

325 TO 265 M.Y.-OLD GRANITIC PLUTONS IN THE PIEDMONT OF THE SOUTHEASTERN APPALACHIANS

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ABSTRACT. Rb-Sr whole-rock age determinations, plus several mineral and whole-rock ages, establish the presence of at least twenty 325 to 265 m.y.-old granitic plutons in the central and eastern Piedmont of the southeastern Appalachians. These late Paleozoic plutons range in size from large batholiths to small stocks, with the larger bodies typically composed of porphyritic, coarse- to medium-grained granite. Most of these plutons postdate regional metamorphism and deformation. Only those plutons in the southeastern Piedmont of South Carolina show signs of significant deformation and metamorphism. Ages for these plutons provide the first good evidence for Alleghanian deformation and metamorphism in the southern Appalachian Piedmont.

All the late Paleozoic plutons are normal calc-alkaline granites. The plutons in the central Piedmont differ chemically from the plutons in the eastern Piedmont only by having much higher Sr contents. The initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios for most of the granites are low, ranging from 0.7024 to 0.7052. These values suggest that the granitic magmas were derived from the upper mantle or lower crust; anatexis of high Rb/Sr ratio continental crust could not have played a significant role in their formation.

If continent-continent collision were directly responsible for the late Paleozoic Blue Ridge and Valley and Ridge thrusting, it seems reasonable that the Pennsylvanian-Permian age granitic plutons also would have been deformed. The general lack of such deformation suggests that continent-continent collision primarily caused uplift of the Piedmont, which ultimately resulted in gravitational spreading and the resultant deformation to the west.

INTRODUCTION

New Rb-Sr isotopic and major-element chemical data plus field observations are reported for two sub-parallel belts of granitic plutons in the central and eastern Piedmont of the southeastern Appalachians. These will be referred to as the York-Churchland (Western) and Main (Eastern) groups of plutons, respectively.

Data for these plutons are compared to published data for other plutons from the same region.

The main purposes of this investigation were: (1) to determine the ages and areal extent of the late Paleozoic granitic plutons; (2) to compare field characteristics and chemical compositions of these plutons; (3) to use Sr isotopic compositions to place constraints on magma genesis; and (4) to determine the implications these plutons have for the late Paleozoic evolution of the southern Appalachians.

GEOLOGIC SETTING

The crystalline southern Appalachians may be divided into lithologic-structural belts (King, 1955; Hatcher, 1972). The part of the Inner Piedmont shown on figure 1 is mainly gneiss and schist with widespread granitic intrusions. The Kings Mountain belt is characterized by low-to-medium rank mica schist, amphibolite, prominent ridge-forming quartzite and conglomerate, marble, and calc-silicate rocks. The Charlotte belt is predominantly intrusive rocks with a wide range of composition and has some areas of high-rank metamorphic rocks. The Carolina slate

belt comprises mainly late Precambrian-early Paleozoic volcanogenic rocks locally more than 7000 m thick, metamorphosed in the greenschist facies, and intruded by a variety of igneous bodies. Rocks typical of the Carolina slate belt occur on both flanks of and between two belts containing higher rank gneisses, the Raleigh belt in the north and the Kiokee belt in the south (fig. 1).

The late Paleozoic (325-265 m.y.-old) plutons discussed in this paper are limited to the region southeast of the Kings Mountain belt. Although the Inner Piedmont includes granitic intrusions with ages of about 340 to 350 m.y., they are significantly older than most of the late Paleozoic plutons discussed herein (Kish, 1977; Kish and Fullagar, 1977; Harper, ms). The Stone Mountain pluton in the Inner Piedmont of Georgia, 30 km east of Atlanta, yielded a Rb-Sr whole-rock plus mineral isochron age of 285 ± 7 m.y. (Whitney, Jones, and Walker, 1976) and is a possible member of the late Paleozoic group, although the isochron might represent a post-crystallization disturbance rather than the time of crystallization.

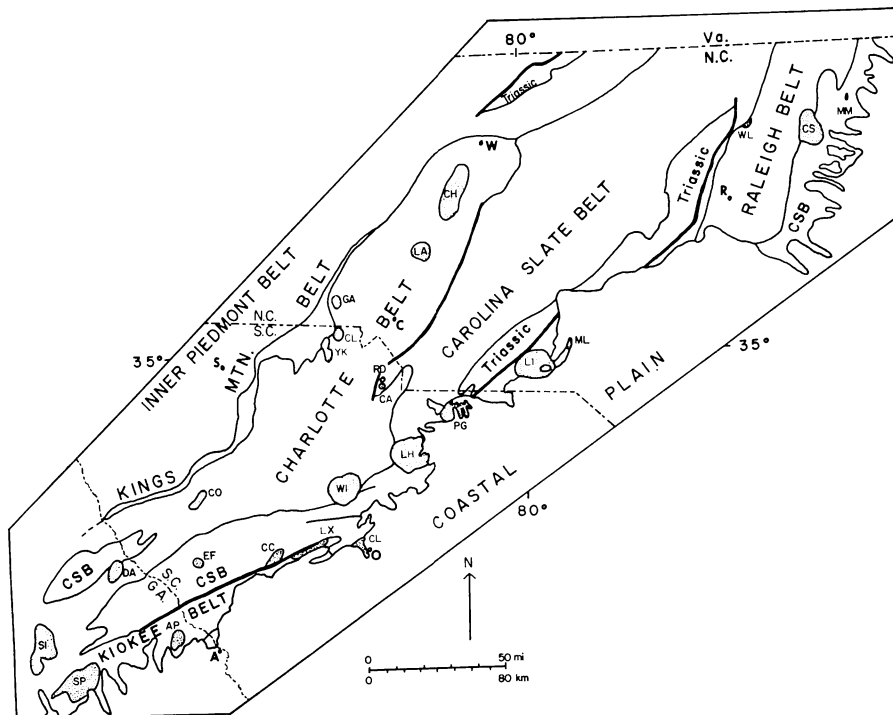


Fig. 1. Generalized geologic map showing 325 to 265 m.y.-old (late Paleozoic) granitic plutons (stippled pattern) in the central and eastern Piedmont of North Carolina, South Carolina, and Georgia. Symbols for each pluton are explained in table 1. CSB is Carolina slate belt. Known faults are shown as heavy lines. Cities: W-Winston-Salem, N.C.; R-Raleigh, N.C.; C-Charlotte, N.C.; S-Spartanburg, S.C.; O-Columbia, S.C.; A-Augusta, Ga.

TABLE I
Late Paleozoic granitic plutons

Group and Pluton Name	Area Km ²	Number of Samples Analyzed Chemical	Isotopic	Rb-Sr Age, m. Y.	(⁸⁷ Sr/ ⁸⁶ Sr) ₀	References for Chemical and Isotopic Data
<u>Main (Eastern) Group</u>						
Medoc Mountain (NM) *	3	-	10	301 ± 6	0.7024 ± 0.0002	(10), (11)
Castalia (CS)	312	4	6	313 ± 13	0.7141 ± 0.0045	(6), (12), (14)
Wilton (WL)	10	-	5	285 ± 10**	---	(13)
Lilesville (LI)	324	6	4	326 ± 27	0.7047 ± 0.0007	(3), (14)
Catawba (CA)	5	1	7	323 ± 14	0.7037 ± 0.0005	(3), (4), (14)
Pageland (PG)	240	6	4	296 ± 5	0.7038 ± 0.0002	(3), (12), (14)
Liberty Hill (LH)	363	15	5	293 ± 15	0.7046 ± 0.0010	(1), (3), (14)
Wimmsboro (WI)	122	31	9	295 ± 4	0.7047 ± 0.0004	(3), (4), (7)
Columbia (CL)	18	-	8	285 ± 7	0.7051 ± 0.0004	(14)
Lexington (LX)	59	-	4	292 ± 15	0.7047 ± 0.0004	(14)
Clouds Creek (CC)	36	4	9	313 ± 2***	0.7099 ± 0.0001***	(1), (3), (14)
Edgefield (EF)	23	-	4	293 ± 14	0.697 ± 0.026	(14)
Coronaca (CO)	50	-	9	278 ± 2***	0.7045 ± 0.0002***	(14)
Danburg (DA)	95	1	-	---	---	(3)
Appling (AP)	32	2	-	---	---	(14)
Silloam (SI)	260	40	12	264 ± 3	0.7052 ± 0.0001	(5), (8)
Sparta (SP)	332	29	24	281 ± 3**	---	(14)
				289 ± 2	0.7035 ± 0.0004****	(2), (9)
<u>York-Churchland</u>						
<u>(Western) Group</u>						
Churchland (CH)	326	2	4	282 ± 6***	0.7048 ± 0.0004***	(3), (14)
Landis (LA)	85	4	5	292 ± 29	0.7045 ± 0.0002	(3), (14)
Gastonia (GA)	25	1	-	---	---	(3)
Clover (CL)	34	4	1	---	---	(1), (3), (14)
York (YK)	60	7	7	322 ± 6	0.7044 ± 0.0001	(1), (3), (14)

(1) Sloan, 1908
 (2) Watson, 1910
 (3) Butler and Ragland, 1969
 (4) Fullagar, 1971
 (5) Radcliffe and Humphrey, 1971
 (6) Julian, ms
 (7) Wagener, 1973
 (8) Jones and Walker, 1976
 (9) Fullagar and Butler, 1976
 (10) Andersen and Fullagar, 1977

(11) G. Andersen, unpub. data
 (12) H. Bell, III, unpub. data
 (13) Klinge and Fullagar, unpub. data
 (14) This paper

** Model age calculated assuming (⁸⁷Sr/⁸⁶Sr)₀ = 0.705
 *** Mineral and whole-rock data
 **** Some samples have significantly higher (⁸⁷Sr/⁸⁶Sr)₀ ratios (Fullagar and Butler, 1976)

TABLE 2
New Rb-Sr isotopic data

Pluton and Sample Number	$(\text{Sr}^{87}/\text{Sr}^{86})_n$	Rb ppm	Sr ppm	$\text{Rb}^{87}/\text{Sr}^{86}$
<u>Main (Eastern) group</u>				
Castalia				
1144	0.8265	270	31.9	24.81
Lilesville				
1285	0.7089	122	385	0.91
1288	0.7130	137	224	1.77
1290	0.7141	153	211	2.10
1291	0.7142	145	210	1.99
Catawba				
CBA-2(383)	0.7092	138	333	1.20
CBA-4(352.3)	0.7073	117	448	0.71
CBA-5(147.3)	0.7067	116	433	0.77
Pageland				
1293	0.7090	136	318	1.24
1299	0.7122	128	187	1.98
1301	0.7229	174	110	4.58
1302	0.7226	167	110	4.40
Columbia				
1764	0.7172	252	222	3.28
1767	0.7604	311	66.6	13.60
1768	0.7468	285	78.5	10.56
1771	0.7531	290	73.7	11.47
1773	0.7168	186	189	2.85
1777	0.7141	192	255	2.18
1782	0.7153	193	221	2.53
1784	0.7152	208	259	2.33
Lexington				
1549	0.7168	203	204	2.88
1740	0.7111	170	335	1.47
1741	0.7126	200	297	1.95
1746	0.7095	164	409	1.16
Clouds Creek				
SC-101	0.7225	155	155	2.91
1001	0.7239	152	148	2.99
1748	0.7197	145	189	2.22
1749	0.7201	145	185	2.28
1750	0.7209	149	180	2.40
1752	0.7232	162	156	3.01
1762				
Whole-rock	0.7236	167	157	3.08
Biotite	0.9985	616	28.3	64.95
Plagioclase	0.7145	69.4	180	1.12

TABLE 2 (continued)

Pluton and Sample Number	(Sr ⁸⁷ /Sr ⁸⁶) _n	Rb ppm	Sr ppm	Rb ⁸⁷ /Sr ⁸⁶
Edgefield				
1591	1.2255	322	7.71	127.21
1593	1.2807	304	6.63	140.21
1594	1.2940	300	6.43	143.10
1597	1.2409	287	6.73	129.78
Coronaca				
1583	0.7135	107	129	2.40
1585	0.7139	103	130	2.29
1586	0.7129	97.5	130	2.18
1588				
Whole-rock	0.7131	95.3	125	2.21
Biotite	1.2037	390	9.38	126.15
Plagioclase	0.7048	2.31	62.9	0.11
1809	0.7137	127	147	2.49
1814	0.7150	129	147	2.54
1815	0.7155	124	138	2.62
Siloam				
975	1.6640	369	4.87	239.9
976	1.5107	342	5.31	201.6
<u>York-Churchland</u> <u>(Western) Group</u>				
Churchland				
1405	0.7058	107	1671	0.20
1405-B10	0.7375	449	164	7.94
1420	0.7063	153	953	0.46
1420-B10	0.7922	666	87.2	22.28
Landis				
NC-101	0.7059	108	971	0.32
NC-102	0.7061	117	853	0.40
NC-104	0.7066	148	773	0.56
NC-105A	0.7073	157	741	0.61
NC-105B	0.7082	190	605	0.91
Clover				
1368	0.7067	154	761	0.59
York				
1369	0.7145	171	224	2.21
1370	0.7132	162	241	1.95
1372	0.7128	175	272	1.87
1374	0.7146	178	226	2.28
1375	0.7128	175	283	1.79
SC-69	0.7059	42.5	347	0.36
YD-92	0.7061	42.3	331	0.37

Plutons with ages of 325 to 265 m.y. are concentrated in the Piedmont southeast of the Kings Mountain belt but may not be limited to that region. Rb–Sr radiometric data are available on many of the major types of granitic rocks of the Piedmont, so that probably relatively few large members of the group still remain to be recognized.

These are no obvious structural controls on emplacement of the plutons. They occur within belts as well as on belt boundaries and intrude a wide variety of rocks of different metamorphic ranks. Most of the larger intrusions, with the exception of the Churchland, occur at or near the edge of the Coastal Plain, but the significance of this alignment is not known. It is likely that additional members of the group are buried beneath the Coastal Plain, and we, therefore, cannot yet define the southeastern edge of the intrusive belt.

GEOCHRONOLOGY

Analytical techniques.—For whole-rock analyses, rock specimens weighing 2 to 6 kg were crushed, split, and ground to less than 200 mesh. All analyzed samples were fresh when observed in both hand specimen and thin section. Using magnetic and density differences, minerals were separated from splits of selected samples. Rb and Sr concentrations were determined by standard isotope-dilution methods. Isotopic measurements were made on a 60-degree sector, 30 cm-radius, solid-source mass spectrometer. Data output is digital, and instrument operation plus data reduction are performed by an on-line computer.

Based on duplicate analyses of samples and replicate analyses of NBS-70a K-feldspar standard, our one-standard-deviation (1σ) errors for $\text{Rb}^{87}/\text{Sr}^{86}$ are estimated to be less than 1 percent. Rb and Sr blank values were insignificant compared to the Rb and Sr concentrations in the analyzed samples plus the quantity of sample used for analysis. Ten recent analyses of the Eimer and Amend SrCO_3 standard give an average $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7080 ± 0.0002 (1σ) when normalized to $\text{Sr}^{86}/\text{Sr}^{88} = 0.1194$. Six analyses of NBS standard SrCO_3 , SRM-987, yield an average $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7102 ± 0.0002 (1σ). These analyses, plus duplicate analyses of actual rock samples, indicate that our 1σ errors for $\text{Sr}^{87}/\text{Sr}^{86}$ are less than 0.05 percent. Where scales on the isochron plots permit, data points are drawn so as to indicate the estimated analytical uncertainties.

Isochron ages and initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios were determined by the regression treatment of York (1966), and the errors given represent 1σ . All Rb–Sr ages reported or discussed herein are based on a Rb^{87} half-life of 48.9×10^9 yr ($\lambda_{\text{Rb}^{87}} = 1.42 \times 10^{-11}$ yr $^{-1}$). All ages and initial ratios are summarized in table 1, and isotopic data are given in table 2. Sample locations may be obtained from Paul D. Fullagar.

Main (eastern) group of plutons.—These plutons occur in the eastern portion of the Piedmont of North Carolina, South Carolina, and Georgia (fig. 1). Ages and initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios are given in table 1; data are plotted in figures 2, 3, and 4. The northernmost granitic unit in this group is the Medoc Mountain pluton. Similar granites may exist

to the north in Virginia; our investigations have been limited to North and South Carolina and Georgia.

The large uncertainty in the initial ratio of the Castalia pluton is due to the highly radiogenic character of the samples analyzed. One sample plots off the isochron (fig. 2) and was not used in the regression calculation. The Lilesville pluton is intruded by the Pee Dee gabbro which has a nearly identical Rb-Sr mineral and whole-rock age (S. A. Kish, personal commun.). Some of the Columbia granite data points plot off the regression line (fig. 3) by amounts exceeding analytical uncertainties. Some of the scatter could reflect small differences in age and/or initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio. The four samples with the highest Rb/Sr ratios were collected at the Lone Star quarry, Richland County, S.C. Considered separately, these samples yield an age of 297 ± 11 m.y. with an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7032 ± 0.0016 . The other samples, which have much lower Rb/Sr ratios, were collected in the Cayce quarry, Lexington County, S.C. The Cayce quarry samples have an age of 265 m.y. ± 49 m.y. and an initial ratio of 0.7060 ± 0.0017 . Additional samples collected from this quarry have no greater range in Rb/Sr values than do the samples analyzed for isotopic composition. Reconnaissance and petrographic studies show no significant differences in the rocks from the two quarries, which are less than 1 km apart. However, the different degree of differentiation as suggested by Rb/Sr values plus the scatter of data

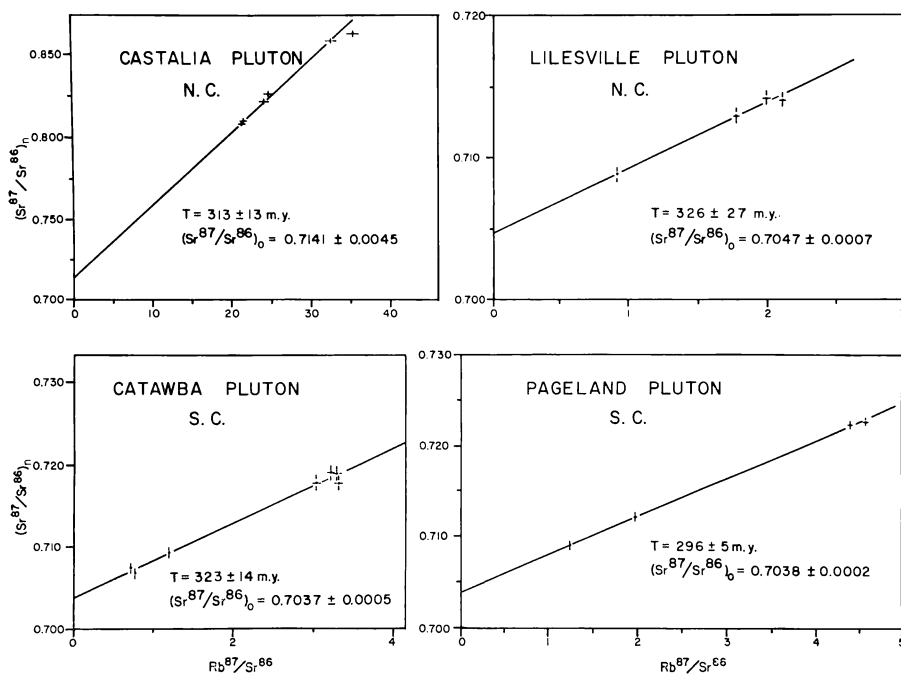


Fig. 2. Rb-Sr isochron diagrams.

points on figure 3 suggest that the quarries are in separate plutons. Nonetheless, the data indicate that all the analyzed rocks are about 300 m.y.-old. Long, Kulp, and Eckelmann (1959) obtained K–Ar dates of 226 ± 9 and 233 ± 9 m.y. on biotite from the Cayce quarry; these dates probably represent uplift and cooling of the granite long after crystallization.

The Clouds Creek pluton is typical of many granitic rocks in the southeastern Piedmont in that samples exhibit a narrow range of Rb/Sr ratios. A consideration of just seven whole-rock samples gives an age of 319 ± 27 m.y. with an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7097 ± 0.0010 . Since field and petrographic information suggest that this pluton is an epizonal to upper mesozonal post-metamorphic pluton, minerals might have cooled relatively rapidly; if so, they would be expected to yield ages close to the time of intrusion and crystallization. A plagioclase concentrate and a biotite separate from sample 1762 were analyzed to define better the age of this pluton. Whole-rock plus minerals give these results: 314 ± 3 m.y. and 0.7097 ± 0.0002 . All data (fig. 3) yield an age of 313 ± 2 m.y. and an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7099 ± 0.0001 . This initial ratio is high relative to most other members of this group.

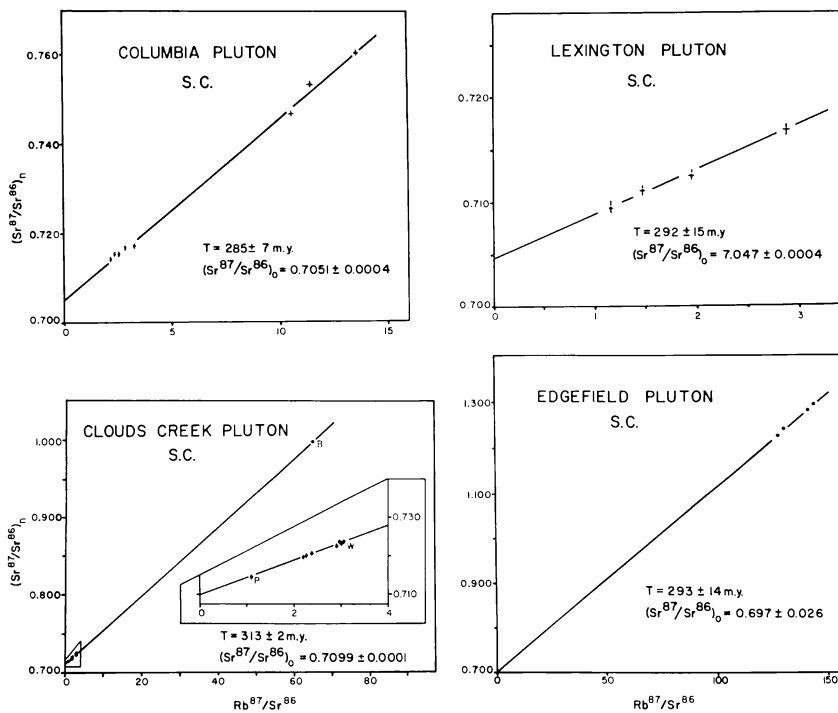


Fig. 3. Rb–Sr isochron diagrams. W represents a whole-rock sample from which biotite (B) and plagioclase (P) were separated and analyzed.

The samples from the Edgefield pluton have very high Rb/Sr ratios causing the error for the initial ratio to be so high as to make the calculated initial ratio meaningless. No whole-rock samples with lower Rb/Sr ratios could be found. This granite has recently been referred to as the Cuffytown Creek pluton (Becker, 1978).

Whole-rock samples from the Coronaca pluton have too limited a range of Rb/Sr ratios to permit calculation of a meaningful age. Biotite and plagioclase separates from sample 1588 plus the whole-rock sample give the following results: 278 ± 1 m.y. and 0.7044 ± 0.0001 . All data give an age of 278 ± 2 m.y. and an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7045 ± 0.0002 (fig. 4). As this pluton is also post-metamorphic and epizonal to upper mesozonal, the mineral-whole rock age may be quite close to the time of intrusion and crystallization. This interpretation is supported by data from other about 300 m.y.-old plutons from this general area. There is close agreement between mineral or mineral-whole rock ages and whole-rock isochron ages for the Clouds Creek pluton (this paper), the Sparta granite from the Weston and Brooker quarry, and the Siloam granite (Fullagar and Butler, 1976; Kulp and Eckelmann, 1961; Jones and Walker, 1973). Also, if the biotite lost radiogenic Sr^{87} for a significant time following crystallization, the initial ratio determined from all Coronaca data should be higher than 0.7045.

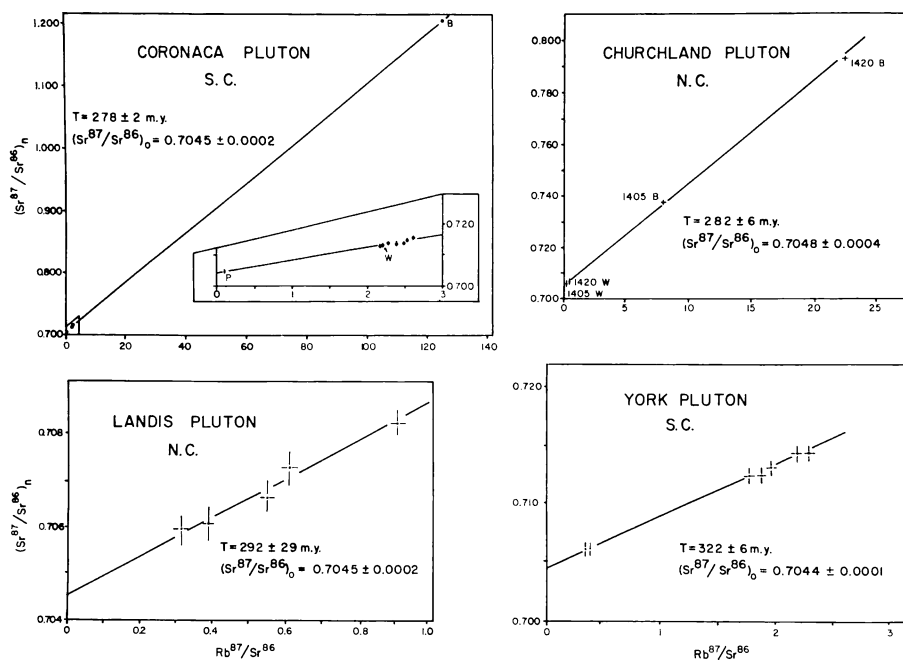


Fig. 4. Rb-Sr isochron diagrams. W represents a whole rock sample; B and P represent biotite and plagioclase splits, respectively.

Jones and Walker (1973) obtained a Rb/Sr age of 264 ± 3 m.y. for the Siloam granite, with an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7052 ± 0.0001 . Additional data suggest the possibility that the Siloam granite mapped by Radcliffe and Humphrey (1971) may represent multiple intrusions. Two new samples, collected with the assistance of Humphrey and Radcliffe, are highly radiogenic ($\text{Rb}^{87}/\text{Sr}^{86} > 200$) and using an assumed initial ratio of 0.705 yield an average model age of 281 ± 3 m.y. These two samples are atypical Siloam granite in that they do not contain phenocrysts. Instead of being older than the typical Siloam granite as suggested by the model age calculations, it is possible that the atypical granite is 264 m.y.-old or younger but with a higher initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio than the typical samples.

Samples collected from the Appling pluton had very similar and low Rb/Sr ratios, making it impossible to determine an age. This pluton is included in table 1, as it is virtually identical in hand specimen and thin section to other coarse prophyritic plutons from the eastern Piedmont which are about 300 m.y.-old. The Danburg pluton, which is also petrographically similar to known late Paleozoic plutons, probably has an age similar to that of the 264 m.y.-old Siloam granite (L. Jones, personal commun.).

Two other undated plutons petrographically classified with the late Paleozoic intrusions are the Millstone Lake (ML) pluton in North Carolina, which is similar to the Lilesville pluton, and the Roddey (RD) pluton in South Carolina (fig. 1). Only weathered samples of the Roddey pluton could be found, but these are very similar to samples of the Catawba pluton.

Jones and Walker (1973) suggested that the late Paleozoic group of granites shows a trend in ages from old to young going from northeast to southwest within the eastern Piedmont. Based on the same data plus their 330 m.y.-old U-Pb zircon age for the Petersburg Granite in Virginia, Wright, Sinha, and Glover (1975) also suggested that the 265 to 325 m.y.-old plutons become younger to the southwest. The Rb-Sr ages listed in table 1 do not show as clear a trend as was suggested by the earlier more limited data. Clearly, the youngest plutons are in the southern part of the belt: Coronaca, Siloam, and Danburg (L. Jones, personal commun.). Farther north, the plutons have ages of 285 to 325 m.y. but show no apparent trend.

York-Churchland (western) group of plutons.—These plutons are located in the northern portion of the Charlotte belt, in North and South Carolina (fig. 1). Ages and initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios are listed in table 1; data are plotted in figure 4. Whole-rock samples of the northernmost pluton, the Churchland pluton, all had very similar Rb/Sr ratios. Whole-rock samples and biotite samples separated from whole-rock samples 1405 and 1420 give an age of 282 ± 6 m.y. and an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.7048 ± 0.0004 (fig. 4). Petrographic and field studies (Privett, 1973) indicate that this pluton is postmetamorphic. Radiometric data for other plutons within the Charlotte belt suggest that this 282 m.y. age, although

a minimum age, probably is close to the time of crystallization of the Churchland pluton. Mineral and mineral plus whole-rock ages for metamorphosed plutons located 15 and 20 km from the Churchland pluton are 350 and 362 m.y.; these intrusions were emplaced and crystallized about 400 m.y. ago (Butler and Fullagar, 1978). These ages suggest that the 282 m.y. age for the Churchland pluton does not simply reflect uplift, erosion, and cooling of rocks (and thus retention of radiogenic Sr^{87} in biotites) within the Charlotte belt. Also, Privett (1973) has suggested that the Churchland and the 292 m.y.-old Landis pluton crystallized from a single magma.

Two postmetamorphic plutons, the Gastonia and Clover, listed in table 1 are included because of their close chemical and petrographic similarity to known late Paleozoic plutons within this belt.

CHARACTERISTICS OF THE LATE PALEOZOIC PLUTONS

Field characteristics and petrography.—Outcrop areas of the plutons range through two orders of magnitude, from large batholiths down to small stocks (table 1). Most of the larger bodies are composed mainly of porphyritic, coarse- to medium-grained granite, but there is a wide range of modal compositions. Rocks range in composition from granite to tonalite and to syenite or quartz syenite.

There is also a wide variation in textures among the plutons and, in some cases, within a single pluton. The Liberty Hill pluton, largest member of the group, is composed mainly of porphyritic, medium- to coarse-grained granite but has a central core of fine-grained, non-porphyritic granite (Overstreet and Bell, 1965a; Wagener, 1977). The two textural types are similar chemically and plot along the same isochron, so there appears to be little, if any, difference in origin and age between them. The textural differences are probably related to conditions of emplacement and perhaps water content. The most conspicuously porphyritic rocks make up the Churchland and Siloam intrusions, with microcline phenocrysts as much as 13 cm long (Butler and Ragland, 1969) and 6 cm long (Jones and Walker, 1973), respectively. The Lilesville, Page-land, Clouds Creek, Danburg, Appling, Landis, Clover, and York plutons are also mainly porphyritic rock. The other intrusions are composed mainly of non-porphyritic, medium-grained rock.

Microcline, plagioclase, and quartz nearly always make up more than 80 percent of the rocks in the intrusions. Quartz-poor rocks are common only in the Coronaca intrusion, where the dominant rock is quartz syenite (McSween, 1970). Biotite (as much as 15 percent) is the most common accessory, and hornblende (as much as 5 percent) is present in several intrusions. Muscovite is common and is the main accessory in the Catawba and Roddey intrusions. Sphene is nearly ubiquitous.

Contact-metamorphic aureoles are conspicuous only around the larger plutons emplaced in the low-rank metamorphic rocks of the Carolina slate belt. Plutons emplaced in amphibole-facies rocks of the Char-

lotte belt and in other intrusive rocks rarely have discernible aureoles. Aureoles are best known around the Lilesville (Waskom and Butler, 1971; Schmidt, ms) and Pageland plutons (Bell and others, 1974; Butler and Howell, 1977). The aureoles are in the hornblende–hornfels facies, and biotite and hornblende are the major contact-metamorphic minerals. The rocks of the inner aureoles are fine-grained black hornfels with granoblastic texture. Schmidt (ms) reported cordierite hornfels in the Lilesville aureole. The Pageland aureole is about 2100 m wide and grades into regional greenschist facies (Butler and Howell, 1977).

The plutons in most cases are clearly younger than regional metamorphism and deformation (Butler, 1966; Butler and Ragland, 1969; Jones and Walker, 1973; Bell and others, 1974). The Lilesville pluton is cut by the border fault of the Wadesboro Triassic basin, but is undeformed except along the fault zone (Waskom and Butler, 1971). Rocks in the plutons are predominantly massive, although a foliation defined by the alignment of microcline crystals and/or biotite flakes is locally present. The foliated rocks, as well as the massive ones, have hypidiomorphic-granular or xenomorphic-granular igneous textures without evidence of deformation. The foliation was probably formed by magmatic flow.

The exception to the general lack of post-crystallization deformation and metamorphism is the group of plutons in the eastern Piedmont of South Carolina near Columbia. The Lexington body commonly has a distinct foliation (Wagener, 1977), although parts are massive. The foliation is defined by aligned lenticular aggregates of quartz and biotite flakes. The Lexington pluton is highly variable in composition and further work may show that it includes granitic rocks of different ages. The Columbia pluton is excellently exposed in two very large quarries on opposite sides of the Congaree River (Lone Star and Cayce quarries). Much of the rock is homogeneous and massive, but there are zones of variable composition and foliation. Both quarries show northeast-trending zones of intensely fractured and altered rock as much as 4 m thick. There is much brick-red staining along fractures. The Clouds Creek pluton is truncated on the southeast by the Modoc (or Batesburg-Edgefield) fault zone and shows foliation, especially near the fault zone (Snoke, Secor, and Metzgar, 1977). Samples throughout the pluton show undulatory or polygonized quartz grains and extensive sericitization. All three plutons near Columbia therefore show evidence of deformation and alteration. Diabase dikes of probable Mesozoic age, which cut the plutons, are undeformed and unaltered, providing an upper age bracket on these events. Since deformation and alteration are extensive and not limited to the vicinity of fault zones, we conclude that this area is the northwestern edge of a zone of Alleghanian deformation and regional metamorphism that is largely buried beneath the Coastal Plain. Secor and others (1978) and Kish and others (1978) have reached the same conclusion. A detailed description of this Alleghanian deformation and metamorphism is to be presented elsewhere (Snoke and others, in preparation).

Two of the late Paleozoic plutons are cut by gabbroic bodies that are distinctly different from the Mesozoic diabase dikes. The Lilesville granite is intruded by the Pee Dee gabbro-diorite body (Waskom and Butler, 1971). S. A. Kish (personal commun., 1977) has obtained a Rb-Sr whole-rock plus mineral isochron that indicates the Pee Dee is only slightly younger than the Lilesville. The Coronaca pluton is cut by a norite-diorite body (McSween, 1970). These gabbroic bodies are younger than the gabbro-diorite-syenite intrusions extending in a belt from central North Carolina to central Georgia, which are probably about 400 m.y. old (Butler and Ragland, 1969; Fullagar, 1971). Therefore, we can recognize at least four groups of mafic intrusions in the Charlotte and Carolina slate belts of the Carolinas: (1) pre-metamorphic mafic intrusions (Butler and Ragland, 1969; Stromquist and Sundelius, 1969) probably more than 450 m.y.-old; (2) gabbro-diorite-syenite intrusions, probably about 400 m.y. old (Butler and Ragland, 1969; Fullagar, 1971); (3) gabbro-norite-diorite plutons, only two of which are recognized so far, slightly (?) younger than the late Paleozoic granitic plutons; and (4) northwest-trending Mesozoic diabase dikes, which are the youngest intrusions in the region and which cut many of the late Paleozoic granitic plutons.

Molybdenum-copper mineralization is associated with some of the Main (Eastern) group of late Paleozoic granitic plutons. This relationship is considered elsewhere (Speer, 1978).

Chemical composition.—One hundred fifty-seven samples of the late Paleozoic granitic plutons have been analyzed for major-element chemical composition (tables 1 and 3). Approximately one-fourth of these analyses were reported by Butler and Ragland (1969) in a petrochemical survey of plutonic rocks of the southern Appalachian Piedmont. Our mean compositions and standard deviations are somewhat different than their values, partly because of the additional analyses available to us (see table 1 for references) and partly because new ages and petrographic information have resulted in revised groupings of plutons. New analyses are available for 10 samples of the Main (Eastern) group of plutons (table 4). These analyses were made using a combination of atomic absorption and X-ray spectrometry. Procedures and estimates of analytical error are given in Fullagar, Lemmon, and Ragland (1971).

Table 3 shows that the major-element chemistry for the Main (Eastern) and York-Churchland (Western) groups of granitic plutons is very similar; only K_2O is slightly higher in the Main (Eastern) group. The only highly significant difference in chemistry is the Sr contents of the two groups, first noted by Price (ms). The Main (Eastern) group has an average Sr content of 138 ppm, whereas the York-Churchland (Western) group averages 636 ppm. A plot of SiO_2 versus Sr (fig. 5) shows there is essentially no overlap of the two groups of plutons. Compilations of average Sr contents of granitic rocks (for example, Taylor, 1965) suggest that 636 ppm is unusually high for a group of granitic rocks. Perhaps the magmas were contaminated by a Sr-rich component; none can

be suggested based on the geology of the area. If the magmas were contaminated, the added Sr must have had a relatively low $\text{Sr}^{87}/\text{Sr}^{86}$ ratio, as these granites all have relatively low initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios of 0.7044 to 0.7047.

In terms of major-element chemistry, both groups of plutons are close to average calc-alkaline granites. On an $\text{Na}_2\text{O}-\text{CaO}-\text{K}_2\text{O}$ diagram the post-metamorphic granites plot near the end of the trend for the Southern California batholith (fig. 6). On an AMF diagram (fig. 6), the granites show typical calc-alkaline trends; the Winstsboro samples and the Sparta samples show greater and less Fe-enrichment, respectively, than the other granites.

As stated above, two gabbroic bodies cut members of the late Paleozoic group of granitic plutons, and the age of at least one is close to that

TABLE 3
Summary of chemical data

Pluton		SiO_2 %	Al_2O_3 %	TiO_2 %	Fe as		MgO %	MnO %	CaO %	K_2O %	Na_2O %	Rb ppm	Sr ppm
					Fe_2O_3 %	FeO %							
<u>Main (Eastern) group</u>													
Castalia (4)*	\bar{x}	76.2	13.5	0.08	0.60	0.10	-	0.81	4.66	3.97	270	34	
	s	1.9	0.4	0.01	0.01	0.01	-	0.05	0.19	0.19	13	2	
Lilesville (6)	\bar{x}	65.6	15.7	0.87	4.48	1.17	0.09	2.41	4.23	3.82	125	267	
	s	2.0	0.5	0.16	0.79	0.27	0.01	0.30	0.59	0.12	7	14	
Catawba (1)	\bar{x}	72.3	15.0	0.27	1.94	0.46	0.12	0.55	5.16	3.40	228	171	
Pageland (6)	\bar{x}	70.0	14.5	0.40	2.89	0.61	0.07	1.96	4.72	3.49	141	268	
	s	1.3	0.8	0.21	0.62	0.34	0.02	0.58	0.47	0.40	21	75	
Liberty Hill (15)	\bar{x}	71.8	15.0	0.36	2.09	0.47	0.04	1.52	4.87	3.24	182	189	
	s	3.0	0.8	0.19	0.95	0.33	0.01	0.55	0.45	0.25	42	97	
Winstsboro (31)	\bar{x}	72.6	14.0	0.26	2.35	0.29	0.05	0.92	5.57	3.51	166	87	
	s	3.2	1.5	0.18	1.56	0.24	0.02	0.57	0.81	0.69	64	84	
Clouds Creek (4)	\bar{x}	70.0	15.0	0.74	4.00	0.94	0.07	1.30	4.10	3.05	153	144	
	s	1.5	0.3	0.07	0.87	0.05	0.01	0.51	0.52	0.04	7	9	
Danburg (1)	\bar{x}	69.5	15.2	0.59	3.27	0.88	0.06	2.27	5.04	3.62	199	361	
	s	72.8	14.1	0.30	2.14	0.66	-	1.27	4.74	4.06	187	83	
Sparta (29)	\bar{x}	3.9	1.4	0.18	0.92	0.55	-	0.85	0.67	0.49	54	85	
	s	68.7	15.3	0.40	2.80	0.68	-	1.75	6.05	3.41	-	-	
Appling (2)	\bar{x}	0.8	0.0	0.02	0.45	0.12	-	0.04	0.78	0.01	-	-	
	s	71.1	14.2	0.5	3.1	-	0.05	1.3	4.7	2.8	-	-	
Siloam (40)	\bar{x}	71.9	14.4	0.35	2.42	0.53	0.06	1.31	4.99	3.49	178	138	
	s	3.7	1.3	0.24	1.33	0.44	0.02	0.75	0.79	0.94	54	107	
<u>All Main (Eastern) group</u>													
<u>Except Siloam (99)**</u>													
York - Churchland (Western) group	\bar{x}	69.6	16.0	0.69	2.35	0.96	0.04	1.70	4.42	3.40	139	939	
	s	3.0	0.6	0.53	1.53	0.74	0.02	0.16	0.40	0.54	26	499	
Bald Rock-Churchland (Western) group	\bar{x}	71.0	15.8	0.52	1.85	0.63	0.05	1.29	4.64	3.37	153	743	
	s	1.0	0.2	0.17	0.50	0.14	0.01	0.33	0.28	0.42	30	103	
Gastonia (1)	\bar{x}	69.2	16.5	0.58	2.40	1.00	0.06	1.61	4.32	2.92	181	608	
	s	70.9	15.2	0.34	1.91	0.57	0.03	2.18	3.47	4.12	118	618	
Clover (4)	\bar{x}	1.4	0.4	0.04	0.63	0.14	0.01	0.40	0.28	0.46	10	99	
	s	71.0	14.9	0.41	2.46	0.68	0.06	2.35	3.93	3.63	117	478	
York (7)	\bar{x}	1.5	0.6	0.09	0.39	0.17	0.03	0.66	1.43	0.63	65	142	
	s	70.7	15.4	0.46	2.19	0.69	0.05	1.96	4.06	3.61	133	636	
York - Churchland (Western) group (18)	\bar{x}	1.5	0.7	0.20	0.62	0.26	0.02	0.62	0.98	0.58	45	228	
	s												

* Number following each pluton is the number of samples analyzed; for some samples, MnO, Rb and Sr concentrations were not determined.

** Siloam values not included in total because individual values were not available.

of the intruded granite, suggesting a genetic relationship. However, it seems best not to consider the suite of post-metamorphic plutons as bimodal in composition because there is so little gabbro relative to granite.

Linear belts of granitic plutons [Main (Eastern) and York-Churchland (Western) groups] suggest generation of magmas above a subduction zone approx 300 m.y. ago. Strong and others (1974) have noted that geochemical data for several locations in the Appalachian-Caledonian mountain system suggest a subduction zone dipping in a present easterly or southeasterly direction during much of the Paleozoic era. Chemical data for the late Paleozoic granitic plutons of the southeastern Appalachians have been compared to chemical data from areas where depth to subduction zones has been determined from seismic data. Using Rb/K, Rb versus SiO₂ and K₂O versus SiO₂ as suggested by Ninkovich and Hayes (1972), the Main (Eastern) group of plutons may be 200 to 150 km above an ancient subduction zone and the York-Churchland (Western) group may be about 150 km above one. Thus, if both belts of plutons formed above the same subduction zone, it apparently is dipping gently to the east. Palacios and Oyarzun (1975) have noted that Sr contents for andesitic rocks can be used to determine depth to Benioff zones. Assuming that their observations may be extended to granitic rocks, and that both belts of plutons formed above a single subduction zone, the subduction zone would be dipping to the west. Other possible indicators

TABLE 4
New major element chemistry

Pluton and sample number	SiO ₂	Al ₂ O ₃	TiO ₂	Fe as Fe ₂ O ₃	MgO	CaO	K ₂ O	Na ₂ O
<i>Castalia</i>								
NC-293	73.8	14.1	0.09	0.62	0.10	0.85	4.77	4.25
1141	75.9	13.4	0.08	0.59	0.10	0.84	4.83	3.88
1144	78.4	13.2	0.08	0.59	0.09	0.75	4.40	3.86
1147	76.6	13.3	0.08	0.66	0.09	0.80	4.65	3.89
<i>Lilesville</i>								
1285	62.1	16.6	0.98	5.37	1.44	2.85	4.57	3.96
1290	67.6	15.1	0.85	3.99	0.98	1.93	5.27	3.64
<i>Pageland</i>								
1302	71.0	13.6	0.38	2.46	0.37	1.02	5.40	3.28
<i>Appling</i>								
GA-27	68.1	15.3	0.38	2.48	0.59	1.77	6.60	3.41
GA-28	69.2	15.3	0.47	3.11	0.76	1.72	5.50	3.40
<i>Sparta</i>								
GA-34	64.4	15.6	0.70	4.45	1.28	3.28	4.13	3.88

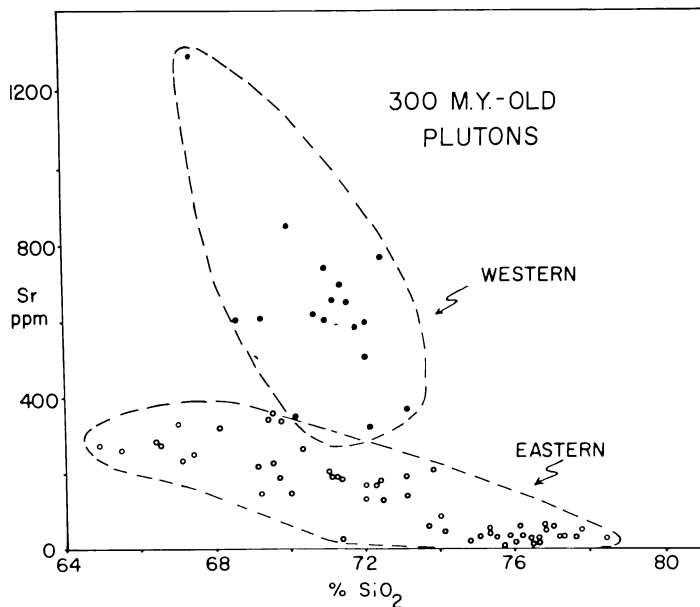


Fig. 5. SiO_2 versus Sr for samples from the Main (Eastern) and York-Churchland (Western) groups of late Paleozoic granitic plutons.

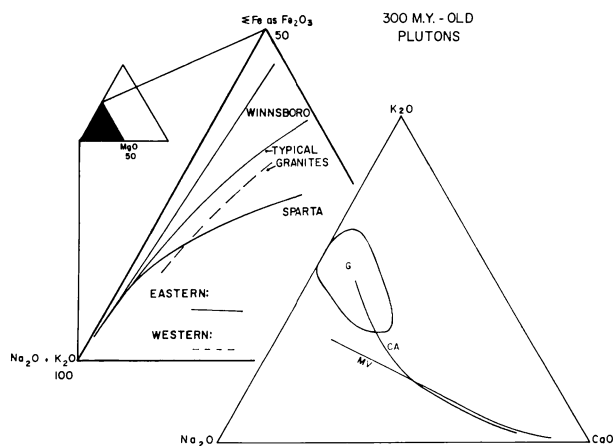


Fig. 6. K_2O - Na_2O - CaO and AMF diagrams. All samples of the late Paleozoic plutons from the central and eastern Piedmont plot within the field labeled G. The line CA represents the trend shown by samples from the Southern California batholith (Larson, 1948). MV represent a Na-rich trend shown by volcanic rocks from the Carolina slate belt (Butler and Ragland, 1969). On the AMF diagram most samples from the Main (Eastern) and York-Churchland (Western) groups define similar trends. Samples from the Winnsboro pluton of the Main (Eastern) group are enriched in Fe, and those from the Sparta pluton are depleted.

of depth of subduction zone(s) such as $K_2O + Na_2O$ versus SiO_2 , K_2O/Na_2O versus SiO_2 , and $(Sr^{87}/Sr^{86})_0$ versus SiO_2 also yielded inconsistent or inconclusive results. Possibly these parameters yield such results for our samples because the granites formed above more than one subduction zone.

Geophysical data.—Relatively few of these granitic plutons have been investigated in detail by geophysical techniques. On the basis of gravity data, Waskom and Butler (1971) concluded that the Lilesville pluton is sheet- or tongue-like with a maximum thickness of about 2.8 km. The large positive Bouguer anomaly (12-14 mgal residual) associated with this granitic pluton is caused by the Pee Dee gabbro which intrudes the eastern portion of the granitic pluton and by the presence of a mica gneiss unit below the granitic pluton.

The simple Bouguer gravity anomaly map of South Carolina (Talani, Long, and Bridges, 1975) shows significant negative anomalies for a number of the late Paleozoic plutons. The Pageland, Liberty Hill, Winnsboro, Edgefield, and the adjacent Catawba-Roddey plutons are all well-defined on this map. The largest anomalies are shown by several of the plutons with the smallest areas of exposure: the Catawba-Roddey (−30 to −35 mgal) and the Edgefield (−15 to −20 mgal) plutons. The Catawba-Roddey anomaly also corresponds to the location of the older (~535 m.y.) Edgmoor pluton (Fullagar, 1971). A large anomaly of −20 to −25 mgal just to the south of Columbia may correspond to the Columbia pluton.

Bell and Popenoe (1976) conducted a gravity study of the area that includes the Pageland and Liberty Hill plutons of South Carolina. They also included in their discussion the Lilesville pluton in North Carolina, which was previously studied by Waskom and Butler. The granitic rocks of these three plutons are very similar in appearance. The Pageland and Liberty Hill plutons are steep-sided intrusives, the Liberty Hill having a single root and the Pageland three roots.

Initial Sr^{87}/Sr^{86} ratios.—Initial Sr^{87}/Sr^{86} ratios are now available for 17 late Paleozoic granitic plutons of the eastern Piedmont; these values plus sources of information are given in table 1. With few exceptions, these initial ratios range from 0.7024 to 0.7052, a range that is quite low when compared to other granitic rocks of generally similar age (see, for example, the compilation in Faure and Powell, 1972, p. 139-142). In addition to these values for granitic plutons, initial ratios are available for several postmetamorphic gabbroic bodies. The Pee Dee gabbro is known to be essentially the same age as the Lilesville pluton it intrudes, and the initial Sr^{87}/Sr^{86} ratio is analytically identical (S. A. Kish, personal commun.). Two other postmetamorphic gabbroic plutons assumed to be late Paleozoic have initial ratios of 0.7035 to 0.7045 (Fullagar, 1971).

Figure 7 is a plot of initial Sr^{87}/Sr^{86} ratio versus age for the granitic rocks listed in table 1. Also shown for comparison are values for 690 to 510 m.y.-old and 430 to 380 m.y.-old intrusive rocks from the Charlotte

and Carolina slate belts of North Carolina, South Carolina, and Georgia. We believe this to be a complete compilation of all published data for late Precambrian to early Paleozoic intrusive rocks from this region. Also included are unpublished data from our laboratory.

The “oceanic basalt field” in figure 7 is taken from Faure and Powell (1972, p. 45), where a detailed explanation of this type of diagram can be found. The “oceanic basalt field” shows the approximate $\text{Sr}^{87}/\text{Sr}^{86}$ ratios of the mantle source regions for oceanic basalts for the period 750 m.y. ago to the present. This field has been drawn by extending lines from the primordial meteorite value (0.699) for the $\text{Sr}^{87}/\text{Sr}^{86}$ ratio 4.6×10^9 yr ago to the present-day approximate maximum (0.706) and minimum (0.702) values observed for oceanic basalts. The $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of the source regions increases through time because of the decay of Rb^{87} to Sr^{87} . It is an oversimplification to show this field bounded by straight lines as the Rb/Sr ratio of the mantle probably decreased with time, so that the boundary lines would be convex upward. The field labeled “continental crust” is somewhat arbitrary as to position, but it is intended to represent typical sialic crust with an average Rb/Sr of 0.25. Taylor (1965) considers 0.25 to be a reasonable average Rb/Sr ratio for continental crust; additional support for this ratio is given below. The lower portion of the “continental crust field” assumes an age of 750 m.y. which is approximately the age of the oldest rocks found thus far in the eastern Piedmont (Black and Fullagar, 1976); the upper portion of the field arbitrarily assumes an age of 1000 m.y. Still older crust would shift the field for continental crust vertically in figure 17; if the crust has an average Rb/Sr ratio greater than 0.25, the slope of the field would be steeper.

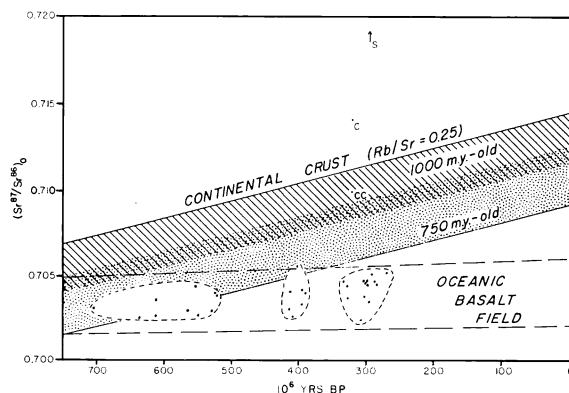


Fig. 7. Initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios versus age for granitic and volcanic rocks of the central and eastern Piedmont. Data given in table 1 were used in this figure, plus information from Hills and Butler (1969), Fullagar (1971), Black and Fullagar (1976), Butler and Fullagar (1978), and Fullagar (unpub. data). The lines representing the oceanic basalt field are from Faure and Powell (1972, p. 26). Construction of the continental crust field is explained in the text. CC, C, and S represent the Clouds Creek, Castalia, and Sparta plutons, respectively. Initial $\text{Sr}^{87}/\text{Sr}^{86}$ values for the Sparta pluton vary but are as high as 0.741 (Fullagar and Butler, 1976).

A granitic rock produced by melting and subsequent crystallization of sialic crust would be expected to have an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio that plots within the "continental crust field." A granite produced from a magma contaminated by a significant amount of such crust usually would have an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio that plots above the "oceanic basalt field." Only if the sialic crust were very young at the time of anatexis or contamination could a granitic rock produced as outlined above have an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio within the "oceanic basalt field." A good discussion on anatexis of young sedimentary rocks is given by Peterman and others (1967). For a discussion of granitic rocks apparently produced by anatexis see Pankhurst and Pidgeon (1976).

With three exceptions, initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios for the late Paleozoic group of granitic rocks plot in the field for oceanic basalts. The possibility must be considered that these low initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio granitic rocks are the products of anatexis of continental crust. No Sr isotopic or Rb/Sr ratio information is available for the country rocks of the Charlotte belt, but some is available for the Carolina slate belt. The country rocks in the Carolina slate belt are dominantly pyroclastic and epiclastic volcanic rocks with a small percentage of lava flows. They range in composition from basalt to rhyolite with an average composition close to that of andesite. Analyzed andesites have average Rb/Sr ratios of 0.25 (P. D. Fullagar, unpub. data). Several units of intermediate to felsic composition have ages >500 m.y. and initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios of 0.703 to 0.704 (Hills and Butler, 1969; Butler and Fullagar, 1975; W. W. Black, ms). Calculations show that 300 m.y. ago these rocks of intermediate to felsic composition had $\text{Sr}^{87}/\text{Sr}^{86}$ ratios in excess of 0.705, a value greater than the initial ratio for most of the late Paleozoic granites. Thus rocks of these Rb/Sr and Sr isotopic compositions could not be the source for the low initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio granites. Partial melting of the mafic portions of the Carolina slate belt probably could have produced the observed initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios. Whitney, Wenner, and Stormer (1977) have suggested that anatexis of amphibolitic lower crust may have resulted in the granitic magmas. Obviously, a large amount of partial melting would be required to produce the quantity of late Paleozoic granite found in the central and eastern Piedmont.

Because nearly all the late Precambrian to early Paleozoic granitic rocks of the southern Appalachians have initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios within the "oceanic crust field," we suggest there may be no >1000 m.y.-old sialic basement beneath most or perhaps all of the central and eastern Piedmont from North Carolina to Georgia, for otherwise many younger granitic rocks would have initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios higher than those observed, due to either anatexis or contamination of magmas. Basement rocks with ages of 1000 m.y. apparently are present in the eastern Piedmont of Virginia (Glover and others, 1978).

Three of the late Paleozoic granitic plutons do have high initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios, ranging from 0.710 to 0.741 (table 1). Interestingly, these granitic rocks either are found in or immediately adjacent to anticlinoria

that expose the structurally lowest rocks, highest in metamorphic rank, and therefore possibly the oldest rocks of the eastern Piedmont. The Castalia granite is in the Wake-Warren anticlinorium in North Carolina and the Sparta granite complex in the Kiokee anticlinorium in Georgia. The Clouds Creek pluton in South Carolina is separated from the Kiokee anticlinorium by a fault. We suggested that the high initial ratios for granites from the Sparta complex resulted from remobilization of at least radiogenic Sr^{87} in older (>520 m.y.) granitic rocks (Fullagar and Butler, 1976). The Castalia and Clouds Creek plutons may simply reflect contamination by sialic crust.

Recent papers (Hamet and Allegre, 1976; Brown, 1977; Armstrong, Taubeneck, and Hales, 1977) discussing initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios and genesis of granitic magmas have suggested that such magmas usually contain a prominent component derived from the mantle. Considering the low initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios and the amount of granite produced, such an origin for these southern Appalachian granites seems very reasonable.

OTHER LATE PALEOZOIC PLUTONS IN THE APPALACHIANS

Granitic plutons of this age are uncommon in the central and northern Appalachians. Wright, Sinha, and Glover (1975) report that one of the plutons mapped as Petersburg Granite in Virginia has a U-Pb zircon age of 330 ± 8 m.y. This pluton is described as a quartz monzonite probably only slightly affected by metamorphism. Wright and others suggest that this 330 m.y. age therefore may define a minimum age for metamorphism in the eastern Piedmont of Virginia.

The Maromas granite gneiss of eastern Connecticut has a Rb-Sr whole-rock age of 279 ± 10 m.y. with an initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratio of 0.712 ± 0.002 (Brookins and Hurley, 1965). This unit occurs primarily as a dome and as several lenses within other units; it is predominantly a granite gneiss with microcline augen. Brookins and Hurley interpret the results to indicate that the Maromas is intrusive and was emplaced 279 ± 10 m.y. ago.

Hercynian activity is reported by Bell and Blenkinsop (1977) for granitic rocks in Newfoundland. Rb-Sr whole rock data for four granitic units give ages of 312, 327, 327, and 338 m.y. These ages are within or very close to the range in ages for southern Appalachian plutons reported in this paper. These Newfoundland granites have relatively high initial $\text{Sr}^{87}/\text{Sr}^{86}$ ratios, ranging from 0.715 to 0.722. Three of these granites are sheared or cataclastically affected by regional deformation, and the fourth is a non-foliated peralkaline granite that intrudes a zone of weakness. Bell and Blenkinsop conclude that the ages indicate either intrusive or deformational events.

LATE PALEOZOIC PLUTONS AND THEIR IMPLICATIONS FOR LATE PALEOZOIC TECTONIC HISTORY OF THE SOUTHERN APPALACHIANS

There is abundant evidence for late Paleozoic (Permian) deformation and retrograde metamorphism in the Blue Ridge province of the

southern Appalachians and for deformation in the Valley and Ridge province (King, 1964; Dennison, 1976). [Many investigators now suggest that some of the deformation began well before Permian time (for example, Cooper, 1964; King, 1964; Odom and Fullagar, 1973).] The implication normally drawn from the late Paleozoic deformation of the Blue Ridge is that there must have been corresponding events in the Piedmont to the east. Except in several plutons in South Carolina, we find no evidence for such events in the 325 to 265 m.y.-old plutons of the central and eastern Piedmont.

Many authors (for example, McKerrow and Ziegler, 1972; Dewey and Kidd, 1974) have suggested that in early Permian time, North America south of New York collided with Africa south of the South Atlas fault. The 325 to 265 m.y. ages of the post-metamorphic plutons of the southern Appalachians require that these plutons formed just prior to or perhaps in several cases coincident with this continent-continent collision. Such a compressional event could be the cause of the westward thrusts in the Blue Ridge and the folds and thrusts of the Valley and Ridge province (see, for example, Hatcher, 1972).

If North America-Africa collision were directly responsible for tens of kilometers of thrusting in the Blue Ridge (Bryant and Reed, 1970), it seems reasonable that the rocks of the central and eastern Piedmont should reflect this deformation. However, few of the late Paleozoic group of plutons show any signs of deformation, either in the field or in thin section. Only the Clouds Creek and Lexington plutons show significant evidence of deformation. The lack of widespread compressional deformation suggests that, if collision occurred, crustal adjustments in the central and eastern Piedmont took place along major fault zones. Hatcher and others (1977) have suggested the existence of a major fault system in the eastern Piedmont.

An alternate and preferred explanation for the lack of deformation in the Pennsylvanian-Permian plutons is that the continent-continent collision did not directly cause the observed deformation to the west of the Piedmont but mainly produced uplift of the Piedmont. This uplift ultimately resulted in gravitational spreading which produced the thrusting, faulting, and folding to the west. Dennison (1976) has proposed such a model for the formation of the structures in the Valley and Ridge province. Uplift of the Piedmont during Pennsylvanian-Permian time is suggested by the Appalachian basin receiving sediments from east of the Brevard Zone during this time (Dennison, 1976). Also, mica ages for the eastern Piedmont (Long, Kulp, and Eckelmann, 1959; Kulp and Eckelmann, 1961) probably indicate significant uplift and cooling of this region (Fullagar, 1971).

The deformed and metamorphosed about 300 m.y.-old plutons in the Kiokee belt of South Carolina provide evidence that Alleghanian deformation and metamorphism did occur in the southern Appalachian Piedmont but only in its easternmost part. Secor and others (1978) suggested that the Kiokee belt may be an exotic slice of rock emplaced along

the eastern flank of the Appalachian orogen during the Alleghanian orogeny.

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