a few feet to 200 feet and were as much as 900 feet long. Kline and Ballard (1948, p. 11) referred to an unpublished report by Lucien Easton, which stated that the ore occurs in shoots that strike N. 57° W., dip 30° SW., and are elongate in a S. 70° W., 30° SW., direction of plunge.

Surface float from the Cranberry deposit was mined as early as 1820 (Bayley, 1923, p. 98), but systematic mining did not begin until 1882 when a railroad was completed to Cranberry from Johnson City, Tenn. (Nitze, 1893). In 1884 a small blast furnace capable of handling 40 tons of ore per day was built at Cranberry. After 1900 the ore was shipped to Johnson City where a 100-ton-per-day blast furnace had been built. From 1882 to 1930, about $1\frac{1}{2}$ million tons of ore was produced (Kline and Ballard, 1948). During and after World War II the U.S. Bureau of Mines made a geophysical survey of the Cranberry iron belt, did some core drilling, and processed ore in a pilot plant (Kline and Ballard, 1948). Since 1930 the mine has not been operated except during the Bureau of Mines' test, although in recent years some ore has been salvaged from dump material which has been crushed for gravel.

The Cranberry mine was worked by open-cut; it was also worked underground on two levels by an adit and slopes from the upper level. The workings underlie an area about 3,700 feet long and 700 feet wide (Kline and Ballard, 1948). Goldich and Wedow (1943) estimated that between 450,000 and 600,000 tons of ore might be taken from the mine by robbing the pillars if the mine were abandoned in the process. They estimated that there might be 1–2 million tons of ore below the present mine workings. Kline and Ballard (1948, p. 85) believed that there are more ore shoots at Cranberry like those already mined, and possibly others elsewhere along the iron-bearing belt.

Other iron prospects in the Cranberry belt in the Grandfather Mountain area have had negligible production, and many are overgrown and difficult to locate. The U.S. Bureau of Mines conducted magnetometer surveys in the Fork Mountain area northwest of Newland and along a strip from the Cranberry

mine to the Tennessee Stateline. One magnetic anomaly was drilled about half a mile west of Elk Park; as much as 44.5 feet of ore having more than 30 percent total iron content over a length of 52.5 feet was found in one hole (Kline and Ballard, 1948), but the other drill holes suggest that ore of that thickness and grade is of limited extent to the depth of 250–440 feet tested.

The origin of the Cranberry deposits is not really known. Keith (1903), who recognized that replacement played an important role in their genesis, attributed the iron-bearing solutions to the Bakersville Gabbro and suggested the Roan Gneiss (his name for the amphibolites) as a possible source of the iron. Bayley (1923) thought that the iron deposits were formed by intrusion of magmas composed of (1) magnetitic pyroxene pegmatite, (2) pyroxene-magnetite, and (3) magnetite. He also thought that the material of these intrusives originated by differentiation from Precambrian or upper Precambrian mafic magmas.

Megascopic and microscopic textures (Bayley, 1923; Ross, 1935) show that the magnetite and iron-rich silicates replaced the wallrock—probably during the plutonic metamorphism when the Cranberry Gneiss was formed—because the ore is cut by pegmatite and because both the ore bodies and pegmatite were sheared and partly metamorphosed to low grade along the wallrock. The ore has zones which lack much cataclasis and retrogression. The lenses as a whole may be largely tectonic in their present distribution and shape. The linear distribution of the mines and prospects in the Linville quadrangle and 6 miles west into Tennessee suggests that their present position is related to Paleozoic tectonism, for they are subparallel with the boundary between rocks of low and medium-grade Paleozoic metamorphism. This boundary may be major thrust fault of Paleozoic age. Neither the distribution nor any possible stratigraphic or tectonic control on the emplacement of the ore deposits before the pervasive shearing is known. Any theory for their origin would be highly speculative. Perhaps the deposits were derived by segregation of iron from amphibolites and schists when those rocks were converted to Granberry Gneiss during the plutonic metamorphism.

In the northern part of the Linville quadrangle, near Big Ridge, phyllonite zones in Cranberry Gneiss of the Blue Ridge thrust sheet contain magnetite, hematite, and small amounts of sphalerite. Concentrations of hematite with or without magnetite are abundant in phyllonite zones in the Cranberry Gneiss throughout its outcrop area, but they are generally less than 10 feet thick and 100 feet long. Some of the concentrations have been explored.

Hematite is also locally concentrated in phyllonite in the Wilson Creek Gneiss near Tar Ridge in the Blowing Rock quadrangle. We located only one of the four prospects mentioned by Nitze (1893, p. 118–119).

TITANIUM

A deposit of ilmenite and magnetite in the Wilson Creek Gneiss near Richlands in the Blowing Rock quadrangle has been known for a long time (Kerr, 1875). Selected ore contained as much as 41.21 percent TiO_2, but the average was 14.90 percent TiO_2 and 36.00 percent metallic iron (Nitze, 1893). The deposit was mined from 1942 to 1952 by the Yadkin Valley Ilmenite Co., a subsidiary of the Glidden Co. About 230,000 tons of titanium concentrates was produced.

The ore body consists of a series of narrow, closely spaced lenses forming a nearly continuous vein which is about 1,000 feet long, and which, as shown by core drilling, extends to a depth of about 200 feet. Mining was discontinued after soft ore near the surface was removed.

The main part of the mine is an open pit 50–100 feet deep and about 400 feet long. Its bottom is near the level of the Yadkin River. The ore body trended N. 15° E. and dipped 25°–45° SE. The ilmenite and magnetite occur in a gangue of epidote, amphibole, chlorite, biotite, talc, and accessory pyrite. Talc and biotite form segregations. The deposit has sharp contacts with partly layered cataclastic gneiss. The foliation in the gangue material and the enclosing gneiss is parallel. The ore contains concordant wisps of more felsic gneiss 1 inch to 4 feet long and as much as 3 inches thick. Locally, thin stringers rich in ilmenite are found in the wallrock.

In thin section a specimen of gneiss, which was included in the ore and which resembles typical Wilson Creek Gneiss, contains crystals and fragments of crystals of plagioclase

altered to albite from the originally coarser grained granitic rock in a matrix of recrystallized albite, quartz, biotite, epidote, and chlorite.

The ore body parallels the regional structural trend of both Paleozoic and Precambrian structural and lithologic elements in this area of the Grandfather Mountain window. The ore apparently replaced the Wilson Creek Gneiss along a linear zone and is younger than the gneiss, which was emplaced 1,000–1,100 million years ago (Davis and others, 1962). The ore has been sheared along with the country rock and is pre-late Plaeozoic in age. The iron and titanium may have been derived from preexisting rock and segregated during the plutonism, but their source is unknown.

A similar, but low-grade, ore body three-quarters of a mile to the southeast was reported by Hunter and Gildersleeve (1946, p. 81). It consists of ilmenite mixed with chlorite and serpentine minerals, and is as much as 25 feet thick and 3/4 mile long.

URANIUM

There was considerable prospecting for uranium in the Grandfather Mountain area in the middle 1950's, but no minable deposits were found. The areas of greatest activity were in the Wilson Creek Gneiss in the Linville Falls and Linville quadrangles and in the Cranberry Gneiss north of the window in the Linville quadrangle. Radioactive minerals were prospected in (1) heavy mineral partings rich in zircon in the clastic rocks of the Chilhowee Group in the tectonic slices north and west of the window and in arkoses of the Grandfather Mountain Formation within the window; (2) small pegmatites (mostly less than 10 ft in diameter) in Cranberry Gneiss, especially in pegmatites rich in biotite and quartz; and (3) strongly sheared and phyllonitic zones in the Wilson Creek Gneiss.

The most promising of the three occurrences is that in the Wilson Creek Gneiss. The principal prospects were on Ripshin Ridge near North Carolina Highway 181 in the Linville Falls quadrangle, north of the road between Edgemont and Pineola in the Linville quadrangle (the Little Lost Cove prospect), and on and near North Harper Creek at and north of the boundary between the Linville and Linville Falls quadrangles. These prospects were stripped and trenched, and the North Harper Creek deposit was core drilled.

The most abundant uranium minerals occur in scattered uraninite-filled joints in sheared pegmatites in phyllonite zones. The joints commonly dip steeply and strike almost parallel to the regional northwest-trending mineral lineation in the wallrocks. The joints are poorly developed in the surrounding phyllonite and are sparsely mineralized or barren in the phyllonite (fig. 2). Secondary uranium minerals are disseminated in the phyllonites; but their distribution is spotty, and the phyllonite zones themselves are discontinuous.

The following information concerning claims on the Wilson Creek Gneiss is summarized from unpublished data compiled in 1955 and 1956 by S. J. Meliherscik of E. J. Longyear Co.

The uranium-bearing mineral in the phyllonites is torbernite. Selected samples from phyllonites contained as much as 0.28 percent

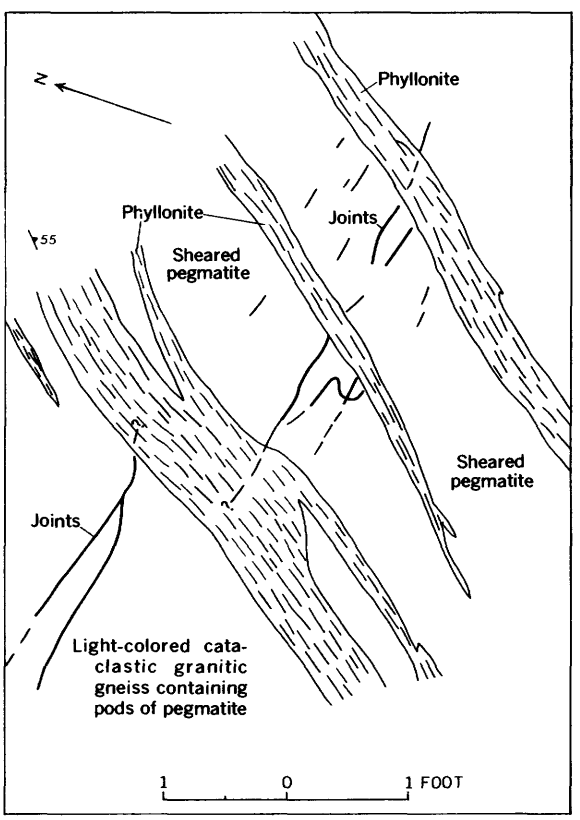


Figure 2.—Uraninite veinlets at the foot of Bard Falls on North Harper Creek, Linville quadrangle. View downdip of foliation. Mineralized joints shown as heavy lines.

U_3O_8. The prospects in phyllonite on Ripshin Ridge and Little Lost Cove were explored by bulldozer cuts. At Ripshin Ridge the radioactive rock was destroyed by the first cut of the bulldozer, and no more could be located in a pit 20 by 100 by 15 feet. Bulldozing at the Little Lost Cove anomalies showed that there the phyllonite lacked horizontal and vertical continuity. The torbernite showings were interpreted as resulting from near-surface weathering and secondary enrichment of disseminated uraninite.

The best surface showing is at North Harper Creek just below Bard Falls (fig. 3). The average analysis of 6 samples cut at 10-inch intervals across the showing was 1.01 percent U_3O_8. These samples contained

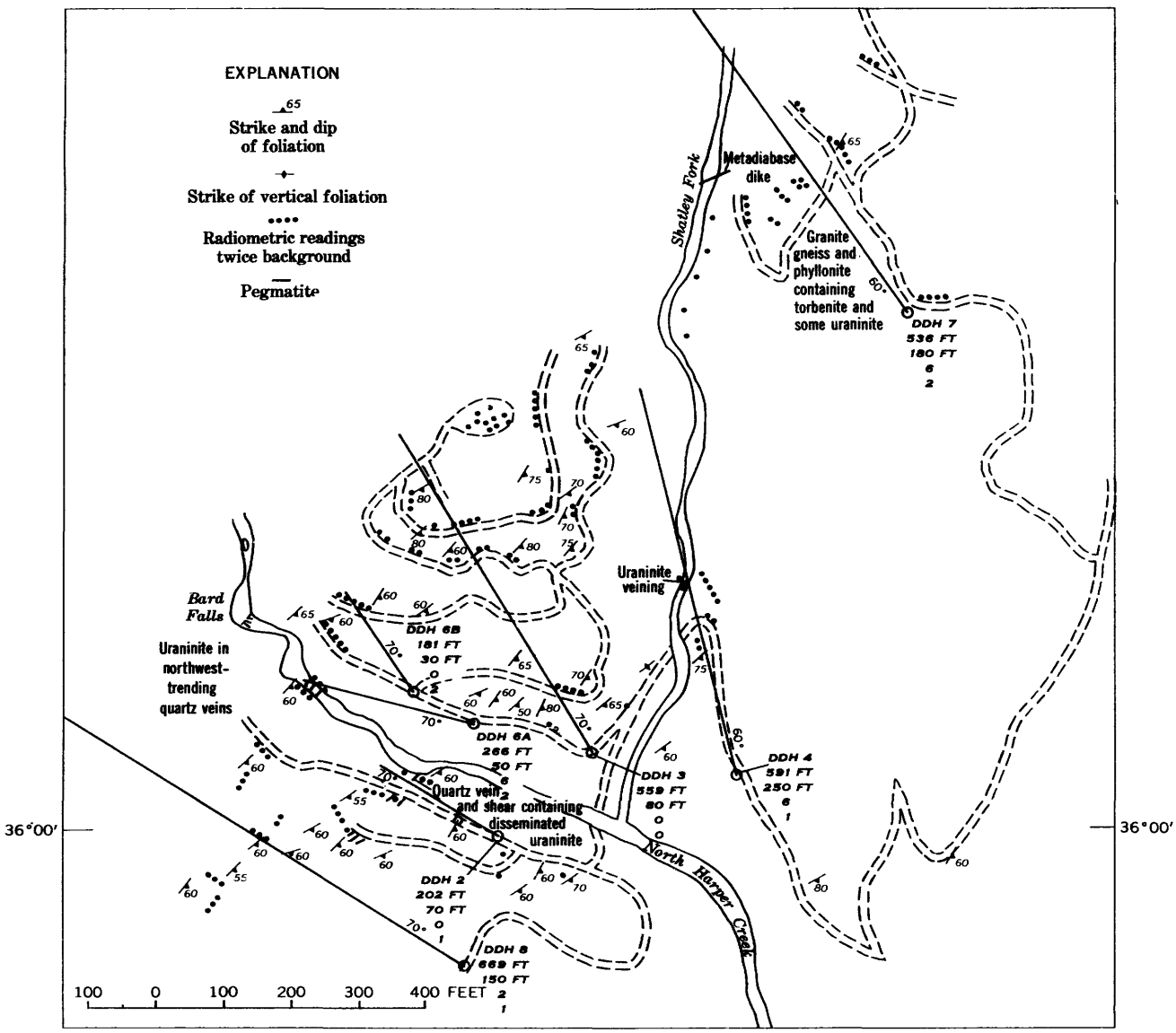


Figure 3.—Map of uranium prospects on North Harper Creek showing locations of diamond-drill holes and surface radiometric anomalies. Lengths of lines of drill hole represent approximate projection of hole to surface along foliation planes. Numbers indicate, in descending order, length of hole, thickness of pegmatite in hole, number of uraninite-bearing veins penetrated, and number of radiometric anomalies indicating 0.1 percent U_3O_8 in first 500 feet of hole. From map by E. J. Longyear Co.

a trace of gold, silver, and ThO_2, and about 0.1 percent copper. Channel and chip samples over a 4-foot width in brecciated granitic rock in Shatley Fork averaged 0.23 percent U_3O_8. The country rock has a radioactivity 1.5 times background.

In addition to the obvious northwest-trending veinlets, some paper-thin veinlets of uraninite occur on shear planes parallel to the regional structure. Pyrite, pyrrhotite, and chalcopyrite are also found on thin seams parallel to the foliation. Uraninite is also disseminated in a pegmatite about 350 feet downstream from Bard Falls.

Seven holes, totaling 3,055 feet, were drilled inclined steeply to the northwest (fig. 2) in order to intersect the zones of more sheared rock and phyllonite, which are parallel with the regional structural trend. They intersected the pegmatites which occur as tectonic lenses in and parallel to the zones of phyllonite and strongly sheared gneiss and the very thin seams of uraninite which are parallel with the shear planes. However, as the prominent minerals in the surface showings are in veins trending northwest parallel with the drill holes, the principal uranium-bearing structures were not intersected. Ratioactive logging showed only a few anomalies exceeding 0.1 percent U_3O_8.

Drilling and detailed surface mapping indicated that it was difficult to draw contacts between phyllonite, sheared gneiss, and less sheared granitic rock. These subdivisions are not continuous along strike or downdip.

According to our interpretation, the uranium mineralization occurred during and immediately after the Paleozoic retrogressive metamorphism of the Wilson Creek Gneiss. The high background readings on that rock unit suggest that the showings formed by local mobilization of uranium during the metamorphism and concentration in shear zones in the gneiss and joints in the pegmatities, which formed relatively brittle competent lumps in the shear zones.

GOLD

A few small gold prospects and mines are found on quartz veins in the rocks of the Inner Piedmont. At the time of our survey these workings were either overgrown or inaccessible. According to Bryson (1936, p. 136), the quartz veins of the South Mountain region, including the southern part of the Grandfather Mountain area, are generally too small to be worked profitably for gold, and no vein in the South Mountain region has ever been worked on a large scale.

Many of the gold prospects are northeast of, and alined parallel to, the northwest-trending diabase dike in the Lenoir quadrangle. However, Nitze and Wilken (1897) reported that the quartz veins in several of the prospects strike N. 50°-60° E. and are 8–10 inches thick, although in the Baker mine the vein strikes N. 35°-45° W. and is 2–5 feet thick. The prospects we saw are in the belt of polymetamorphic rocks adjacent to and southeast of the Brevard fault.

The most recent prospecting has been near the Miller and Scott Hill mines on Celia Creek in the Lenoir quadrangle. There the small growth on the dumps and the state of preservation of the headframe suggest that work has been done since 1936.

Keith (1903) reported that a quartz vein containing gold-bearing pyrite was mined on the north side of Grandfather Mountain in the Grandfather Mountain window in the Linville quadrangle and that similar veins were prospected on the east side of the mountain. Several of these old prospects, at which little or no work has been done in this century, were located in our survey. Most of the prospects are in sericite phyllite and phyllitic siltstone containing quartz veins and lenses and some pyrite. Two prospects are in phyllonitic gneiss on the ridge south of Bellows Creek in the Linville and Blowing Rock quadrangles.

Placer mining has yielded small amounts of gold on the Blue Ridge upland on Howard Creek in the Blowing Rock quadrangle and near Gragg in the Linville quadrangle (Keith, 1903).

ZINC AND LEAD

Disseminated sphalerite associated with small amounts of cuprite, chalcopyrite, pyrite, and some secondary copper minerals is found in the Shady Dolomite of the Tablerock thrust sheet near Linville caverns in the Linville Falls quadrangle. The ore minerals with quartz and calcite occur in veinlets and irregular replacements in dolomite. One small prospect trench has been opened on the hillside, and in 1943–44, four holes were

diamond drilled. No further exploration was done between that time and 1958.

Selected samples from old iron prospects in phyllonite zones in the Cranberry Gneiss on Big Ridge north of Beech Mountain in the Linville quadrangle contain interesting amounts of zinc. The zinc occurs in black sphalerite associated with sericite, magnetite, epidote, albite, fluorite, chlorite, quartz, and accessory apatite and carbonate. No significant amount of copper or lead accompanies the zinc (table 1). A brief examination of surface exposures and the prospects suggest that the sphalerite has a spotty distribution; no minable bodies were seen.

Analysis of a somewhat mineralized graphitic phyllonite, from a graphite prospect south of Dark Ridge Creek in the Cranberry Gneiss lying above the Mountain City window but below the Blue Ridge thrust sheet, revealed 0.1 percent zinc and no unusual amounts of Pb, Cu, or Ni.

Galena reportedly was mined on the ridge where Buckeye Creek turns east to join Beech Creek in the Linville quadrangle (Keith, 1903). A shaft was still visible in 1957, but no lead minerals were found in the phyllonite on the dump.

Galena, in euhedral cubes as much as 5 mm across, and small amounts of chalcopyrite and sphalerite were found in a 25- to 30-foot-thick vein of granular quartz on the north side of Upper Creek in the Linville Falls quadrangle. The vein strikes northeastward parallel to the foliation of the enclosing schist and gneiss of the Piedmont. It is exposed in several prospect pits over a distance of 200 feet; but no recent work has been done, and the pits are slumped and overgrown. Reportedly, the galena carries small quantities of silver.

Reports of the occurrence of native lead are widespread in the area, but no specific localities are mentioned. Such reports have a long history, for Elisha Mitchell (1905), who visited the area in 1828, heard them and recorded in his diary: "Such in substance is the account that I received in so many different places and from so many different persons that I am ready to knock down the man who shall tell the tale again."

MANGANESE

Botryoidal psilomelane, clayey pyrolusite, and ocherous wad occur in alluvial and colluvial clay which caps a small quartzite knob 0.5 mile S. 20° W. of the village of North Cove (formerly Pitts Station) in the Linville Falls quadrangle. The clay contains lenses of gravel. D. A. Brobst (written commun., 1960) estimated that the manganiferous clay is at least 30 feet thick and that it is covered by a soil mantle 5–10 feet thick. Some prospecting and development work was done on the deposit between 1943 and 1950, and several carloads of ore were shipped. All the opencuts and small adits described by Brobst were caved, and the workings were partly overgrown at the time of our visit in 1959.

Concentrations of manganese oxides a few inches thick are locally found in alluvium and fan deposits.

COPPER

The Montezuma Member of the Grandfather Mountain Formation contains copper minerals at scattered localities. Malachite is the copper mineral more commonly visible in

Table 1—*Metal content, in percent, of selected specimens from iron prospects on Big Ridge, Linville quadrangle*

[Spectrographic analysis by J. C. Hamilton. Results are reported in percent to the nearest number in the series 1, 0.7, 0.5, 0.3, 0.2, 0.15, and 0.1, etc., which represent approximate midpoints of group data on a geometric scale. The assigned group for semiquantitative results will include the quantitative value about 30 percent of the time. M, major constituent, > 10 percent]

Lab. No.	Field No.	Fe	Ti	Cu	Ni	Pb	Zn	Description
291880	G-70-1-b	5.0	0.2	0.015	0.01	0.002	0	Phyllonite containing pyrite.
291881	G-70-1-d	M	.05	.05	.0015	.005	2.0	Mineralized phyllonite.
291882	G-71-1-a	M	.07	.02	.0015	.02	M	Do.

Table 2.—*Copper content of samples of Montezuma Member of the Grandfather Mountain Formation*

[Determined by colorimetric method by Dwight L. Skinner]

Lab. no.	Field no.	Source	Cu (ppm)
271275	RE-71-1	Outcrop	10
271276	AC-14-1	do	16
271277	H-5-3-e	Prospect; no obvious evidence of copper minerals in specimen.	38
271278	H-5-5	Outcrop; evidence of copper mineralization nearby	88

hand specimen; it occurs in amygdules, along fractures, and in epidote segregations. Azurite also occurs but is less abundant. No extensive area of mineralized rock of ore grade has yet been found. Analyses (table 2) show that the copper content of the Montezuma Member is very low, even in areas containing visible copper minerals. Several prospects were found in the upper part of the valley of Pigeonroost Creek in the Linville quadrangle.

NONMETALLIC RESOURCES

MICA AND FELDSPAR

Both sheet and scrap muscovite has been obtained from the granodiorite pegmatites of the Blue Ridge thrust sheet in the Grandfather Mountain area. Most of the production has come from the southwestern part of the Linville quadrangle and the northwestern part of the Linville Falls quadrangle. This area is part of the Spruce Pine pegmatite district. Most of the productive pegmatites occur in the mica schist and gneiss unit, some in the amphibolite, a few in the granodiorite, and a very few in the unit of mixed rocks. No pegmatites containing commercial muscovite have been found in the Cranberry Gneiss.

Some mica has been produced from pegmatites in mica schist and gneiss north of Boone in the Blowing Rock quadrangle. The prospects near Deep Gap do not appear to have been very productive. A few mica prospects and one mine reportedly are in rocks of the Blue Ridge thrust sheet southeast of the window in the Blowing Rock quadrangle, but we did not visit them.

Various mines in the Grandfather Mountain area have been described (Sterrett, 1923; Kesler and Olson, 1942; Olson, 1944; F. G. Lesure, written commun., 1964), and the economic geology of the pegmatites has been summarized (Brobst, 1962).

Most of the pegmatites form peneconcordant lenses and pods, the largest a few hundred feet long and several tens of feet thick. Many small ones have been completely removed by mining. Most of the pegmatites lack conspicuous zoning, although a few have quartz cores. The smaller pegmatites have conspicuous cataclastic textures, and their muscovite books are bent and ruled; yet commercial mica has been produced from some foliated pegmatites only a few feet thick. The pegmatites in the Blue Ridge thrust sheet southeast of the window are on the average more strongly deformed than elsewhere, and the largest muscovite we saw there was about 3 inches in diameter.

Scrap mica is obtained as a byproduct of kaolin mining in the northwestern part of the Linville Falls quadrangle.

Feldspar is commonly recovered as a byproduct of the mica mines, but in some mines it is more valuable than the mica. The prospects and small mines in the mixed unit on Bellevue Mountain in the Linville quadrangle appear to have produced only feldspar. These pegmatites are rich in biotite and poor in muscovite, and the micas are very deformed. A small amount of feldspar has been produced from pegmatites in the Cranberry Gneiss.

The value of sheet mica production fluctuates, depending upon the demand and on the encouragement given by the U.S. Government through its lending and buying policies. For instance, Avery County produced about $186,000 worth of sheet mica in 1958 under Government support (Vallely and others, 1959),

but only $9,850 worth in 1962 after support was withdrawn (Beck and others, 1963).

The reserves of sheet mica in the Spruce Pine district probably are at least equal to the production to date, according to Brobst (1962, p. 19).

KAOLIN

Kaolin is mined from light-colored muscovite granodiorite saprolite along the north side of Brushy Creek in the northwestern part of the Linville Falls quadrangle. The deposits were opened in 1937, and several large open-pit mines are currently being operated. Scrap muscovite is recovered as a byproduct. Smaller deposits on the north side of Threemile Creek (Parker, 1946), at the west margin of the Linville Falls quadrangle, had not yet been mined in the quadrangle at the time of our mapping (1957).

Twelve samples from the Gusher Knob deposit (just outside the Linville Falls quadrangle north of Threemile Creek) contained an average of about 24 percent quartz, 16 percent mica, 0.5 percent feldspar, 47 percent hydrated halloysite, and 12 percent kaolin (Sand, 1956). The hydrated halloysite is derived from feldspar and the kaolin from muscovite.

The kaolin is as much as 60 feet thick and is overlain in part by terrace gravels averaging 16 feet in thickness and in part by residual soil and stained kaolin averaging 6 feet in thickness (Parker, 1946). The deposits have been formed by deep weathering of the light-colored granodiorite, which almost lacks mafic minerals. The deep weathering took place on broad valley floors, the bottoms of which now stand as gravel-covered terraces as much as 100 feet above the present streams. Commercial kaolin is found as high as 250 feet above Brushy Creek on relatively gently sloping valley sides (Parker, 1946).

Reserves in 1942 were estimated by Parker (1946) to be $1\frac{1}{2}$–3 million tons in the Brushy Creek deposits and $\frac{1}{2}$–$1\frac{1}{4}$ million tons in the deposits north of Threemile Creek (Gusher Knob deposits). No records of production or estimates of current reserves are available.

A possible additional source of kaolin in the Grandfather Mountain area is near Deep Gap in the northeast corner of the Blowing Rock quadrangle. The rocks on the gentle slopes near Gap Creek appear to be deeply weathered and to contain numerous bodies of pegmatite and granitic rock, some of which are plagioclase rich and lack mafic minerals. Judged from exposures in the Stony Fork drainage, whatever bodies of kaolin are found would be relatively small compared to those in the Brushy Creek area and would have a width of only several tens of feet.

ASBESTOS

Small amounts of anthophyllite asbestos have been mined from ultramafic rocks in the Blue Ridge thrust sheet and the Inner Piedmont in the Grandfather Mountain area.

In 1957, just west of Cow Camp Gap in the Linville quadrangle, an ultramafic body 320 feet long and 60 feet wide was being mined for anthophyllite asbestos. The fibers commonly are $\frac{1}{2}$–1 inch long, and some are as much as 4 inches. Most are slip fibers and are parallel to the fabric of the rock. Some veins of cross fibers, which are perpendicular to walls of veins, transect the mass; these veins are as much as 2 inches thick. The ultramafic body appears to be concordant with the amphibolite and hornblende gneiss which forms the wallrock. Talc is common at the margin of the body.

Other small ultramafic bodies on the south side of Hawshore Mountain and south of Hughes in the Linville quadrangle have been prospected unsuccessfully for commercial anthophyllite. Asbestos prospects on Snakeden Mountain in the Blowing Rock quadrangle appear to be much older because the pits are overgrown.

The prospect on Camp Branch in the northeastern Blowing Rock quadrangle contains veinlets of asbestiform tremolite with fibers several inches long parallel to the veins and one-fourth inch long perpendicular to the veins.

In the Inner Piedmont one small anthophyllite asbestos mine has been worked northeast of the junction of the Johns River and Wilson Creek in the Lenoir quadrangle. There the

asbestos occurs in veins about 1 foot thick in a dunite which has been entirely serpentinized in its interior and converted to talc schist at its margins.

The mines near Cow Camp Gap and the Johns River have been more fully described by Conrad and others (1963, p. 21–22, 42–44).

ROAD METAL

Road metal has been quarried from many different rock units throughout the Grandfather Mountain area. The largest active quarries in 1961 were in the Shady Dolomite at Woodlawn in the Little Switzerland quadrangle and in migmatitic gneiss at the Causby quarry in the southwestern part of the Lenoir quadrangle. The quarry at Woodlawn, which was operated by the State Highway Department, and an inactive one in Shady Dolomite at Ashford were described by Conrad (1960).

SAND AND GRAVEL

Sand and gravel is obtained from stream beds and flood plains at various localities throughout the area. Although many of the operations last only a few months in one place, they have been noted on the quadrangle maps where they were in progress at the time of mapping or had been recently completed.

The coarser grained deposits containing the fewest fragments of weathered rock are found in streams draining quartzite or arkose. Such deposits have been exploited at the head of the Watauga River and along the Linville River just west of the gorge through the Tablerock thrust sheet in the Linville quadrangle (where the deposits are as much as 15 ft thick) and along the Linville River and Paddy Creek in the Linville Falls quadrangle. In the pits on Paddy Creek and the Linville River in the Linville Falls quadrangle, the gravel is poorly sorted and consists of rounded pebbles to boulders of quartzite 1 inch to 3 feet in diameter in a matrix of gray sandy clay. The deposit ranges in thickness from 4 to 10 feet and rests on bedrock. It is overlain by 2–5 feet of gray-yellow or brown sandy clay containing scattered pebbles and cobbles; the clay, in turn, is overlain by brown organic soil.

Most of the larger streams draining the steep southeast-facing margin of the Blue Ridge have considerable fresh sand and gravel in their alluvial deposits. In 1961, gravel operations at the junction of Buffalo Creek with the Yadkin River in the southeast corner of the Blowing Rock quadrangle exposed above water level 6–10 feet of sand, gravel, carbonaceous sand, and clay. Sand is the dominant material. The gravel consists mainly of pebbles and cobbles, and it has a maximum grain size of 1 foot.

Sand is obtained from the bed of the Catawba River near Morgantown.

Plentiful supplies of sand and gravel remain to be exploited on the flood plains of the major streams, such as Wilson Creek, the Johns River, Buffalo Creek, and Elk Creek. In 1962, sand and gravel was probably the most valuable commodity produced in the Grandfather Mountain area. Production for that year was valued at $122,000 in Watauga County and $208,000 in Burke County (Beck and others, 1963).

BUILDING STONE

In the Grandfather Mountain area, building stone is obtained principally from the metamorphosed sedimentary rocks of the Grandfather Mountain window. The most actively worked quarries are in the lowest arkose of the Grandfather Mountain Formation south and east of Grandfather Mountain in the Linville quadrangle. The arkose most used for building is medium grained, light greenish gray, has cleavage parallel with bedding, and is known as "Grandfather Stone." Council (1955) described the quarries on the road between U.S. Highway 221 and Gragg, and also the Green and Taylor quarry east of Linville. Other small quarries are found in the arkose unit north of Foscoe in the Linville quadrangle and north and east of Shulls Mills in the Blowing Rock quadrangle.

Slices of Chilhowee quartzite which are quarried for building stone are along the Linville Falls fault in the Linville Falls quadrangle near North Carolina Highway 181 (Causby and Dula quarries of Council, 1955), on U.S. Highway 221 at the south edge of the Little Switzerland quadrangle (Woodlawn [Teastor] quarry of Council, 1955), and at

other places in that vicinity. The quartzite in these quarries is light gray to light greenish gray and has bedding parallel with cleavage.

On Timber Ridge in the northwestern part of the Linville quadrangle a well-foliated medium-grained phase of the Beech Granite is quarried for building stone.

Along the Blue Ridge Parkway, Blowing Rock Gneiss was quarried for bridge construction. The inactive quarry in this unit near Spruce Knob was a building stone quarry rather than a road-metal quarry, as was shown on the Blowing Rock quadrangle map. This quarry was the source for the bridge materials.

North of Rock View Church on Elk Creek in the northeastern part of the Blowing Rock quadrangle, a layer of coarse-grained uniform well-jointed cataclastic biotite-quartz monzonite gneiss, at least 30 feet thick, is quarried for building stone.

East of Turkey Knob in the Blowing Rock quadrangle, soapstone was quarried from an ultramafic body.

OTHER COMMODITIES

Graphitic phyllonite has been prospected for graphite, but none of the deposits is of sufficient grade or tonnage to be considered minable.

Quartz crystals have been found in the Blue Ridge thrust sheet in the southwestern part of the Linville quadrangle, but few of them are salable for manufacture of oscillator plates (Mertie, 1959, p. 281). The better ones have value as specimens. Well-shaped but small crystals are also found locally in some veins in the rocks of the Grandfather Mountain Formation in the Linville quadrangle.

Small amounts of pure silica might be obtained near the Bradshaw School in the Blowing Rock quadrangle where a lens of almost pure white granular quartzite 10–30 feet thick and at least 500 feet long is found in Wilson Creek Gneiss. Similar but mostly less pure quartz bodies are found on White Rock Ridge.

In a study of high-silica materials in North Carolina, Broadhurst (1949) listed analyses of the upper quartzite of the Chilhowee Group in the Tablerock thrust sheet that range, in percent, from 96.7 to 91.0 SiO_2; 2.7 to 7.2 Al_2O_3; and 0.12 to 0.27 Fe_2O_3. He pointed out that Al_2O_3 content should be less than 0.5 percent in material for silica refractory industries.

The sillimanite schist unit in the southeastern part of the Lenoir quadrangle was investigated by Hash and Van Horn (1951) as a potential source of refractory material. In the laboratory they were unable to make a satisfactory concentrate of marketable grain size.

Agricultural lime has been quarried from the Shady Dolomite in the North Cove area in the Linville Falls quadrangle (Conrad, 1960). It is somewhat impure to be ideal for many industrial uses, but geographic location in relation to the industry needing dolomite is usually of prime importance in determining the economic potential of a dolomite deposit. Partial analyses of the Shady show the following ranges, in percent: MgO, 10–21; CaO, 27–31; ignition loss, 41–46; Fe, 0.25–0.6; and acid insoluble 0.7–8.6 (Hunter and Gildersleeve, 1946, p. 27–28). Complete analyses show the following ranges, in percent: SiO_2, 0.60–5.96; Al_2O_3, 0.60–1.76; Fe_2O_3, 0.49–0.73; CaO, 29.13–30.93; MgO, 19.56–21.22; K_2O, 0.26–0.41; P_2O_5, 0.01–0.02; and CO_2, 40.07–47.10 (Loughlin and others, 1921).

REFERENCES

Bayley, W. S., 1923, The magnetic iron ores of east Tennessee and western North Carolina: Tennessee Div. Geology Bull. 29, 252 p.

Beck, W. A., Stuckey, J. L., and Rivers, M. E. 1963, The mineral industry of North Carolina: U.S. Bur. Mines 1962 Minerals Yearbook, v. 3, p. 775–794.

Broadhurst, S. D., 1949, A general survey of some high silica materials in North Carolina: North Carolina Dept. Conserv., Div. Mineral Resources Inf. Circ. 7, 30 p.

_____1955, The mining industry in North Carolina from 1946 through 1953: North Carolina Dept. Conserv. Devel., Div Mineral Resources Econ. Paper 66, 99 p.

Brobst, D. A., 1962, Geology of the Spruce Pine district, Avery, Mitchell, and Yancey Counties, North Carolina: U.S. Geol. Survey Bull. 1122-A, 26 p.

Bryant, Bruce, 1962, Geology of the Linville quadrangle, North Carolina-Tennessee—A preliminary report: U.S. Geol. Survey Bull. 1121-D, p. D1–D30.

_____1963, Geology of the Blowing Rock quadrangle, North Carolina: U.S. Geol. Survey Geol. Quad. Map GQ-243.

_____1965, Geology of the Linville quadrangle, North Carolina-Tennessee: U.S. Geol. Survey Geol. Quad. Map GQ-364.

Bryson, H. J., 1936, Gold deposits in North Carolina: North Carolina Dept. Conserv. Devel. Bull. 38, 157 p.

Conrad, S. G., 1960, Crystalline limestone of the Piedmont and Mountain regions of North Carolina: North Carolina Dept. Conserv. Devel., Div. Mineral Resources Bull. 74, 56 p.

Conrad, S. G., Wilson, W. F., Allen, E. P. and Wright, T. J., 1963, Anthophyllite asbestos in North Carolina: North Carolina Dept. Conserv. Devel., Div. Mineral Resources Bull. 77, 61 p.

Council, R. J., 1955, Petrography and economic aspects of the miscellaneous commercial rocks of North Carolina: North Carolina Dept. Conserv. Devel. Inf. Circ. 13, 26 p.

Davis, G. L., Tilton, G. R., and Wetherill, G. W., 1962, Mineral ages from the Appalachian Province, North Carolina and Tennessee: Jour. Geophys. Research, v. 67, p. 1987–1996.

Goldich, S. S., and Wedow, Helmuth, Jr., 1943, Preliminary report on the magnetic iron ores of western North Carolina and eastern Tennessee: U.S. Geol. Survey open-file report.

Hash, L. J., and Van Horn, E. C. 1951, Sillimanite deposits in North Carolina: North Carolina Dept. Conserv. Devel., Div. Mineral resources Bull. 61, 52 p.

Hunter, C. E., and Gildersleeve, Benjamin, 1946, Minerals and structural materials of western North Carolina and north Georgia: Tennessee Valley Authority Report C, 94 p.

Keith, Arthur, 1903, Description of the Cranberry quadrangle [North Carolina-Tennessee]: U.S. Geol. Survey Geol. Atlas, Folio 90, 9 p.

Kerr, W. C., 1875, Report of the geological survey of North Carolina; v. 1, Physical geography, résumé, economical geology: North Carolina Geol. Survey, 325 p., map.

Kesler, T. L., and Olson, J. C., 1942, Muscovite in the Spruce Pine district, North Carolina: U.S. Geol. Survey Bull. 936-A, p. 1–38.

Kline, M. H., and Ballard, T. J., 1948, Cranberry magnetite deposits, Avery County, North Carolina, and Carter County, Tennessee: U.S. Bur. Mines Rept. Inv. 4274, 85 p.

Loughlin, G. F., Berry, E. W., and Cushman, J. A., 1921, Limestones and marls of North Carolina: North Carolina Geol. and Econ. Survey Bull. 28, 211 p.

Mertie, J. B., Jr., 1959, Quartz crystal deposits of southwestern Virginia and western North Carolina: U.S. Geol. Survey Bull. 1072-D, p. 233–298.

Mitchell, Elisha, 1905, Diary of a geological tour in 1827 and 1828: North Carolina Univ. James Sprunt Hist. Mon. 6, 73 p.

Nitze, H. B. C., 1893, Iron ores of North Carolina: North Carolina Geol. Survey Bull. 1, 239 p.

Nitze, H. B. C., and Wilkins, H. A. J., 1897, Gold mining in North Carolina and adjacent south Appalachian regions: North Carolina Geol. Survey Bull. 10, 164 p.

Olson, J. C., 1944, Economic geology of the Spruce Pine pegmatite district, North Carolina: North Carolina Dept. Conserv. Devel., Div. Mineral Resources Bull. 43, 67 p.

Parker, J. M., III, 1946, Residual kaolin deposits of the Spruce Pine district, North Carolina: North Carolina Dept. Conserv. Devel., Div. Resources Bull. 48, 45 p.

Reed, J. C., Jr., 1946a, Geology of the Lenoir quadrangle, North Carolina: U.S. Geol. Survey Geol. Quad. Map GQ–242.

_____1964b, Geology of the Linville Falls quadrangle, North Carolina: U.S. Geol. Survey Bull. 1161-B, p. B1–B53.

Reed, J. C., Jr., and Bryant, Bruce, 1964, Geologic map of part of the Grandfather Mountain window, North Carolina, Sheet 2—Southwestern extension of the window: U.S. Geol. Survey open-file map.

Ross, C. S., 1935, Origin of the copper deposits of the Ducktown type in the southern Appalachian region: U.S. Geol. Survey Prof. Paper 179, 165 p.

Sand, L. B., 1956, On the genesis of residual kaolins: Am. Mineralogist, v. 41, p. 28–40.

Sterrett, D. B., 1923, Mica deposits of the United States: U.S. Geol. Survey Bull. 740, 342 p.

Vallely, J. L., Stuckey, J. L., and Rivers, M. E., 1959, The mineral industry of North Carolina: U.S. Bur. Mines 1958 Minerals Yearbook, v. 3, p. 681–699.

★ U.S. GOVERNMENT PRINTING OFFICE : 1967 O—256-885