

U-Pb Dating of Granites from the Charlotte Belt of the
Southern
Appalachians

by

Erik A. Hund

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APPROVED:

A. K. Sinha, Chairman

D. A. Hewitt

S. C. Eriksson

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Erik Adrian Hund

Committee Chairman: A. K. Sinha
Department of Geological Sciences

(ABSTRACT)

New U-Pb zircon ages from plutons in the Charlotte belt of the southern Appalachians have provided evidence of Cambro-Ordovician and Siluro-Devonian magmatic activity. Several U-Pb zircon ages of Cambro-Ordovician plutons predate their Rb-Sr whole rock ages by as much as 60 m.y., suggesting a post emplacement disturbance of the Rb-Sr isotopic systems. Comparison of geologic setting, chemistry, and temporal and spatial distribution of Charlotte belt Siluro-Devonian plutons with those of other tectonic environments, specifically plutons from tensional environments, suggests a model for strike-slip accretion.

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1. INTRODUCTION

The southern Appalachians is a region of multiple geologic provinces (King, 1955). There have been many papers written describing the tectonic histories of part or all of the southern Appalachians (Odom and Fullagar, 1973; Glover and Sinha, 1973; Rankin, 1975; Hatcher, 1972, 1978; Cook and others, 1979; Hatcher and Odom, 1980; Harper and Fullagar, 1981; Pavlides, 1981; Zen, 1981; Williams and Hatcher, 1982; Sinha and Zietz, 1982; Higgins and others, 1984; Sinha and others, 1985). Many of these tectonic models have been supported by isotopic dating of igneous and metamorphic rocks. However, with limited numbers of geochronologic studies the models are not very well constrained. By confining the study area to a specific geologic province and concentrating on a narrow period of geologic time, it may be possible to further enhance our understanding of the tectonic processes that have occurred in the southern Appalachians.

One of the methods of understanding the tectonic processes affecting an area is by characterizing the thermal history of the region, which can be studied by understanding the temporal and spatial distribution of igneous rocks, as

they are the most direct indicators of thermal anomalies in the crust.

The method used in this investigation to understand the temporal aspects of the thermal history was U-Pb dating of zircons from granitic plutons. The area of study was within a segment of the Charlotte belt, which extends from Virginia to Georgia. U-Pb zircon ages were used to determine crystallization ages of granitic plutons and to provide evidence, if any, relating to the source of the granitic magmas through the presence of an inherited lead fraction.

The plutons selected for U-Pb geochronologic studies were the Leatherwood, Melrose, Shelton, Yadkin, Southmont, Lowrys North, Pacolet Mills, Concord, Woodleaf, and Bald Rock plutons. To provide checks on U-Pb ages, several of these plutons were also dated by the Rb-Sr method.

Previous studies in the southern Appalachians have suggested the existence of linear belts of igneous rocks confined to specific geologic provinces that may or may not be associated with corresponding metamorphic and deformational events (Hatcher, 1972, 1978; Odom and Fullagar, 1973; Rankin, 1975; Williams and Hatcher, 1982). Ages of crystallization in the southern Appalachians vary from one geologic province to the next, but in general fall into three episodes of plutonism between the Cambrian and the Carbonifer-

ous (Overstreet and Bell, 1965a; Butler and Ragland, 1969; Fullagar, 1971; Fullagar and Butler, 1979; Speer and others, 1980; Sinha and others, 1985). Higgins and others (1984) have suggested an opposing point of view, in which the metamorphism, deformation, and periods of igneous intrusion in the southern Appalachians from Alabama to North Carolina were continuous processes lasting from the Ordovician to the Late Carboniferous. Numerous geochronologic studies of plutons in the southern Appalachians have been related to periods of regional metamorphism, specifically the Taconic, Acadian, and Alleghanian orogenic events (Butler, 1972; Woodward, 1958; Rodgers, 1970, 1971), which are not necessarily related to the three episodes of plutonism stated above.

This study evaluates the thermal history in the Charlotte belt during the Siluro-Devonian and also provides a brief discussion of the thermal history in the Charlotte belt during the Cambro-Ordovician. Although the study was designed to evaluate only the Siluro-Devonian events, new U-Pb data acquired in this study suggested that some of the proposed 400 m.y. old plutons were significantly older (~460 m.y.).

2. REGIONAL GEOLOGY

The southern Appalachians have been divided into several different geologic provinces, each with its own geologic history. These geologic provinces are the Valley and Ridge, Blue Ridge, Piedmont and Coastal Plain (King, 1955; Williams and Hatcher, 1982). The Blue Ridge province can be subdivided into three smaller belts, and the Piedmont province can be further subdivided into six major northeasterly trending geologic belts. These include the Inner Piedmont, Kings Mountain belt, Charlotte belt, Kiokee belt, Raleigh belt and Carolina slate belt (Figure 1) (King, 1955; Hatcher, 1972, 1978; Hatcher and others, 1980).

The Blue Ridge is a northeasterly trending group of belts, involving a western, a central, and an eastern belt consisting of Upper Precambrian and Lower Paleozoic rocks with complex geologic histories (Rankin and others, 1973; Rankin, 1975; Hatcher, 1972, 1978; Sinha and Bartholomew, 1984; Bartholomew and Lewis, 1984). The western and eastern belts are composed of a complex assemblage of low-grade metasedimentary rocks, with a major distinction between the two belts being the presence of metavolcanic and plutonic rocks in the eastern belt (Hatcher, 1978). The central belt is composed of Precambrian crystalline basement rocks and

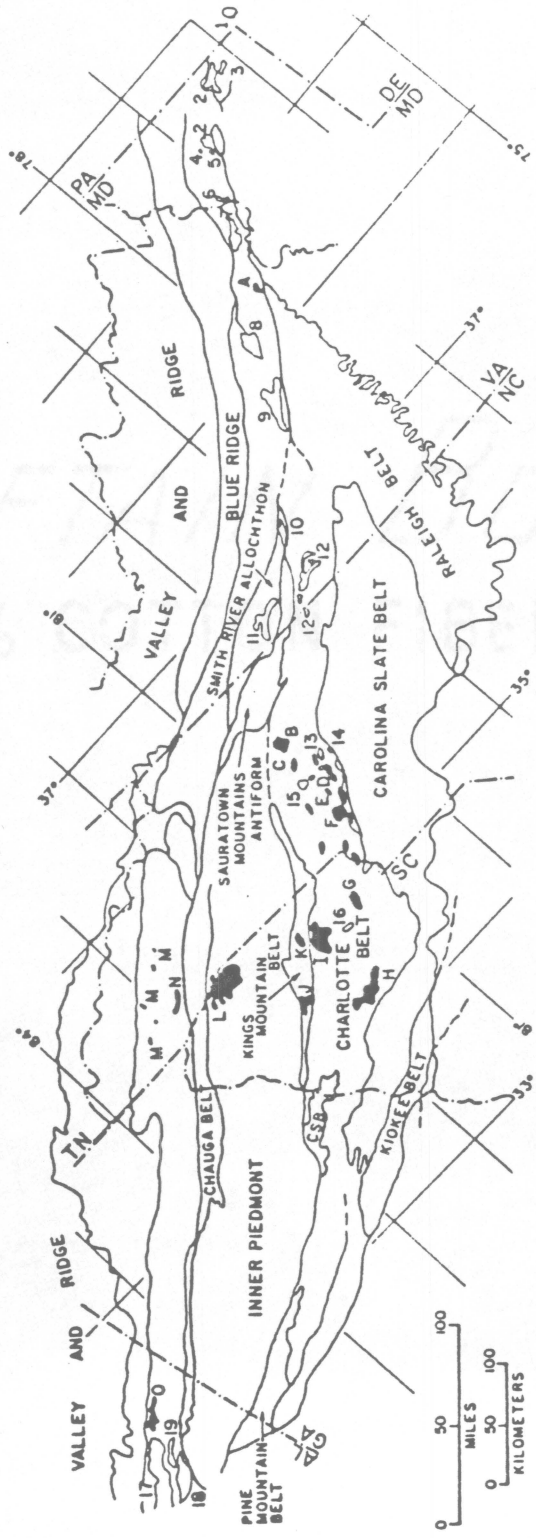


Figure 1. Distribution of Cambro-Ordovician and Siluro-Devonian plutons in the Southern Appalachians.

younger metasedimentary rocks (Hatcher, 1978). To the east of the Blue Ridge lies the Inner Piedmont, a complex assemblage of metamorphic rocks and ultramafic to felsic plutons (Bentley and Neathery, 1970; Bryant and Reed, 1970; Goldsmith and others, 1978; Griffith, 1974; Schamel and others, 1980; Lemmon, 1980; Hatcher and others, 1980). East of the Inner Piedmont lies the greenschist to amphibolite facies metamorphic rocks of the Charlotte belt. They are intruded by Paleozoic plutons ranging from gabbro to diorite to syenite to granite (Fullagar, 1971; Fullagar and Butler, 1979; Gilbert and others, 1982; Butler and Ragland, 1969; Goldsmith and others, 1978). The lower-grade Precambrian to Cambrian metamorphic rocks of the Carolina slate belt are situated to the east (Butler and Ragland, 1969; Glover and Sinha, 1973; Seiders, 1978; Harris, 1982) and this sequence is intruded by plutons of various ages (Hills and Butler, 1969; Fullagar, 1971; Wright and Seiders, 1980; Glover and Sinha, 1973). The Raleigh and Kiokee belts consist of medium to high-grade metamorphic rocks which are intruded by Hercynian gabbroic to granitic plutons (Parker, 1978; Stoddard and others, 1978; Secor and Snoke, 1978). The metamorphic rocks of the Kiokee and Charlotte belts have been correlated with those of the Carolina slate belt (Overstreet and Bell, 1965b; Daniels, 1974; Secor and Snoke, 1978; Goldsmith and others, 1978; Butler and Ragland, 1969).

Recently, an alternative model to the belt concept for explaining the regional geology of the southern Appalachian orogen from Alabama to North Carolina has been described by Higgins and others (1984). It is suggested that the crystalline part of the orogen consists of two large terranes of folded thrust stacks, the Georgiabama and the Little River thrust stacks. In such a model the Georgiabama thrust stack is composed of rocks from the Blue Ridge, Chauga and Inner Piedmont belts, while the Little River thrust stack is composed of rocks from parts of the Inner Piedmont, Pine Mountain, Carolina slate, Charlotte, Kiokee and Kings Mountain belts (see Fig 1). A more complete description of the rock units in these two thrust stacks is given in Higgins and others (1984). Similarly, a detailed description of the geologic belts that correspond to the two thrust stacks are given in the references listed in the preceding paragraphs.

3. CAMBRO-ORDOVICIAN PLUTONS

Cambro-Ordovician plutons of the southern Appalachians are dispersed in areas of the Blue Ridge, Charlotte belt and Smith River allochthon and those with published mineral ages are shown in Figure 1. These plutons intrude amphibolite

facies metavolcanic and metasedimentary rocks of the Charlotte belt and Smith River allochthon. They vary in area from 13 to 430 square km, but generally are less than 100 square km. Cambro-Ordovician plutons that were dated in this study are the Leatherwood, Melrose, Shelton, Yadkin, Southmont and Lowrys North plutons.

The plutons are generally medium to coarse-grained, hypidiomorphic granite to quartz monzonite. The mineral phases consist of some or all of the following: plagioclase, microcline, quartz, biotite and perthite with accessory apatite, sphene, zircon, epidote, magnetite, pyrite and molybdenite. Secondary minerals include muscovite, chlorite, garnet, calcite, fluorite and epidote.

4. SILURO-DEVONIAN PLUTONS

Siluro-Devonian plutons of the southern Appalachians are distributed throughout the Blue Ridge, Inner Piedmont, Kings Mountain and Charlotte belts. Plutons with published mineral ages are shown in Figure 1. Smaller plutons which are thought to be of Siluro-Devonian age (Kish, 1983; Butler, 1984; Fullagar, 1971; Butler and Fullagar, 1978; Goldsmith and others, 1978) are also shown in Fig. 1. Plutons

used in this study for new U-Pb ages are the Pacolet Mills, Bald Rock, Concord and Woodleaf plutons. They intrude meta-volcanic and metasedimentary rocks of the Charlotte and Kings Mountain belts. They vary in area from 3 to 260 square km. Pacolet Mills, Concord, Woodleaf and Bald Rock plutons.

In general, the Siluro-Devonian plutons are hypidiomorphic or porphyritic, medium to coarse-grained granite, quartz monzonite, syenite and gabbro (Butler and Ragland, 1969). The felsic plutons consist of combinations of some or all of plagioclase, microcline, perthite, quartz and biotite with accessory sphene, zircon, apatite, muscovite, allanite, epidote, hornblende, magnetite, pyrite, molybdenite, chalcopyrite, clinopyroxene, monazite and riebeckite. The plutons may also contain secondary epidote, calcite, chlorite, muscovite and fluorite. Mafic plutons are composed of varying amounts of plagioclase, pyroxene, hornblende, olivine, biotite and accessory apatite, magnetite, ilmenite, hematite and iron sulfides (McSween and others, 1984).

5. ANALYTICAL METHODS FOR U-PB AGES OF ZIRCONS

Zircons were separated from twenty five to fifty kg of fresh rock, using a Wilfley table, Franz magnetic separator, and the heavy liquid solutions bromoform and clerici. Zircons were then picked and acid-washed for 30 minutes in warm 8N nitric acid before picking to remove sulphides. After handpicking, the zircon sample was washed in 8N, teflon-distilled nitric acid. Ten to thirty milligrams of sample were then dissolved in an hydrofluoric-nitric acid mixture for five days in teflon bombs at 220 degrees Centigrade. Pb and U fractions were separated using cation exchange chemistry, according to techniques described by Krogh (1973). The U concentrate was loaded using the tantalum oxide-phosphoric acid method onto a rhenium filament outgassed at $< 6 \times 10^{-8}$ torr at 3 amps. The Pb was loaded using the silica gel-phosphoric acid method onto a rhenium filament (Cameron and others, 1969; Sinha and Bartholomew, 1984).

U-Pb analyses were performed on a 35cm, solid-source AVCO mass spectrometer with an on-line LSI/1 minicomputer. For each sample, at least 15 to 20 cycles were measured of the different masses using an automatic peak switching system 208-207-206-204-base. Several measurements of CIT Pb standards analyzed during the course of this study yielded

values of $^{208}\text{Pb}/^{206}\text{Pb} = 2.1777 + .04\%$ (2 s.d.), $^{207}\text{Pb}/^{206}\text{Pb} = 1.0751 + .03\%$ and $^{204}\text{Pb}/^{206}\text{Pb} = 0.06024 + .04\%$. Six analyses of NBS standard 983 gave values of $^{208}\text{Pb}/^{206}\text{Pb} = 73.266 + .04\%$, $^{207}\text{Pb}/^{206}\text{Pb} = 0.071179 + .02\%$ and $^{206}\text{Pb}/^{204}\text{Pb} = 2695.0 + 2.0\%$. Four analyses of NBS standard 500 gave an average value of $^{238}\text{U}/^{235}\text{U} = 1.0019 + 1.0\%$. Total Pb blanks ranged from 1-2 ng, while U blanks were 150 pg. Errors on intercepts on concordia are reported at a two sigma confidence interval.

Decay constants for age calculations were taken from Steiger and Jaeger (1977). The common Pb values used for corrections (400 Ma) are $^{208}/^{204}\text{Pb} = 37.89$, $^{207}/^{204}\text{Pb} = 15.59$, $^{206}/^{204}\text{Pb} = 18.08$ (Stacey and Kramers, 1975).

6. GEOCHRONOLOGY

Zircons were separated into size populations of >150 ($+150$) microns, 75-150 ($+75, -150$) microns and <75 (-75) microns. All zircon populations were placed in a high refractive index oil (1.735) to determine whether overgrowths or zoned crystals were present. Selected samples of zircons are shown in Fig. 2.

Cambro-Ordovician: Zircons from all samples in this group are euhedral to subhedral. Zircons from the Leatherwood (LW), Melrose (ME) and Lowrys North (LN) are colorless to light brown, prismatic and contain small randomly oriented clear, cloudy and opaque inclusions. Some zircons from the Lowrys North pluton are zoned. Zircons from the Yadkin (YA), Southmont (SO) and Shelton (SH) plutons are dark brown. Some of the zircons from the latter three plutons have thin, colorless rims. Zircons from the Salisbury pluton of North Carolina appear to be very similar to those of the Southmont and Yadkin zircons. The Salisbury pluton was not dated in this study, but its crystallization age is believed to be similar to the age of the Southmont and Yadkin plutons (Butler and Fullagar, 1978). Yadkin, Southmont and Shelton zircons are prismatic and contain many microscopic opaque inclusions. Some zircons from the Leatherwood contain cores, but it is difficult to determine whether the cores are metamict zircons or separate mineral species. Length to width ratios are as follows: LW = 3.90:1.0, ME = 3.10:1.0, LO = 2.50:1.0, YA = 2.15:1.0, SO = 2.30:1.0, SH = 1.80:1.0.

Siluro-Devonian: Zircons from plutons of Siluro-Devonian age are euhedral to subhedral, although some from the Concord (CO) syenite are anhedral. Zircons from the Pacolet

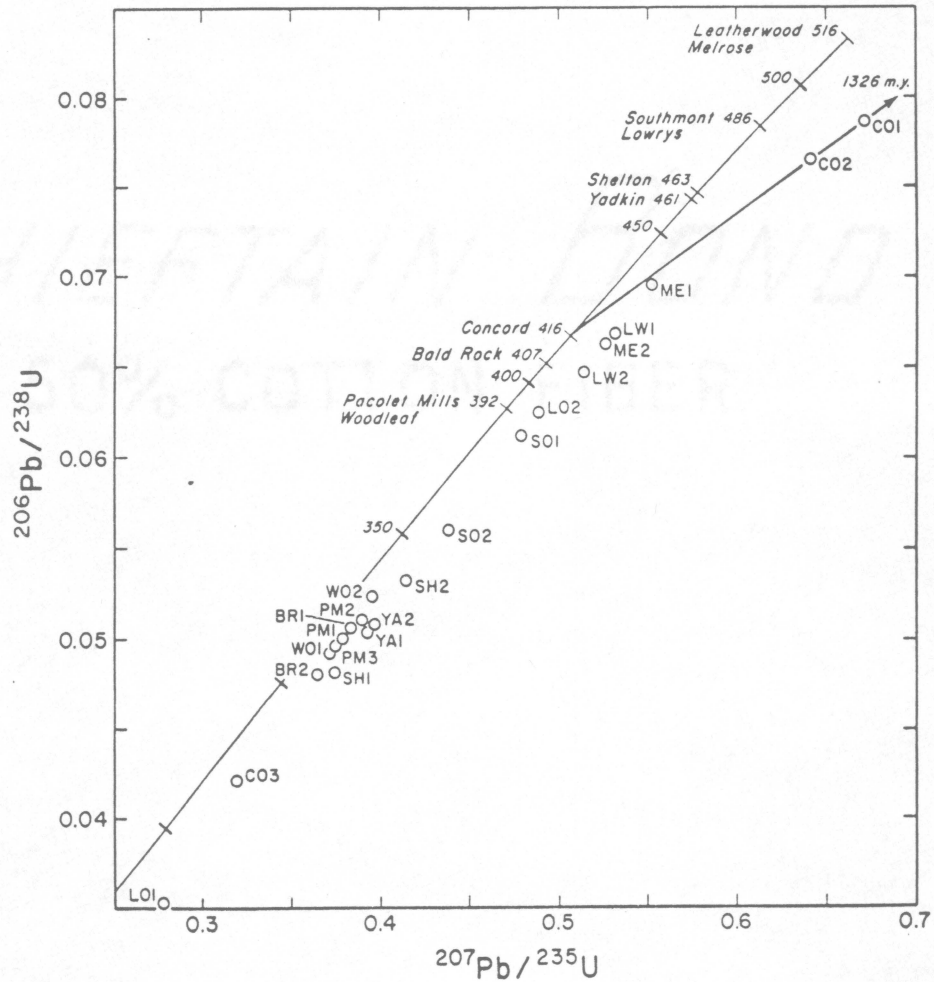


Figure 2. Concordia diagram showing plot of zircon population samples. Refer to Table 3 for pluton names and sizes of zircons.

Mills (PM), Bald Rock (BR), Concord and Woodleaf (WO) plutons are colorless to light brown, are prismatic and contain small randomly oriented cloudy, opaque and clear inclusions. Some zircons from the Woodleaf pluton are dark brown and resemble the zircons from the Southmont and Yadkin plutons. Some zircons from the Bald Rock and Pacolet Mills plutons are zoned. Cores are present in some zircons of the Bald Rock, Concord and Woodleaf plutons, however it is difficult to determine whether the cores are separate mineral species or metamict zircons. Length to width ratios of Siluro-Devonian zircons are: PM = 3.45:1.0, BR = 3.80:1.0, CO = 3.05:1.0, light brown Woodleaf WO = 5.10:1.0 and dark brown Woodleaf WO = 2.10:1.0. All zircons from both age groups are interpreted as crystallizing during formation of the plutonic rocks, and any metamict cores are treated as having separate geologic histories.

Zircon analyses are given in Table 3. Linear extrapolation by regression analyses of the zircon fractions define discordia that intersect the concordia at various upper intercepts and within 30 Ma of zero. The reported errors are related to discordia taken through a zero intercept. The reason the reported errors are relatively small (< 10 million years) is that the discordia are defined by only two or three points. With the exception of the Concord syenite,

the ages are interpreted to be igneous crystallization ages if the episodic lead-loss model of Wetherill (1956) is used.

Cambro-Ordovician Plutons: Zircon fractions of the Lowrys North, a slightly foliated pluton, define a discordia with an upper intercept of 486 ± 6 Ma (Fig. 2). The Southmont and Yadkin plutons, both part of the Salisbury group plutons of Butler and Ragland (1969), have zircon fractions which define discordia that intersect the concordia at 486 ± 0.6 Ma for the Southmont and 461 ± 1.2 Ma for the Yadkin. Zircon fractions from the Shelton granite gneiss define a discordia that intersects the concordia at 463 ± 14 Ma, while zircons from the Melrose granite yield an age of 515 ± 1 Ma.

The age of the Leatherwood granite is defined by a two zircon fraction discordia that intersects the concordia at 516 ± 10 Ma. The $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the two zircon fractions are 11 Ma apart, which may imply that an inherited component is present. Because the $^{206}\text{Pb}/^{204}\text{Pb}$ ratio of zircon fraction LW1 is so low (872), any variation of this ratio will affect the $^{207}\text{Pb}/^{206}\text{Pb}$ age by several million years. A 1% difference in the measured $^{206}\text{Pb}/^{204}\text{Pb}$ ratio (863 and 881) would affect the $^{207}\text{Pb}/^{206}\text{Pb}$ age by 7 m.y. Within analytical error (1.0%) of the $^{206}\text{Pb}/^{204}\text{Pb}$ ratio, the $^{207}\text{Pb}/^{206}\text{Pb}$ ages of the Leatherwood pluton are similar and are interpreted as not having any clearly detectable inher-

TABLE 1

U-Pb and Rb-Sr Ages of Selected Cambro-Ordovician Plutons

Cambro-Ordovician	Age	Ref
1 Arden	502 + 20	08
2 Baltimore gabbro	490 + 20	06
3 Port Deposit	525 + 20	13
4 Woodstock	444	04
5 Ellicott City	448	15
6 Bear Island	469 + 20	12
7 Occoquan	494 + 28	14
8 Ellisville	440 + 08	10
9 Columbia	454 + 09	14
10 Melrose	515 + 01	01
11 Leatherwood	516 + 10	01
	464 + 20	09
12 Shelton	463 + 14	01
	429 + 07	05
13 Yadkin	461 + 01	01
	386 + 08	03
14 Southmont	486 + 01	01
	402 + 02	03
15 Barber gabbro	479 + 24*	02
16 Lowrys North	486 + 06	01
	399 + 04	07
17 Elkahatchee	490 + 13	11
18 Kowaliga	437 + 47	11
19 Zana	460	11

* = Sm-Nd age. Pluton numbers correspond to map in Fig. 1.
 1. This report; 2. McSween and others (1984); 3. Butler and Fullagar (1978); 4. Wetherill and others (1966); 5. Kish (1983); 6. Shaw and Wasserburg (1984); 7. Fullagar (1971); 8. Foland and Muessig (1978); 9. Odom and Russell (1975); 10. Pavlides and others (1982); 11. Russell (1978); 12. Muth and others (1979); 13. Lesser (1982); 14. Mose and Nagel (1982); 15. Sinha, unpublished data.

ited component. The low $^{206}\text{Pb}/^{204}\text{Pb}$ ratios may be caused by sulfide inclusions in the zircons, based upon optical examinations of zircon populations under the microscope.

Siluro-Devonian Plutons: The zircon fractions from the Woodleaf pluton define a discordia which intersects the concordia at 392 ± 4 Ma. Zircon fractions from the Pacolet Mills metagranite yield an age of 392 ± 6 Ma. A duplicate run (PM2) of PM1 plots slightly to the right of the discordia defined by PM1 and PM3 (Figure 2). When all three size fractions are plotted together, the discordia intersects the concordia with a lower intercept of 304 ± 2 Ma and an upper intercept of 1567 ± 15 Ma, suggesting a late Carboniferous magmatic age with a xenocrystic component. But because of the close similarity of the 392 m.y. age with the 415 ± 40 Ma Rb-Sr age of Fullagar and Kish (1981), and 383 ± 5 Ma Rb-Sr age of Fullagar (personal comm., 1986), we favor the Devonian age. However we cannot completely rule out the possibility of inherited zircon in the sample analyzed.

Zircons of the Bald Rock granite yield an age of 407 ± 6 Ma, while three zircon fractions of the Concord syenite define two separate discordia, and are evidence for an inherited radiogenic Pb component. A discordia can be drawn through CO3 with a lower intercept of zero Ma and an upper intercept of 407 Ma. A second discordia can be regressed

TABLE 2

U-Pb and Rb-Sr Ages of Selected Siluro-Devonian Plutons

Pluton	Age	Ref
A Falls Run	408 + 05	10
B Farmington gabbro	399 + 27*	02
C Woodleaf	392 + 04	01
D Salisbury	413 + 04	04
E Kannapolis	362 + 16	03
F Concord gabbro-	407 - 416	01
syenite	407 + 36*	02
	404 + 21	07
G Ogden gabbro	406 + 32*	02
H Newberry	415 + 09	06
I Bald Rock	407 + 06	01
J Gray Court	378 + 24	06
K Pacolet Mills	392 + 06	01
	415 + 40	09
	383 + 05	12
L Caesars Head	400 + 30	08
M Spruce Pine pegmatites	379 - 435	05
N Looking Glass	390 + 27	05
O Bluff Springs	370 + 50	11
	366 + 09	05

*Sm-Nd age. Pluton letters correspond to map in Fig. 1. 1. This report; 2. McSween and others (1984); 3. Butler and Fullagar (1978); 4. Fullagar and others (1971); 5. Kish (1983); 6. Fullagar (1981); 7. Fullagar (1971); 8. Olsen (1984); 9. Fullagar and Kish (1981); 10. Pavlides and others (1982); 11. Russell (1978); 12. Fullagar, personal comm. (1986).

through points CO1 and CO2 with a lower intercept of 416 Ma and an upper intercept of 1326 Ma. Zircons from CO3 do not show any obvious cores when examined petrographically, and no second population is visible optically. The exact age of crystallization of the Concord syenite is uncertain, but probably lies between 407 Ma and 416 Ma, and is similar to published isotopic ages of 407 Ma (McSween and others, 1984) and 404 Ma (Fullagar, 1971). The upper intercept of 1326 Ma indicates that the syenite must have assimilated a portion of Middle Proterozoic crust, or younger sediments with detrital zircons upon ascent of the magma chamber to its present position.

7. COMPARISON OF U-PB AGES WITH RB-SR AGES

A comparison of U-Pb ages obtained in this study with published Rb-Sr ages indicate that not all the ages are in agreement (Table 4). Since there are no Rb-Sr ages on the Woodleaf and Melrose plutons, they are not discussed in the following section.

Cambro-Ordovician: The Yadkin, Southmont, Lowrys North, Shelton and Leatherwood bodies all have U-Pb ages varying from 30 Ma to 80 Ma older than the Rb-Sr whole rock

TABLE 3
U-Pb Zircon Ages of Plutons from the Charlotte Belt

Sample number and mesh size	Concentration (ppm)		Isotopic Composition of Pb (atom percent)		Age (m.y.) $\frac{207\text{Pb}}{235\text{U}}$	$\frac{207\text{Pb}}{206\text{Pb}}$
	Pb	U	$\frac{204\text{Pb}}{206\text{Pb}}$	$\frac{207\text{Pb}}{208\text{Pb}}$		
Cambro-Ordovician						
Lowry's North SC						
LO-1 (+150)	30.5	564.8	.3148	8.105	223	436
LO-2 (+75,-150)	54.7	670.7	.1655	6.324	390	431
Southmont NC						
SO-1 (+75,-150)	139.7	2176.3	.0390	5.263	382	433
SO-2 (-75)	124.0	2088.1	.0455	5.297	352	432
Yadkin NC						
YA-1 (+75,-150)	174.8	2972.1	.1797	6.967	318	408
YA-2 (-75)	183.8	2890.1	.2437	7.640	320	407
Shelton NC						
SH-1 (+150)	131.2	2406.5	.0635	5.263	303	405
SH-2 (+75,-150)	130.2	2262.6	.0522	5.306	334	414
Leatherwood VA						
LM-1 (+150)	23.3	308.6	.0911	5.819	416	468
LM-2 (+75,-150)	29.0	414.9	.0241	4.963	404	457
Melrose VA*						
ME-1 (+75,-150)	24.3	286.7	.0827	5.422	433	462
ME-2 (-75)	30.6	369.4	.0644	5.167	414	462
Siluro-Devonian						
Hoodleaf NC						
HO-1 (+75,-150)	280.0	5143.8	.0788	5.486	311	338
HO-2 (-75)	195.7	3353.4	.0556	5.061	329	341
Bald Rock SC						
BR-1 (+150)	53.3	994.9	.0288	4.715	318	352
BR-2 (-75)	50.1	909.9	.0284	4.540	303	355
Concord NC						
CO-1 (+150)	3.1	29.3	.0613	4.922	489	611
CO-2 (+150)	-	-	-	-	476	573
CO-3 (+75,-150)	5.0	76.4	.0528	3.860	265	353
Pacolet Mills SC						
PM-1 (+75,-150)	34.7	589.2	.1202	5.841	316	334
PM-2 (+75,-150)	36.1	-	.0878	5.344	321	371
PM-3 (-75)	33.4	554.0	.1119	5.675	313	342

Note: Sample numbers correspond to labels in Figure 2. Blank Pb corrections are in Analytical Techniques section. $238\text{U}/235\text{U} = 137.88$. Isotopic composition of Pb assumed to be $204\text{Pb}:206\text{Pb}:207\text{Pb}:208\text{Pb} = 1:37.89:15.59:18.08$. *Data from Sinha, unpublished.

TABLE 4

U-Pb and Rb-Sr Ages of Plutons in the Charlotte Belt

Pluton	U-Pb	Rb-Sr	Ref
Melrose	515 + 01	-	01,-
Leatherwood	516 + 10	464 + 20	01,02
Shelton	463 + 14	429 + 07	01,03
Yadkin	461 + 01	386 + 08	01,04
Southmont	486 + 01	402 + 02	01,04
Lowry's North	486 + 06	399 + 04	01,05
Woodleaf	392 + 04	-	01,-
Concord gab-syen	407 - 416	404 + 21	01,05
Bald Rock	407 + 06	-	01,-
Pacolet Mills	392 + 06	415 + 40	01,06
		383 + 05	07

1. this report; 2. Odom and Russell (1975); 3. Kish (1983); 4. Butler and Fullagar (1978); 5. Fullagar (1971); 6. Fullagar and Kish (1981); 7. Fullagar personal comm. (1986). U-Pb errors are relatively small because the discordias are defined by two or three points.

ages (Table 1). Age discrepancies of this magnitude between U-Pb and Rb-Sr systems are not uncommon (Welin and others, 1983; Ayuso and others, 1984). The U-Pb ages in this study are interpreted to be the igneous crystallization age based upon zircon morphology and the similarity in $^{207}\text{Pb}/^{206}\text{Pb}$ ages for the different size fractions (Table 3). If a xenocrystic component was present, then the $^{207}\text{Pb}/^{206}\text{Pb}$ ages would show a measurable difference between size fractions.

Recent studies (Raheim and Compston, 1977; Bell and Blenkinsop, 1978; Page, 1978; Black and others, 1978; Field and Raheim, 1979; Matheney and Brookins, 1984; Welin and others, 1983) have indicated that whole rock Rb-Sr isotopic systems of metamorphosed igneous rocks can be partially disturbed and in some cases completely reset, in response to minor mineral alteration and/or low-grade secondary deformations.

Petrographically, the Southmont, Yadkin, Lowrys North and Leatherwood plutons have a strong cataclastic texture. Conley and Henika (1973) noted that some microcline phenocrysts from the Leatherwood granite have cataclastic margins, and that plagioclase and microcline have altered to epidote and sericite. Butler and Fullagar (1978) stated that evidence of deformation was present in all thin sections examined from the Southmont and Yadkin plutons. Visi-

ble petrographic effects include minor corrosion and/or partial to complete alteration of biotite to chlorite, turbidity of feldspars, strained quartz, some strained plagioclase with offset twin lamelli, and irregularly spaced cracks that have been infilled with chlorite + clay minerals. In addition to deformational textures, there are low-grade metamorphic minerals that include chlorite + calcite + epidote + garnet + fluorite. The Shelton granitic gneiss also has a cataclastic texture (Henika, 1977) and contains some of the metamorphic minerals listed above. If a later metamorphism and deformation were to affect the Rb-Sr systems of these plutons, the apparent isochrons would yield younger ages and show some degree of scatter beyond analytical errors. In addition, the $^{87}\text{Rb}/^{86}\text{Sr}$ ratios of the Yadkin pluton taken from Fullagar (1971) and Butler and Fullagar (1978) are relatively high (> 128) and thus these samples may be more amenable to loss of strontium (Fullagar, personal comm., 1986). High $^{87}\text{Rb}/^{86}\text{Sr}$ ratios tend to "control" the isochron of the pluton by placing less significance on lower $^{87}\text{Rb}/^{86}\text{Sr}$ values. This could explain why the U-Pb ages of the Yadkin, Southmont, Shelton, Lowrys North and Leatherwood plutons are significantly older than the published Rb-Sr whole rock ages of the same rocks.

Siluro-Devonian: The U-Pb ages from Siluro-Devonian plutons are similar to the published Rb-Sr whole rock ages as shown in tables 2 and 4. Although the plutons show some evidence of weak metamorphism, the similarity of U-Pb data with Rb-Sr whole rock ages may suggest that the Rb-Sr ages are the true crystallization ages and have not been affected by a later metamorphic episode.

8. INTERPRETATION OF AGES AND TECTONIC MODELS

Several models dealing with the tectonic history of all or parts of the southern Appalachians have been presented in other publications (Odom and Fullagar, 1973; Glover and Sinha, 1973; Rankin, 1975; Hatcher, 1972, 1978; Cook and others, 1979; Hatcher and Odom, 1980; Harper and Fullagar, 1981; Pavlides, 1981; Zen, 1981; Williams and Hatcher, 1982; Sinha and Zietz, 1982; Higgins and others, 1984; Sinha and others, 1985). The period of igneous activity and the tectonic history from 420-375 Ma will be emphasized in this paper, while the period from 570-450 Ma will be summarized from several of the above references.

Cambro-Ordovician: During the Early to Middle Cambrian, magmatic activity in the form of volcanism occurred in

the marginal basin between the North American craton and the Inner Piedmont microcontinent (Hatcher, 1978; Cook and others, 1979). These volcanic rocks would be the equivalent of the James Run formation of Pavlides (1981). Offshore to the east of the Inner Piedmont microcontinent, the Carolina slate belt, the Avalon terrane of Williams and Hatcher, (1982) was generated from oceanic crust being subducted in a westward dipping zone with subsequent island arc magmatism (Odom and Fullagar, 1973; Hatcher, 1978; Cook and others, 1979; Hatcher and Odom, 1980). This volcanism may have evolved in a separate tectonic environment from the Blue Ridge/James Run Formation (Pavlides, 1981). From Middle to Late Cambrian, volcanics were forming above an eastward dipping subduction zone along the western flank of the Inner Piedmont microcontinent as the marginal basin was closing (Cook and others, 1979; Hatcher, 1978; Odom and Fullagar, 1973; Hatcher and Odom, 1980). As the marginal basin closed from Middle to Late Ordovician, the resulting collision of the North American craton with the Inner Piedmont microcontinent produced west vergent thrusting and regional metamorphism, resulting in the Taconic orogeny in what is now the Blue Ridge and Inner Piedmont (Odom and Fullagar, 1973; Hatcher, 1978; Cook and others, 1979; Hatcher and Odom, 1980).

Siluro-Devonian: Siluro-Devonian plutonism in the southern Appalachians is restricted mainly to a group of plutons in the Charlotte belt and another in the Blue Ridge (see Fig 1). A comparison of the similarities and differences between the two belts suggests different tectonic histories of each belt. Modal analyses from some of the Siluro-Devonian granitoids are plotted in Figure 3, adapted from Streckeisen (1973). A number of igneous rocks from the Blue Ridge occur both as trondhjemitic and pegmatitic dikes and as larger trondhjemite to granodiorite plutons (Hadley and Goldsmith, 1963; Kish, 1983; Miller and others, 1983). Siluro-Devonian plutons of the Charlotte belt comprise more than 35 bodies that show the common association of gabbrodiorite-syenite, although granites also are present (Butler and Ragland, 1969; Goldsmith and others, 1978; Butler and McSween, 1983).

Siluro-Devonian igneous rocks of the Blue Ridge and Inner Piedmont are part of the Spruce Pine plutonic group and are chemically distinct from other Blue Ridge plutonic rocks, being peraluminous with normative corundum > 1.5 , $\text{Na}_2\text{O}/\text{K}_2\text{O} > 1.0$, and having accessory muscovite, garnet and epidote (Rankin and others, 1973). The trondhjemitic dikes of Wood and Miller (1984) are of the high-alumina type, suggesting a quartz eclogite or metabasaltic source (Barker and

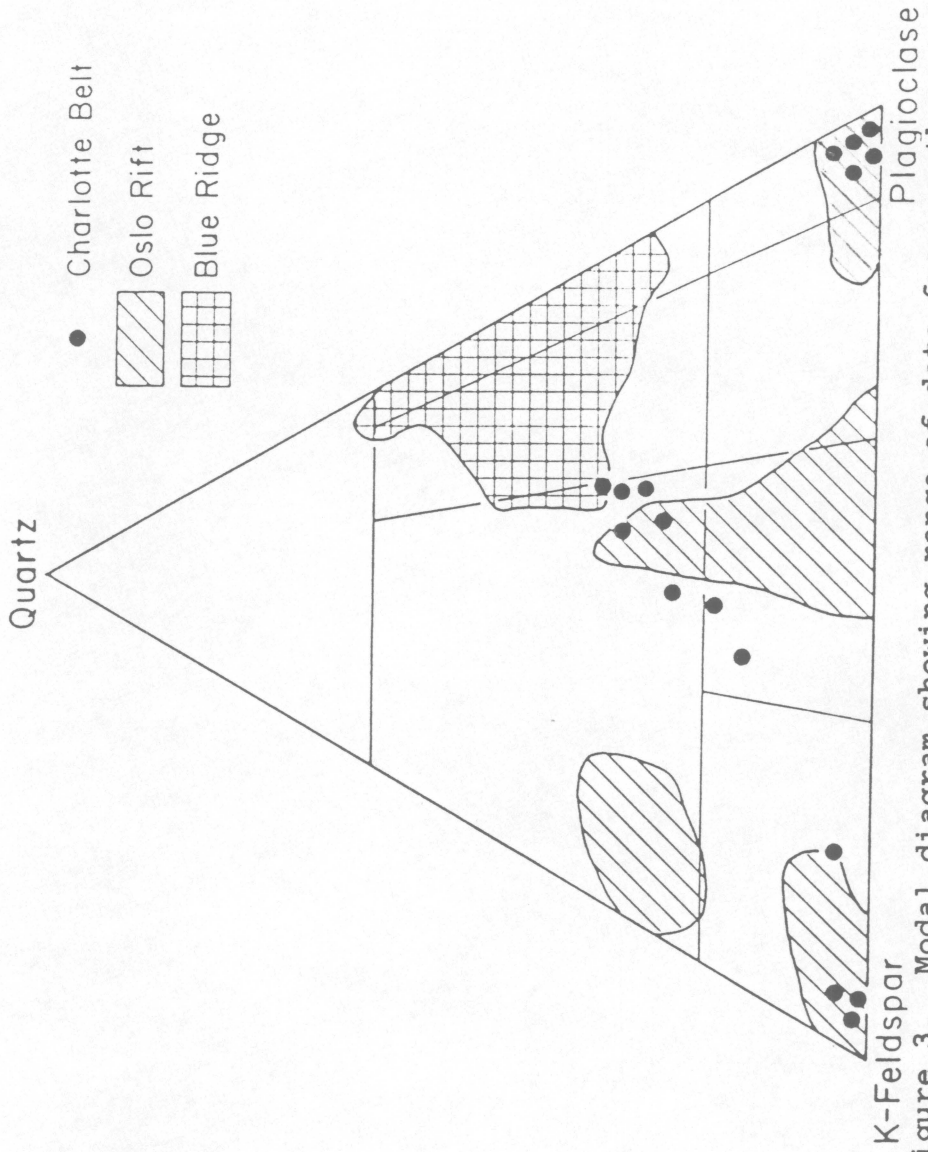


Figure 3. Modal diagram showing range of data from southern Appalachians and Oslo Rift. Blue Ridge data from Kish (1983) and Wood and Miller (1984). Oslo Rift data from Sundvoll (1978), Neumann (1978), and Neumann and others, (1983).

Arth, 1976). Charlotte belt Siluro-Devonian granitic rocks are metaluminous, commonly have accessory biotite and/or hornblende, and modally plot as granite to quartz monzonite. Mafic plutons of the Charlotte belt are tholeiitic (Butler and Ragland, 1969; Butler, 1984; McSween and others, 1984). Syenitic rocks have a higher alkaline content (11.5 % vs 3-8 % $\text{Na}_2\text{O} + \text{K}_2\text{O}$) than the gabbroic and granitic rocks in the Charlotte belt (Butler and Ragland, 1969).

Chemical data from the plutonic rocks of the two belts (Figs. 4-5), show that rocks of the Blue Ridge and Inner Piedmont belts are higher in normative corundum and lower in K_2O and Fe/Mg ratios than the Charlotte belt plutons. Chemical data for the Charlotte belt was taken from Fullagar and Butler (1978) and Butler and Ragland (1969). Data for the Blue Ridge plutons was taken from Kish (1983) and Wood and Miller (1984), while Oslo rift chemical data was taken from Sundvoll (1978), Neumann (1978) and Neumann and others (1983). Initial Sr isotopic ratios (Fig. 6) are slightly higher in the Blue Ridge igneous rocks (.7052-.7172) than in the Charlotte belt plutons (.7024-.7131) (Kish, 1983; Fullagar, 1971, 1981; Butler and Fullagar, 1978). A point of interest concerning the initial Sr isotopic ratios of the Charlotte belt is that the ratios increase with decreasing crystallization age. This could be caused by a melt from a

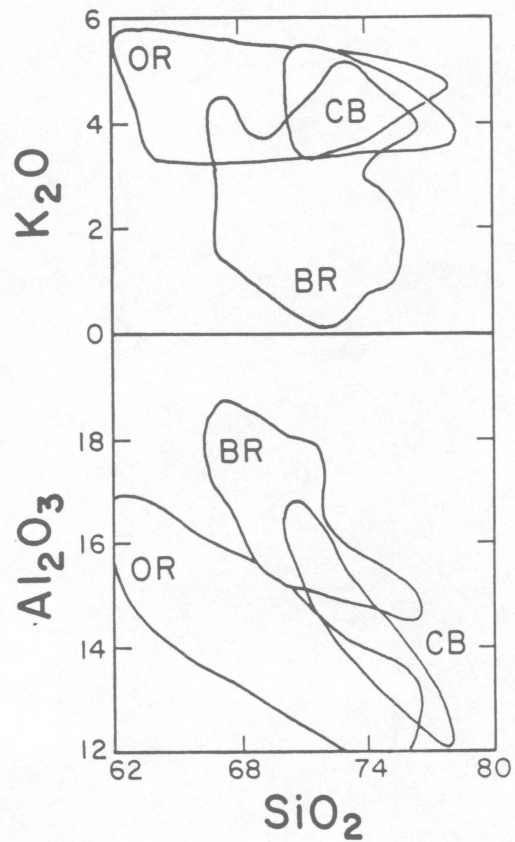


Figure 4. Plots of K₂O and Al₂O₃ vs SiO₂ for Charlotte belt, Blue Ridge, and Oslo Rift. Charlotte belt data from Butler and Fullagar (1978) and Butler and Ragland (1969). Refer to Figure 3 for references on Oslo Rift and Blue Ridge.

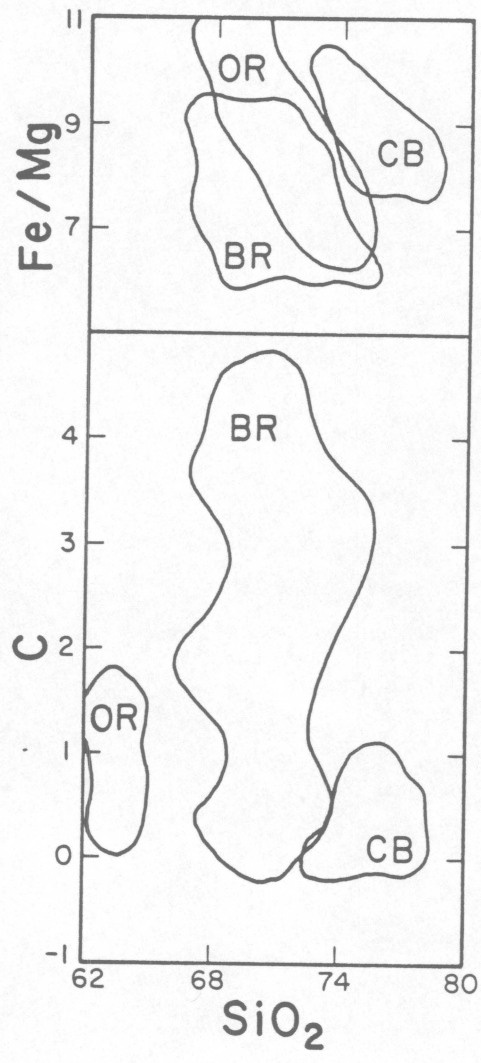


Figure 5. Plots of Fe/Mg and normative corundum vs SiO_2 . Refer to Figures 3 and 4 for references.

depleted upper mantle migrating into the lower crust, providing the heat necessary for the crust to form melts with higher initial Sr ratios. With progressive addition of magmas, the isotherm migrates upward into the crust, forming melts from a more radiogenically evolved source. This process would cause younger plutons to have higher initial Sr ratios.

Modal, chemical and isotopic data suggest that the Blue Ridge igneous rocks were derived from a source distinctly different from those of the Charlotte belt. Current tectonic models for the Blue Ridge Siluro-Devonian rocks require that the plutons formed over a subduction zone (Size, 1984) or that Ordovician thrusting and associated metamorphism (Sinha and Glover, 1978; Hatcher and Odom, 1980) greatly thickened the crust, which was followed by decompressional melting (Sinha and others, 1985). When the crust is thickened as a result of overthrusting, the temperatures required for decompressional melting of a silicic crust can be achieved in 30 to 60 million years after overthrusting (Thompson, 1981; Sinha and others, 1985). Therefore, according to the model of Sinha and others (1985), a separate orogenic or subduction event is not required to produce the igneous rocks, and the variable metamorphic grade seen in the Blue Ridge and Inner Piedmont terranes. A similar interpretation

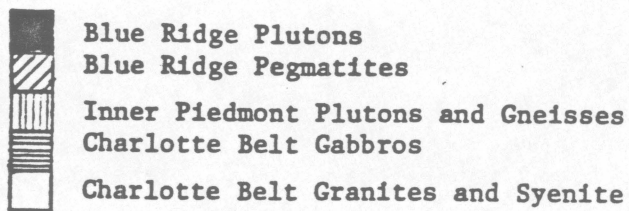
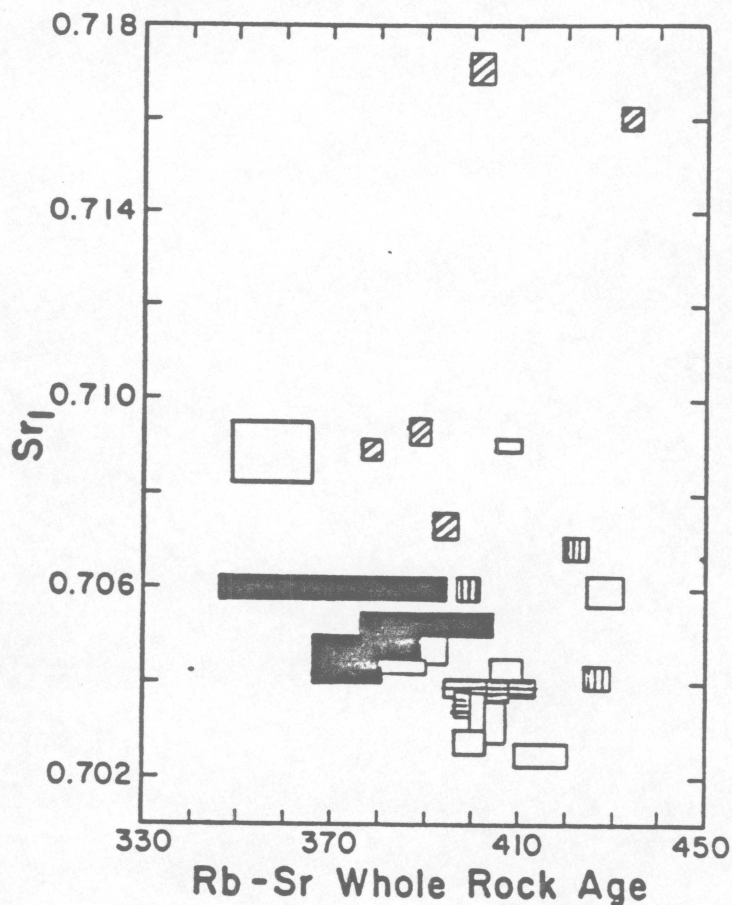


Figure 6. Plot of Initial Sr isotopic ratios against Rb-Sr whole rock age for selected plutons in the Southern Appalachians. Data from Butler and Fullagar (1978), Fullagar (1981), Harper and Fullagar (1981), Kish (1983), and Fullagar (1971).

was made for Devonian plutonic rocks of the northern Appalachians where they were related to melting of an overthickened and compressed crust (Fyffe and others, 1981).

The tectonic models for the Siluro-Devonian plutons in the Charlotte belt have been described by several investigators. Hatcher (1978) suggested the Charlotte belt was an allochthonous, island arc fragment that collided with the North American craton during the Ordovician. Zen (1981) discussed a similar tectonic history for the southern Appalachians with the exception that the allochthonous terranes which collided with the North American craton were a series of unrelated microplates. Higgins and others (1984) include the Charlotte belt as part of their Macon melange, a series of thrust sheets composed of rocks from a wide variety of environments, showing varying metamorphic grades and igneous parentages. Radiometric ages of igneous rocks in this melange do not represent any single tectonic event, but a series of events that are not related to a particular orogeny.

Comparing the characteristics of Charlotte belt plutons with granites from other tectonic environments, and using the categories outlined by Pitcher (1982) (Table 5), the Charlotte belt plutons have similarities with both A-type and Caledonian I-type granites.

TABLE 5
Granite-Types and Geological Environments

<u>I-(Cordilleran) type</u>	<u>I-(Caledonian) type</u>	<u>S-type</u>	<u>A-type</u>
tonalite, diorite to monzo-granite	granodiorite-granite some gabbro	granite, narrow silica range	biotite granite, alkalic granite, syenite
hbl, bio, mag, tit	bio, ilm, mag	musc, bio, ilm, monaz, gar	bio, alkali amph & pyrox
Ksp interstitial and xenomorphic	Ksp interstitial	Ksp megacrystic	perthites
Sr _I 0.706 or less	Sr _I between 0.705 and 0.709	Sr _I 0.708 or greater	Sr _I between 0.703 and 0.712
multiple, linear batholiths	isolated complexes of multiple plutons	multiple batholiths and sheets	multiple cauldron-complexes of small volume
very long plutonism	short plutonism	moderate plutonism	short plutonism
Andinotype marginal continental arc	post-closure uplift	continental collision and encratonic ductile shear-belts	post-orogenic or anorogenic
vertical movements, little lateral shortening	dip-slip and strike-slip faulting	much shortening	doming and rifting
burial-type metamorphism	retrograde metamorphism	low-pressure metamorphism	

This table is summarized from Pitcher (1982). General characteristics of granitic rocks from several geological environments are listed.

Charlotte belt plutons resemble the Caledonian I-type granitoids in that biotite is predominant over hornblende in the granitic rocks, the plutons are syn- to post-kinematic, and have a relatively short-lived period of plutonic activity. Charlotte belt plutons resemble A-type granitoids in the sense that they are associated with syenitic plutons, have some perthitic feldspars, have a considerable range in initial Sr isotopic ratios (.7024 - .7131), have a short-lived period of plutonic activity, and fluorite is present in many plutons. The general association of gabbro-syenite-granite emphasizes the similarities with the A-type granitoids of Pitcher (1982). More similarities exist between Charlotte belt plutons and A-type granitoids than between Charlotte belt plutons and the I or S-type granitoids of Pitcher (1982). Comparisons with other A-type granitoids, in particular those from the Oslo rift in Norway, reinforce tectonic affinity with a tensional regime.

The Charlotte belt plutons and the Oslo rift plutons have many similarities. For example in Fig. 3, the modal data from the tensional related plutons of the Oslo rift are shown. A summary of data from Butler (1984) and Kish (1983) for the Charlotte belt and Williams (1982), Neumann (1978), Neumann and others (1985) and Sundvoll (1978) for the Oslo rift provide a good data base for comparison between the two

provinces. The igneous rocks from the Oslo rift are more alkaline (7-15% vs 3-11.5% $\text{Na}_2\text{O} + \text{K}_2\text{O}$), have a wider range of rock types and a slightly greater areal distribution than those of the Charlotte belt, however in both areas, an extensive zone of plutons containing gabbros, diorites, syenites and granites occupy linear regions 250 km long by 50 km wide. Both areas are usually fault bounded along their long axes, and the periods of major plutonic activity lasted less than 40 m.y. Initial Sr ratios from the Oslo rift complexes range from .7030 to .7109 while in the Charlotte belt they range from .7024 to .7131.

Because of the field, petrographic and chemical similarities between the Charlotte belt plutons and the Oslo rift igneous rocks, our model favors a mechanism of rift related magmatism for the thermal and tectonic history of the Charlotte belt involving strike-slip accretion (Sinha and others, 1985) during the Siluro-Devonian period. Although the Oslo rift is a large graben structure, there is evidence of strike-slip activity (Ramberg and Spjeldnaes, 1978) associated with the rift. The purpose of this comparison is not to show that the tectonic history of the Charlotte belt is identical to that of the Oslo rift, but rather to show that the Charlotte belt plutons are probably related to a tensional environment. It is proposed that the "docking" of

Avalon with the North American craton at this time resulted in the formation of localized rift grabens and the plutonic assemblage of gabbro-diorite-syenite and granite associated with it. The strike-slip accretion during the Siluro-Devonian requires that Ordovician and earlier plutonism in the Charlotte belt (and the Carolina slate belt) be unrelated to North American plate magmatism. Paleogeographic reconstruction by Bambach and others (1980) for the Ordovician period suggests that the Avalon terrane was geographically far removed from the North American craton. Also, studies of Siluro-Devonian rocks in New England suggest that a subduction environment is unlikely for the generation of the New England Siluro-Devonian plutonic rocks (Wones, 1980; Fyffe and others, 1981)

In addition, some models for the northern Appalachians favor generation of plutonic rocks along major shear zones during the Paleozoic (Hanmer, 1981; Gates and Moench, 1981; Thompson, 1984; Hogan, 1987, personal comm.). The emplacement of Siluro-Devonian granites from the metamorphosed Grampian block of Scotland and Ireland was controlled by a system of sinistral shear faults (Leake, 1978; Hutton, 1981). Pitcher and Berger (1972) reported a close space-time relationship between the Grampian biotite granites and granodiorites and the small bodies of diorites and gabbros,

similar to what has been documented in the Charlotte belt. In the southern Appalachians, Butler and Fullagar (1978) suggest that major movement along the Gold Hill-Silver Hill shear zone (a fault zone separating the Charlotte belt from the Carolina slate belt) occurred between 400 m.y. and 368 m.y.

9. SUMMARY

New U-Pb ages of zircons from plutons in the Charlotte belt fall into two distinct groups of Cambro-Ordovician age and Siluro-Devonian age, providing evidence for Cambro-Ordovician plutonism in this part of the southern Appalachians and evidence for Siluro-Devonian magmatic activity. Charlotte belt plutons differ from Blue Ridge igneous rocks of the same age in chemistry, modal composition, spatial distribution, and probably tectonic setting. A model for strike-slip accretion of Siluro-Devonian igneous rocks in the Charlotte has been presented and is separate from the tectonic history of Siluro-Devonian igneous rocks in the Blue Ridge.

The Cambro-Ordovician ages of granitic rocks in the Charlotte belt may provide evidence to link their thermal

history to previous Cambro-Ordovician tectonic models of the southern Appalachians or the ages may imply that the Charlotte and Carolina slate belts had a thermal history during the Cambro-Ordovician that was separate and unrelated to that of the rest of the North American craton. In any case, additional isotopic ages and petrological data will be needed to further understand the tectonic history of the southern Appalachians.

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Appendix A
PLUTON DESCRIPTIONS

A.1 CAMBRO-ORDOVICIAN PLUTONS

LEATHERWOOD GRANITE: The Leatherwood granite of Conley and Henika (1973) is a coarse-grained, porphyritic biotite granite to leucogranite which intrudes the Fork Mountain formation of the Smith River allocthon. The following description is summarized from Conley and Henika (1973).

The Leatherwood consists of sheet-like bodies and thin dikes that intrude the Rich Acres gabbro and Fork Mountain formation, producing a contact aureole in the surrounding country rock of garnetiferous biotite gneiss. Sillimanite and Kyanite also formed in the aureole with chloritoid occurring further away from the center. Microcline is the dominant mineral phase (30-60%), with 20-30% quartz, 10-30% plagioclase, 5-15% biotite and up to 15% muscovite. Accessory minerals include epidote, apatite, zircon, sphene, clinzoisite and opaques. The microcline phenocrysts are perthitic, carlsbad-twinned, and are rimmed by myrmekitic microcline and oligoclase. Some phenocrysts have cataclastic margins. Plagioclase and microcline may show alteration to epidote and sericite respectively.

MELROSE GRANITE: The Melrose granite of Jonas (1932) is a coarse-grained, hypidiomorphic granular, biotite quartz monzonite to quartz diorite (Gates, 1981). It intrudes the Candler Formation of central Virginia. A thorough description of the Melrose pluton is given in Gates (1981) M.S. Thesis and is summarized here.

The Melrose granite can be divided into two areas. The western area is a slightly metamorphosed and undeformed pluton consisting primarily of oligoclase grains (1cm) and perthitic microcline (1.5cm). Lesser amounts of quartz, retrograded biotite, euhedral titanite, zircon, apatite, magnetite with secondary epidote, hematite, calcite and muscovite comprise the remaining mineral phases. Xenoliths of the Candler schist are more common near the western margin of the granite. To the east, the quartz and microcline content increase as the grain size reduces. The eastern granite is banded with a strong planar and weak linear fabric. Here the biotite and titanite is recrystallized or broken, while perthitic microcline grains have non-perthitic rims. Plagioclase grains are sericitized and altered to calcite.

YADKIN AND SOUTHMONT GRANITES: The Yadkin and Southmont granites exhibit many similarities in chemistry, petrography and field relationships. They are associated with a few other granitic plutons in the Charlotte belt, collec-

tively known as the Salisbury group (Butler and Fullagar, 1978). Salisbury group plutons have been discussed in several papers (Butler and Ragland, 1969; Fullagar, 1971; Fullagar and others, 1971). The following description is summarized from Butler and Fullagar (1978).

The Yadkin and Southmont plutons are leucocratic, homogeneous, medium-grained granites which intrude amphibolite grade metasediments and metavolcanics. The plutons are foliated and elongated parallel to regional strike. Plagioclase, quartz, and microcline compose more than 95% of the granite, with accessory chlorite, zircon and monazite. Secondary minerals include muscovite, calcite, garnet, chlorite, fluorite, and epidote. Thin sections show evidence of deformation in the form of fractured feldspars and partially recrystallized quartz grains. Cataclastic textures are common where large quartz grains are rimmed by small recrystallized quartz grains.

SHELTON GRANITE-GNEISS: The Shelton Formation of Henika (1977) (Shelton granite-gneiss of Jonas, 1932) is a coarse-grained quartz monzonitic to granitic gneiss and is exposed in antiformal and synformal folds. It is overlain by metasedimentary and metavolcanic rocks of the Charlotte belt in North Carolina and Virginia. The description which follows is summarized from Henika (1977).

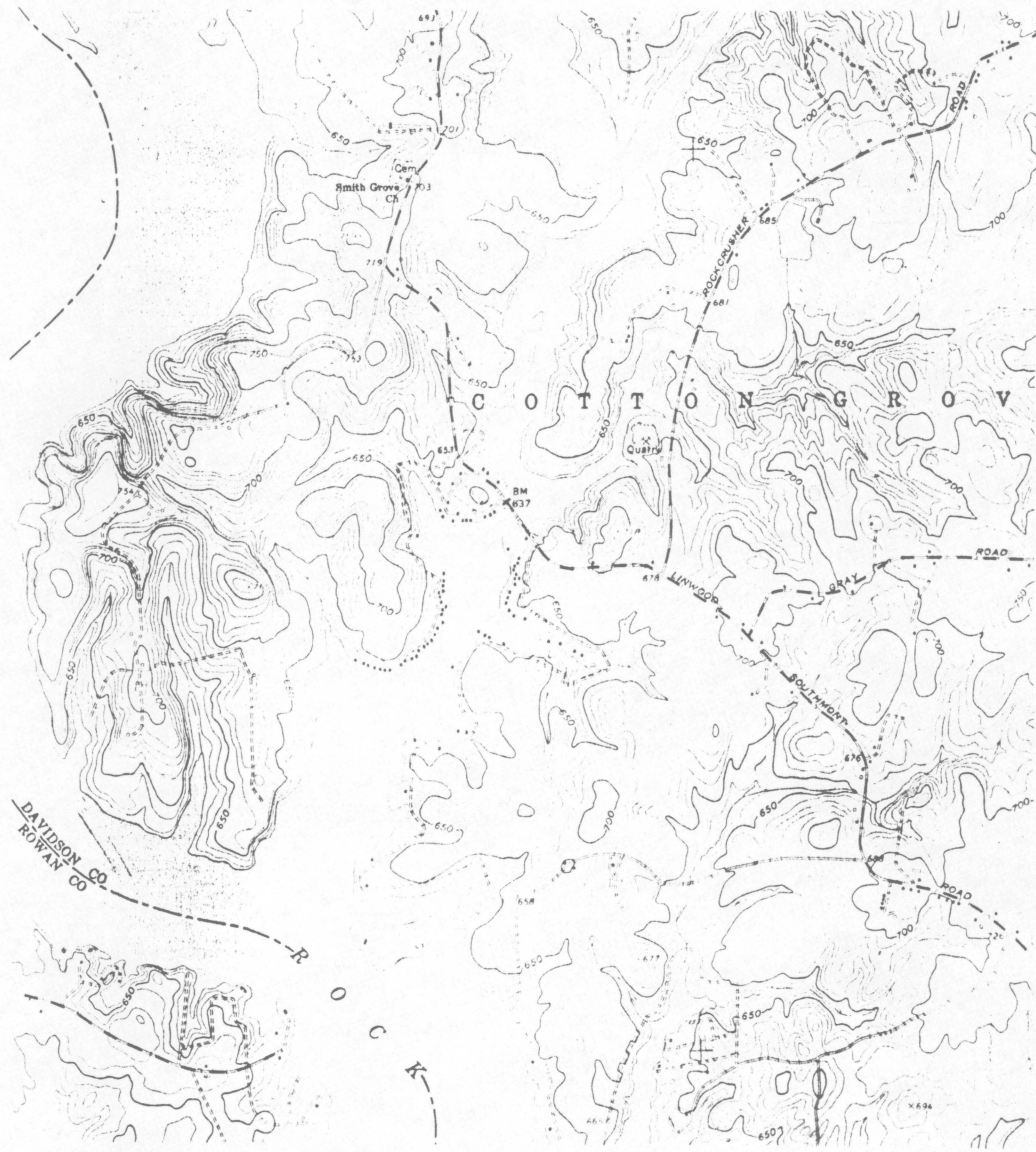


Figure 9: SOUTHMONT

CHIEFTAIN BRAND
50% COTTON FIBER

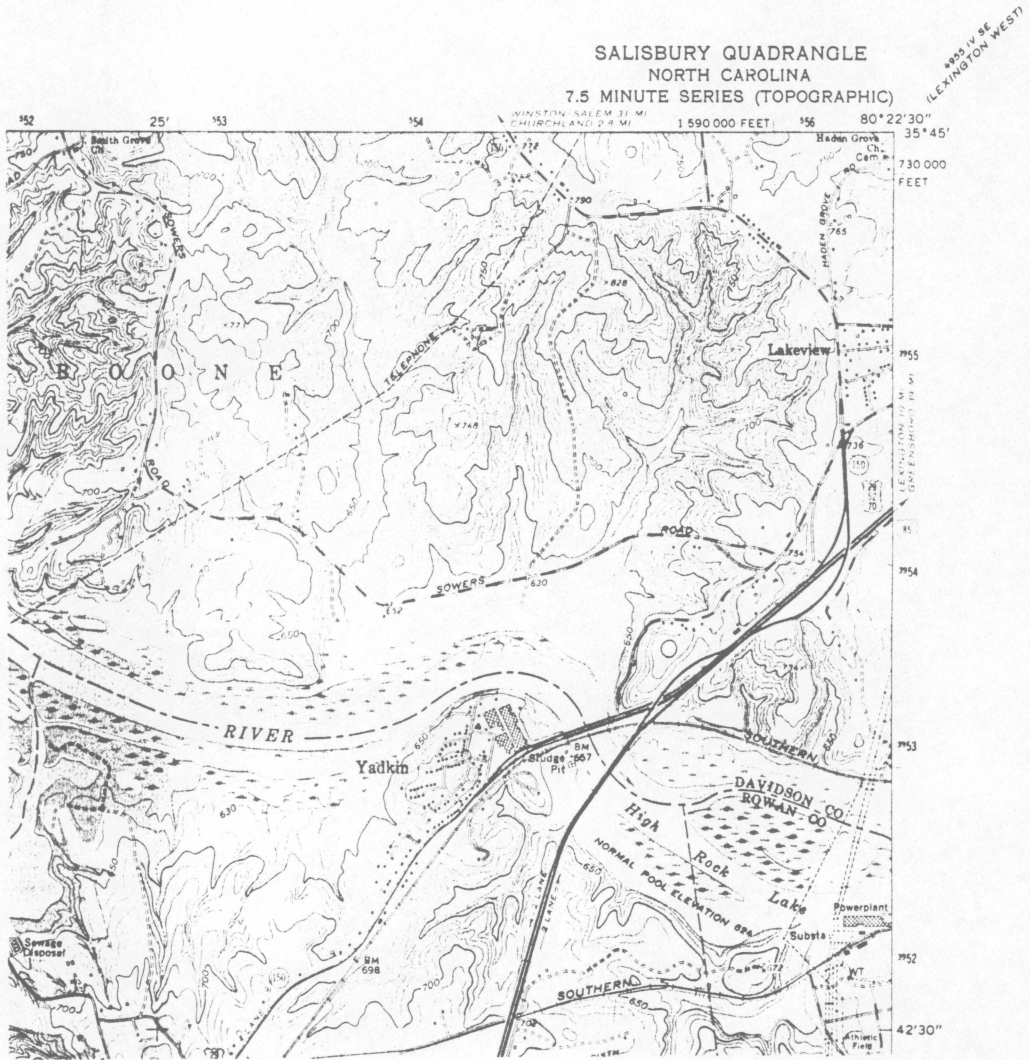


Figure 10: YADKIN

The type exposure of the Shelton Formation is in a quarry near Shelton, North Carolina. Outside the quarry it forms broad pavement exposures and rounded outcrops. The Shelton Formation is a poorly foliated, but well lineated, pink gneiss with bands of biotite and muscovite. It has elongate grains of plagioclase, microcline and quartz, from 1-5 mm in length. It also contains zircon, titanite and opaque minerals. Numerous small veinlets of chlorite, pyrite and fluorite are distributed throughout the gneiss. Some areas of the Shelton Formation have a cataclastic texture with strained quartz and plagioclase which exhibits offset twin lamelli in thin section.

LOWRYS NORTH GRANITE: The Lowrys North granite, part of the Lowrys plutonic complex of Wagener (1977), is a medium-grained, leucocratic granite. It intrudes amphibolite grade metamorphic rocks in the western Charlotte belt of South Carolina. It is exposed along pavement exposures and in quarries. It borders a coarse-grained, porphyritic granite also called the Lowrys granite, however the zircon samples were taken from the medium-grained pluton. The following description is summarized from Wagener (1977) and Glover and others (1983).

The Lowrys North pluton is composed of microcline, plagioclase and quartz with accessory biotite, titanite, apa-



Figure 11: SHELTON

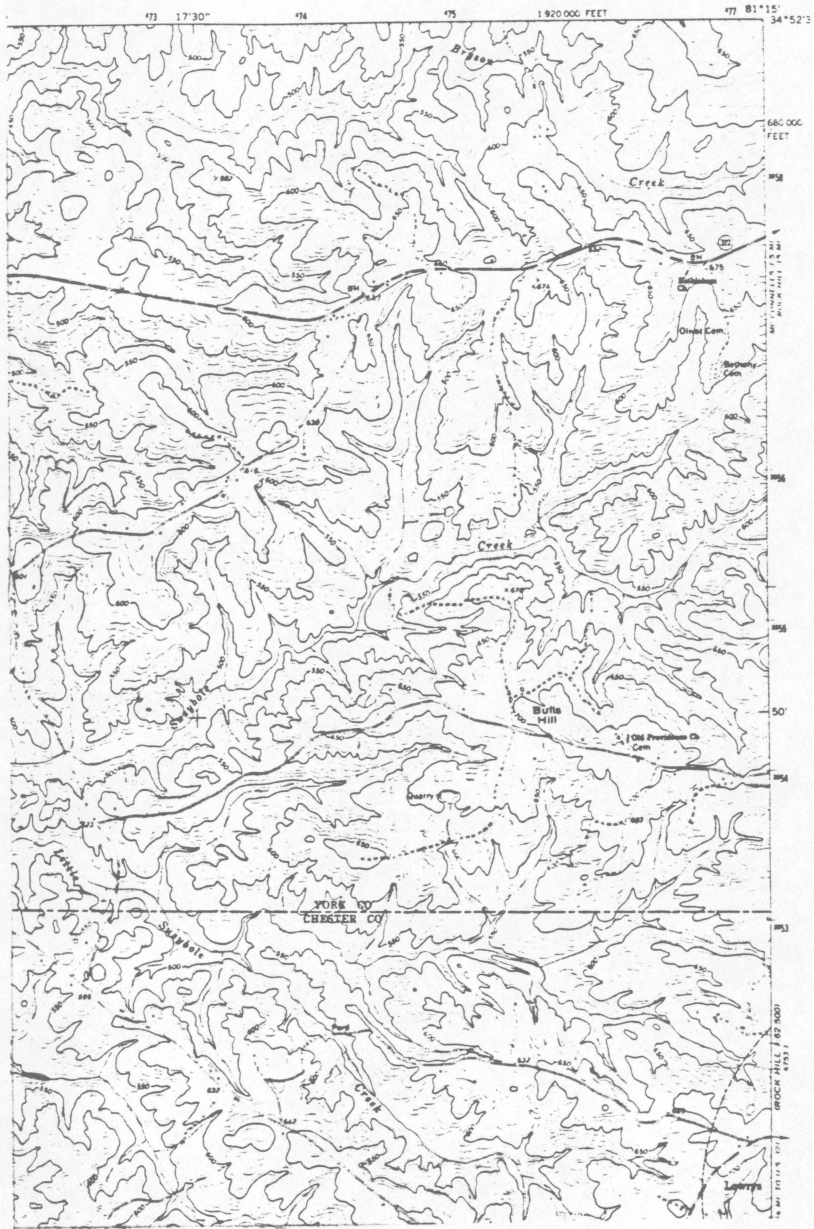


Figure 12: LOWRYS NORTH

tite, zircon, magnetite and pyrite. Secondary minerals include chlorite and muscovite. Many of the grains are partially recrystallized and plagioclase grains are fractured. The texture associated with the deformed and recrystallized grains is a cataclastic texture.

A.2 SILURO-DEVONIAN PLUTONS

BALD ROCK GRANITE: The Bald Rock granite, which intrudes the Charlotte and Kings Mountain belts of South Carolina is a fine-grained equigranular to medium- and coarse-grained porphyritic granite to quartz monzonite (Speer and others, 1980; Van Gelder and McSween, 1981). The following description is summarized from Van Gelder and McSween (1981) and Speer and others (1980).

The country rock surrounding the pluton consists of amphibolites, granitic gneisses, and pelitic schists. Primary mineral phases consist of microcline, plagioclase, quartz, and biotite. Accessory minerals include titanite, zircon, allanite, epidote, hornblende, muscovite, magnetite and pyrite. The coarse-grained porphyritic phase of the Bald Rock granite contains tabular, perthitic microcline megacrysts up to 3 cm in length which are foliated in most exposures. The

TABLE A1 Mineral Assemblages

<u>Pluton</u>	<u>Mineral Phases</u>	<u>Ref</u>
<u>Cambro-Ordovician:</u>	<u>Primary</u>	
LEATHERWOOD	micro,qtz,plag,bio,musc,ep,apa,zir,tit,clino opaq	1
MELROSE	plag,micro,qtz,bio,tit,zir,apa,mag	2
SOUTHMONT	plag,micro,qtz,zir,monaz,chl	3
YADKIN	plag,micro,qtz,zir,monaz,chl	3
LOWRYS NORTH	micro,plag,qtz,tit,mag,apa,zir,py,bio	4,5
SHELTON	plag,ksp,qtz,perth,tit,zir,bio,musc,opaq	6
<u>Siluro-Devonian:</u>		
BALD ROCK	micro,plag,qtz,bio,tit,zir,allan,ep,hbl,mag py,musc	7,8
PACOLET MILLS	micro,plag,qtz,bio,apa,musc,allan,ep,tit,zir	4
WOODLEAF	micro,qtz,plag,musc,bio,tit,zir	9
CONCORD	perth,plag,micro,bio,qtz,zir,opaq,apa,hbl monaz,cpx	10

1. Conley and Henika (1973); 2. Gates (1981); 3. Butler and Fullagar (1978); 4. Wagener (1977);
5. Glover and others (1983); 6. Henika (1977); 7. Speer and others (1980); 8. Van Gelder and
McSween (1981); 9. Privett (1973); 10. Olesen and others (1983).

coarse-grained phase is intruded by a fine-grained phase, which contains a higher concentration of quartz and plagioclase than the coarse-grained phase.

The pluton margins have been contaminated with the country rock by assimilation. Mafic xenoliths are distributed throughout the pluton. The pluton is intruded by felsic dikes, both syn- and post plutonic.

WOODLEAF GRANITE: The Woodleaf granite of Privett (1973) is a medium-grained, hypidiomorphic granular, granite to quartz monzonite, located in the Charlotte belt of North Carolina. The granite intrudes a dioritic pluton and Charlotte belt metamorphic rocks in the form of dikes and sills, and contains xenoliths of the diorite. The following description is summarized from Privett (1973).

The Woodleaf granite consists of microcline, quartz and plagioclase with accessory muscovite, biotite, titanite and zircon. Microcline, quartz and plagioclase grains range from 1-4 mm in size. Secondary minerals include epidote, calcite and chlorite. The plagioclase is usually epidotized and the microcline is almost always partially or completely sericitized. Late stage veins intrude the Woodleaf pluton and consist of two types. Type 1 is composed of microcline with disseminated molybdenite crystals. Type 2 veins consist of vuggy quartz veins with crystals of pyrite, epidote,

50% COTTON FIBER

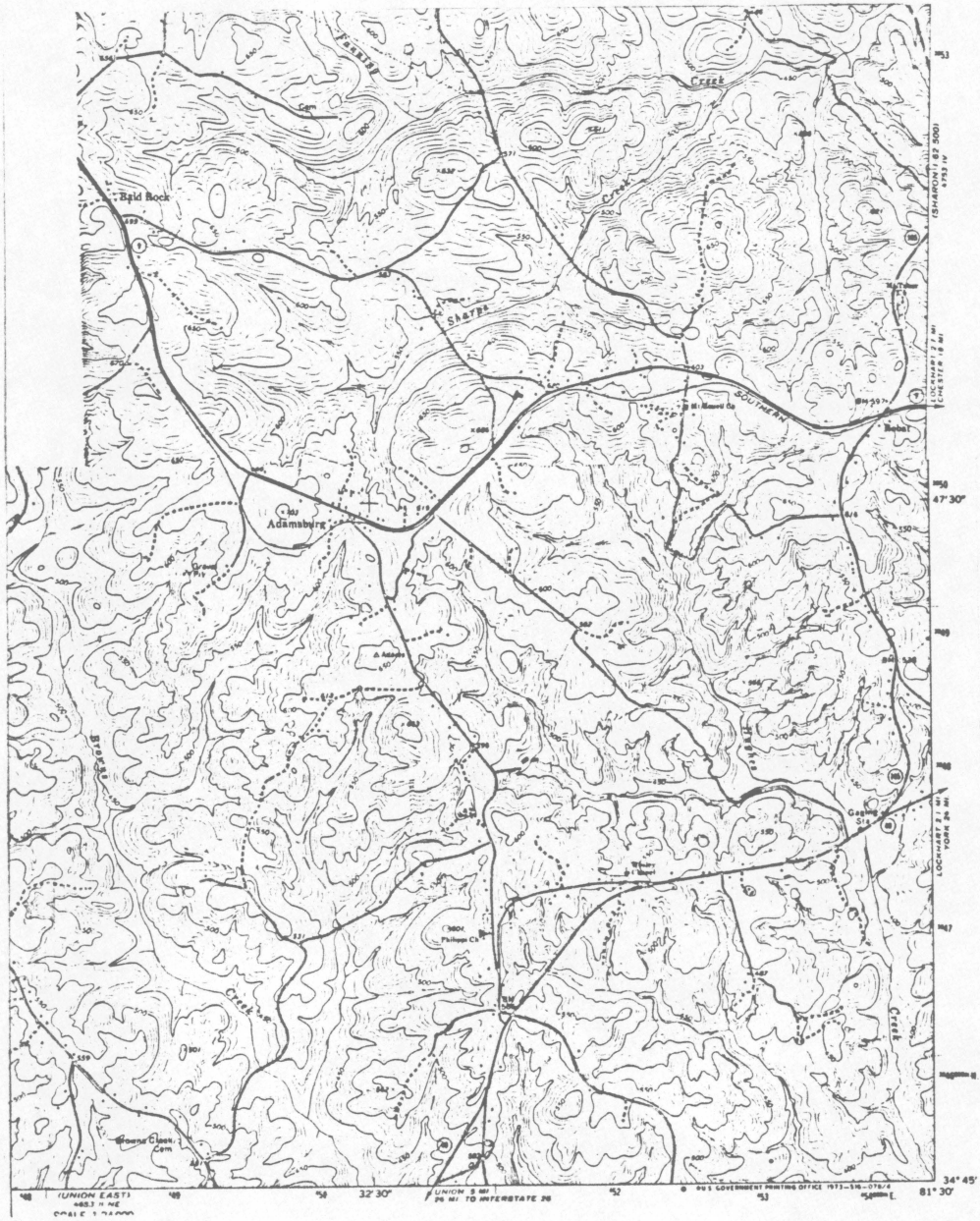


Figure 13: BALD ROCK

quartz, molybdenite, chalcopyrite, calcite and several varieties of zeolites.

CONCORD SYENITE: The Concord gabbro-syenite complex is located in Cabarrus County, North Carolina. It consists of gabbro that is ringed by a syenite, the latter of which is a differentiate of the gabbro (Butler and Ragland, 1969). This complex intrudes the Charlotte belt and is surrounded by foliated mafic rocks along with granitic and granodioritic gneisses (Bell, 1960). The following description is summarized from Olsen and others (1983).

The Concord syenite is coarse-grained and porphyritic, containing phenocrysts of perthite and anti-perthite surrounded by a groundmass of microcline, perthite, plagioclase, quartz, biotite, amphibole, clinopyroxene, zircon, apatite, monazite, sulphides and oxides. Some perthitic feldspars are strongly zoned and range up to 2 mm in length. Quartz appears as myrmekitic intergrowths with albite. Mafic and opaque minerals appear in clusters. Clinopyroxene grains are commonly rimmed by brown amphibole. Some minerals in the groundmass are fractured, and many of the megacrysts contain sericite and clay inclusions.

PACOLET MILLS GRANITE: The Pacolet Mills granite (metagranite of Wagener, 1977) is a medium- to coarse-grained leucocratic granite which is exposed in quarries and as



Figure 14: WOODLEAF

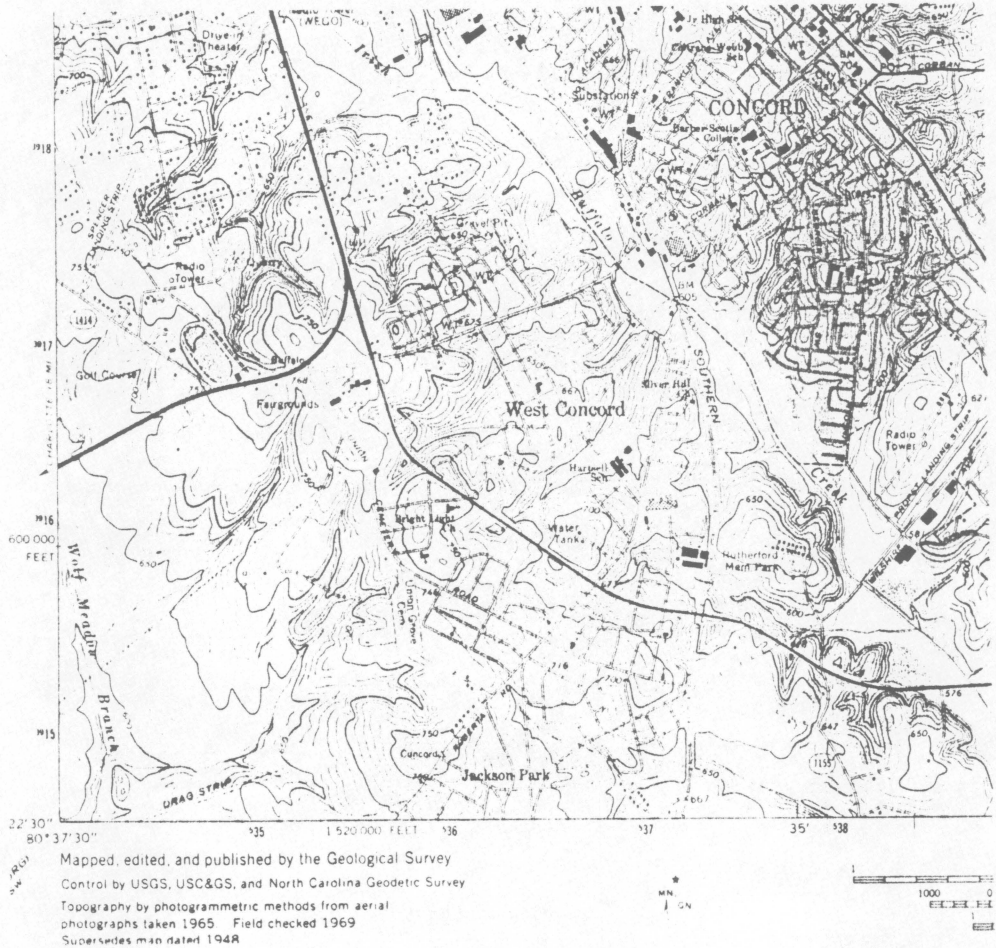


Figure 15: CONCORD

scattered patches of boulders in the South Carolina counties of Union, Spartanburg and Cherokee. The following description is summarized from Wagener (1977).

The Pacolet Mills metagranite is a foliated granitic rock, which is interlayered with a fine-grained biotite gneiss. Both are cut by pegmatite dikes ranging from 3 cm to 75 cm in diameter. It intrudes the metasedimentary rocks of the Kings Mountain belt. In thin section the Pacolet Mills metagranite consists of plagioclase, microcline, quartz, biotite and titanite with accessory apatite, muscovite, zircon, allanite (which is usually rimmed by epidote) and single crystals of epidote. The plagioclase shows gradational zoning and the rock appears to be unaltered in thin section, suggesting an igneous rock rather than a metamorphic rock. The pegmatite dikes are composed of quartz, feldspars, biotite and accessory tourmaline.

A.3 SAMPLE LOCATIONS

Leatherwood granite (LW), Price VA 7.5' Quad, samples LW 1z, 2z, 3, 4.

In abandoned quarry off US 58 near Horsepasture, VA. From Rt. 220 near Martinsville, take exit for US 58 south. Fol-

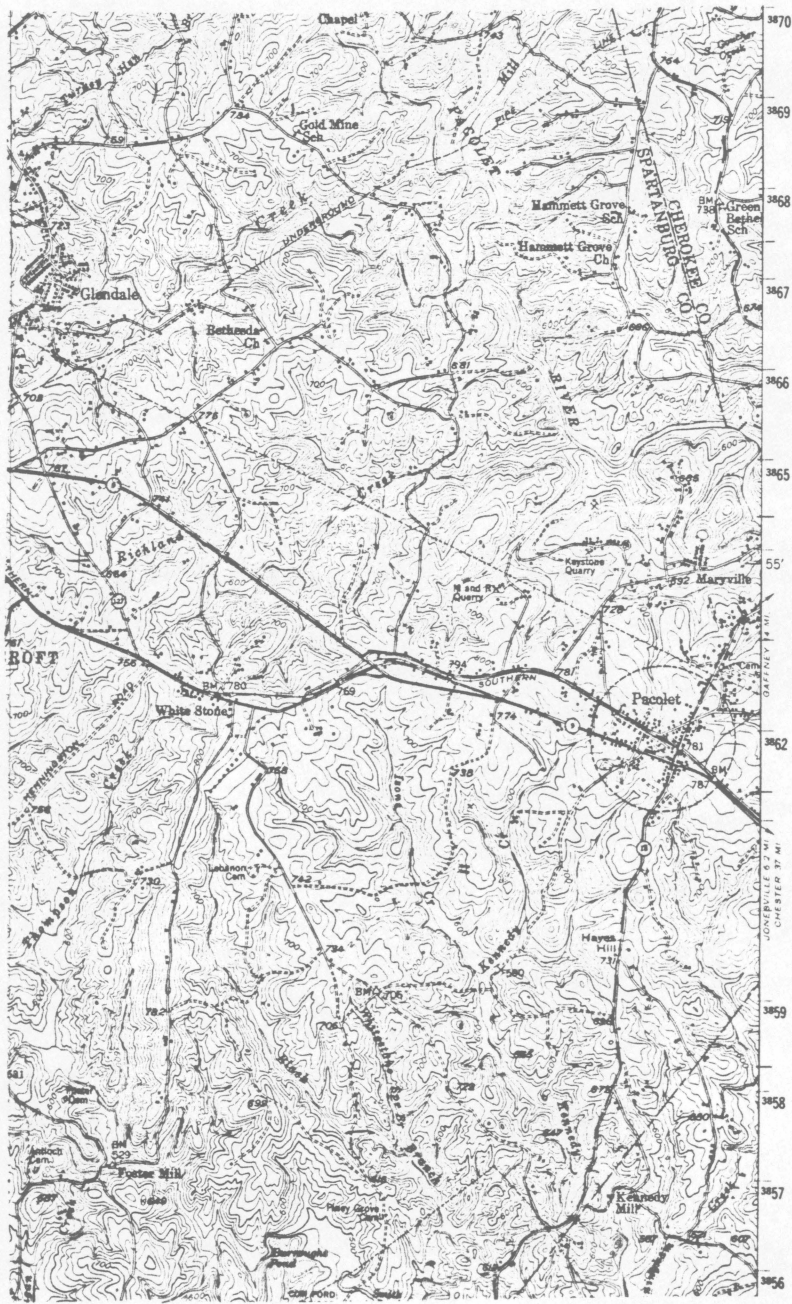


Figure 16: PACOLET MILLS

ENTREMAIN DUND
COTTON CLEER

low 58 2 miles to Horsepasture. Continue on 58 and go 1 mile. Look for Rt. 759 on right. Continue on 58 past 759 for 2000'. The quarry will be on the right side of 58 and may be hard to see from the road.

Southmont granite (SO), Southmont N.C. 7.5' Quad, samples SO 1z, 2z, 3, 4, 5.

Located in abandoned quarry along Rockcrusher Rd near High Rock Lake. From I-85, take Southmont and Linwood exit and proceed south along Linwood-Southmont Rd. 5-6 miles, then turn left onto Rockcrusher Rd. Go 2500' and look for abandoned quarry on left. Quarry contains a small pond in the center.

Yadkin granite (YA), Salisbury, N.C. 7.5' Quad, samples YA 1z, 2z, 3, 4.

Located at intersection of Rt. 150 (US 29, 52) and secondary road on north bank of Yadkin River. Take Rt. 150 north exit off I-85 and go

1800'. Turn left at intersection and go 5000' to intersection with Rt. 150. Outcrop is on left side of road. More exposures lie across Rt. 150 near railroad tracks.

Lowrys North granite (LO), Armenia, S.C. 7.5' Quad, samples LO 4z, 5z, 6, 7, 8.

In abandoned? quarry 3 miles NW of Lowrys, S.C. From Lowrys, take Rt. 663 southwest 3 miles to intersection of 663 and 692. Turn right onto 692 (look for North Chester School on left after turn) and go 4 miles to Rt. 523. Turn right at 523 and go 2 miles to first unpaved road on right (several pavement exposures exist along 523). Turn right and go 2000'. Quarry will be on right and is filled with a pond.

Shelton granite-gneiss (SH), Danville VA-NC 7.5' Quad, samples SH 1z, 2z, 3, 4, 5.

In quarry operated by Vulcan Materials Corp. 1/2 mile south of VA-NC state line. Take US 29 south from Danville, VA and continue 2-3 miles on 29 past Stokesland, VA. Look for exit for Rt. 1353 and go south along 1353 across state line into NC. Continue south on 1353 for .3 miles and look for quarry on right. Must get permission from Vulcan Materials to enter quarry.

Bald Rock granite (BR), Kelton, S.C. 7.5' Quad, samples BR 1, 2, 3z, 4z.

In abandoned quarry .2 miles south of Rt. 9. From town of Adamsburg, SC, go west along Rt. 9 3000'. Turn left at Rt. 666 and go .2 miles to house at dead end. Ask owner of house for permission and directions to abandoned quarry on owners property.

Woodleaf granite (WO), Cooleemee, N.C. 7.5' Quad, samples WO 1z, 2z, 3, 4, 5, 6.

In active quarry operated by Martin Marietta 1 mile north of Woodleaf, NC. From Rt. 801 at Woodleaf, turn north onto Rt. 1702 and go 2000'. Turn left onto paved road and follow to dead end. This is the entrance to the quarry. Must get permission to enter.

Concord syenite (CO), Concord, N.C. 7.5' Quad, samples CO 1z, 2z, 3, 4.

Located in abandoned quarry, 1400' east of radio tower. From I-85, take exit for Concord (US 29 & 601 south) and go 3.5 miles and turn right onto US 29 (where 29 & 601 split). Go 3500' on 29 and turn at second right onto paved road (Rt. 1414). Go 1500' and take second right onto paved road. Follow road around bend until it becomes a dirt road. Look for radio tower on left, then continue on dirt road past radio tower for

1400' and look for abandoned quarry on right.

Pacolet Mills metagranite (PM), Spartanburg, S.C. 15'
Quad, samples PM 1z, 2z, 3, 4, 5.

Located in M & R Quarry owned by Vulcan Materials Corp.
From town of Pacolet, SC, go west 3000' and turn right
onto paved road (the next road after Rt. 781). Follow road
1500' and look for M & R Quarry on left. Must get permis-
sion from Vulcan Materials to enter quarry.

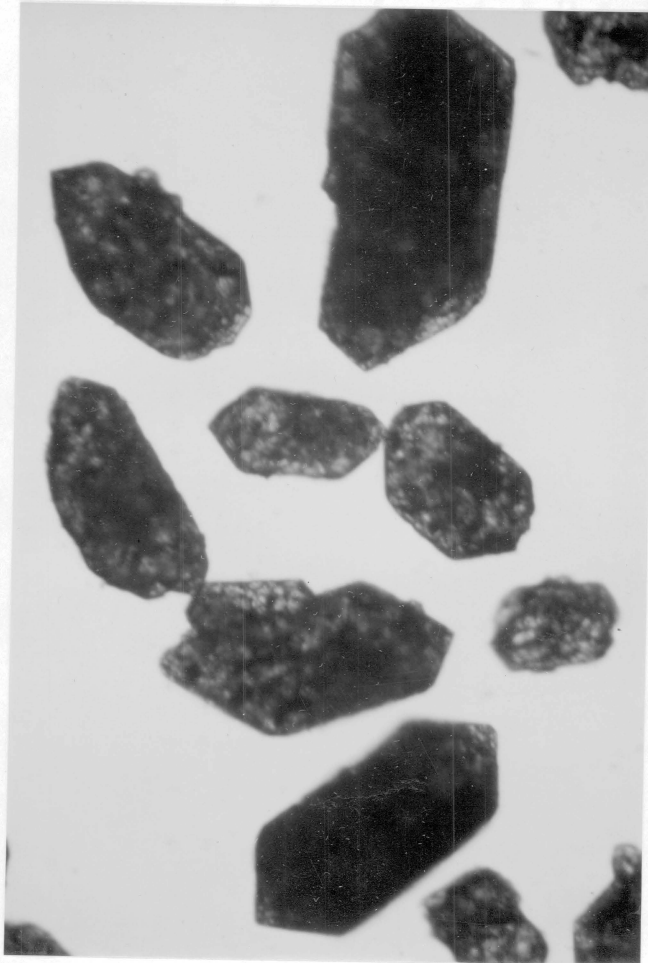


Figure 17. Yadkin, 75-150 microns, 10X. The zircons from this pluton are short, stubby, prismatic, cloudy, and have smaller length to width ratios than most of the zircons from the other plutons in this study.



Figure 18. Southmont, 75-150 microns, 10X. These Cambro-Ordovician age zircons closely resemble those of the Yadkin and also the Salisbury, a pluton that lies in the same area of the Charlotte belt.



Figure 19. Lowrys North, 75-150 microns, 10X. Many zircons from this pluton are filled with inclusions. Some of the zircons show growth zoning.

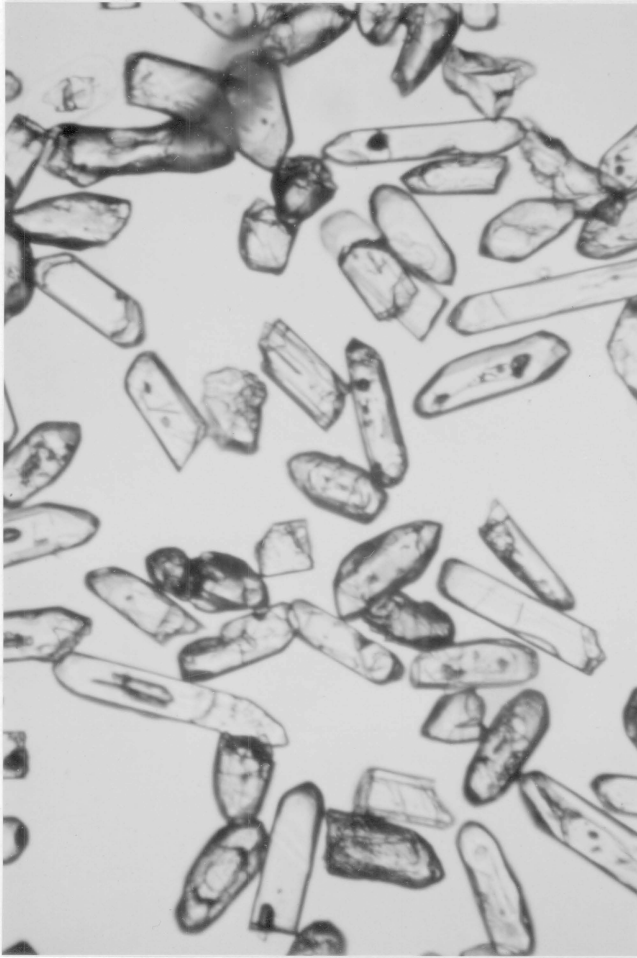


Figure 20. Melrose, <75 microns, 10X. Significant characteristics of these zircons are their long, prismatic shapes and the absence of color. Note the contrast to the short, stubby, and cloudy zircons from the Yadkin and Southmont plutons.



Figure 21. Pacolet Mills, 75-150 microns, 10X. Zircons from this pluton are prismatic, colorless, exhibit growth zoning, contain inclusions, and have rounded edges.



Figure 22. Bald Rock, 75-150 microns, 10X. These zircons closely resemble zircons from the Pacolet Mills. Both plutons are of similar age.

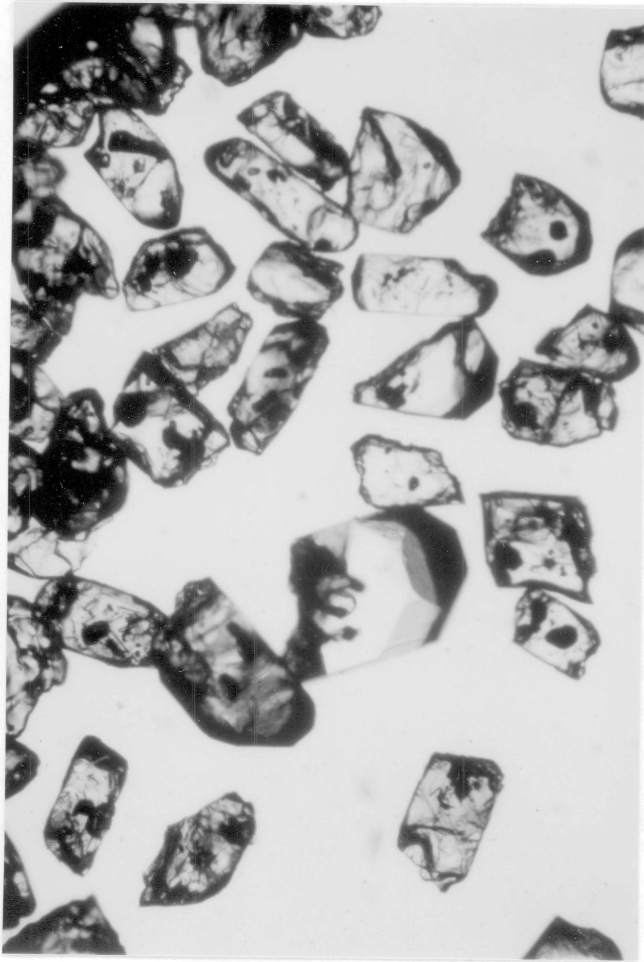


Figure 23. Concord, >150 microns, 2.5X. This population of zircons has a Grenville age component in it. Several crystals have cores of unknown composition.

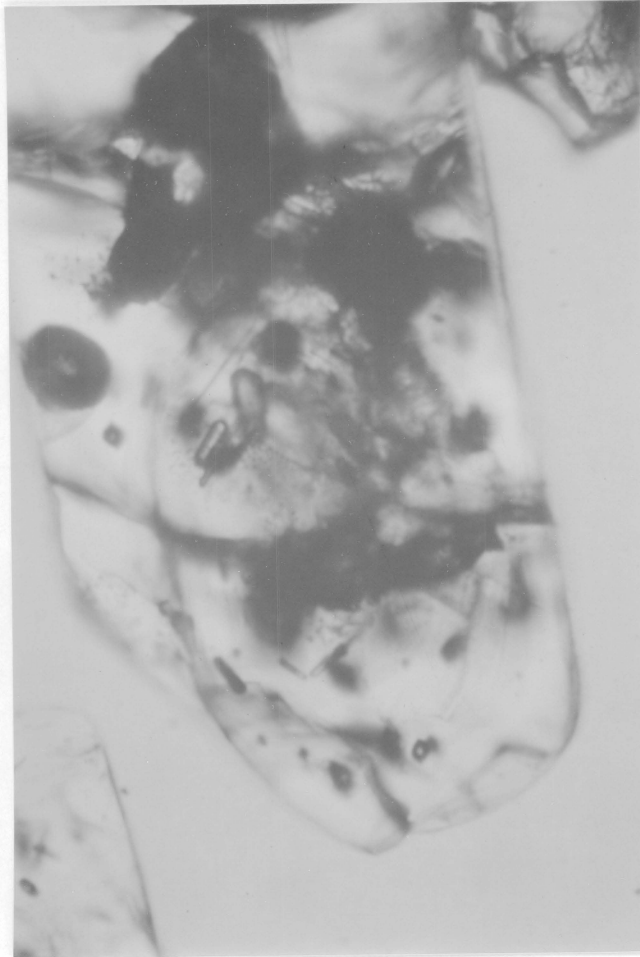


Figure 24. Concord, >150 microns, 10X. This close-up of one of the zircons from Figure 23 shows many inclusions. Note the clouded area in the center of the photo. Here the inclusions are oriented parallel to the edges of the core.

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