Tectonic and Geologic Development of the Charlotte Belt

South Central Virginia Piedmont

by

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(ABSTRACT)

The map area in the south central Virginia Piedmont is primarily in the Charlotte belt, but includes a portion of the adjacent Carolina slate belt. Both the Charlotte belt and the Carolina slate belt are major components of the volcanic arc, Carolinia, that collided with Laurentia during the Late Cambrian to Late Ordovician Taconic orogeny. Both belts consist primarily of volcanic rocks, the major difference being that the Charlotte belt is amphibolite grade gneisses, whereas the slate belt is at greenschist grade.

The major results of the study are as follows:

(1) The Carolina slate belt units, the Hyco Formation and the Aaron Formation, are present in the Charlotte belt, and a correlation between the two belts has been made.

(2) The Charlotte belt has a calc-alkalic index of 64, has a calc-alkaline differentiation trend, is metaluminous to peraluminous, and major and trace element discriminant analyses show that the basalts are predominantly low-K tholeiites with lesser calc-alkaline basalts. These results indicate that the Charlotte belt, like the more well-known Carolina slate belt, originated in a volcanic arc tectonic setting.

(3) The Charlotte belt has undergone four deformational events, a D_1 (Virgilina Deformation?) folding and cleavage-forming event, a D_2 (Taconic) recumbent fold nappe forming event caused by the northwest thrusting of the infrastructural Charlotte belt

sequence beneath a Carolina slate belt suprastructure, a D_3 dextral shearing event (Acadian?-Alleghanian) forming the Brookneal and Clover shear zones bounding the Charlotte belt on the northwest and southeast, respectively, and a D_4 event (Alleghanian) that produced regional-scale northeast-trending open folds across the area.

(4) The Charlotte belt has experienced two metamorphic events, an M_1 metamorphism (Virgilina?-Taconic) up to upper amphibolite grade, and an M_2 metamorphism (Acadian?-Alleghanian) that shows effects only in the Brookneal (amphibolite) and Clover (greenschist) shear zones.

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THE CHARLOTTE BELT, SOUTH CENTRAL VIRGINIA:

PART I. STRATIGRAPHY, AND CORRELATION WITH THE CAROLINA SLATE BELT

ABSTRACT

Stratigraphic equivalence between the Carolina slate belt and the Charlotte belt is one of the lasting questions in southern Appalachian geology. The nature of the boundary has variously been defined as an unconformity, a metamorphic grade change, and a brittle fault. Mapping across the boundary in south central Virginia, however, shows that the Hyco Formation continues across the boundary with little change other than a rise in metamorphic grade. The boundary here is thus primarily a continuous stratigraphic sequence over which is superimposed a later metamorphic event. Based on stratigraphic continuity across the boundary, further mapping of the Charlotte belt shows that stratigraphic equivalence between the two belts exists as well.

The map area is divided into a central Charlotte belt stratigraphy and an eastern Charlotte belt/Carolina slate belt stratigraphy. Units are defined on the basis of lithology, chemical analyses and CIPW norms. The oldest unit investigated is a lower rhyolite unit in the Central Charlotte belt that underlies both the central Charlotte belt and the eastern Charlotte belt/Carolina slate belt sequences. Overlying the lower rhyodacite, the fundamental rock sequence in the central Charlotte belt is (1) a basalt unit, (2) an upper rhyodacite unit, and (3) an epiclastic unit. Overlying the lower rhyodacite unit in the eastern Charlotte belt/Carolina slate belt, the sequence is (1) another basalt unit, (2) the rhyodacitic Hyco Formation, and (3) the epiclastic Aaron Formation. The basalt-upper rhyodacite-epiclastic sequence of the central Charlotte belt is interpreted as correlating with the basalt-Hyco-Aaron sequence of the eastern Charlotte belt/Carolina slate belt.

Structural work demonstrates that the Charlotte belt in the area is a large, infrastructural Taconic recumbent fold nappe thrust to the northwest beneath a Carolina slate belt suprastructure. The nappe is herein named the Milton nappe for the town of Milton, Virginia near its core. The Charlotte belt rocks examined in the study form part of the upper limb of

the nappe. Hyco equivalents are apparently folded completely around the structure, and thus should be present in the northeastern Charlotte belt of North Carolina. Present mapping has thus far established the presence of the Aaron only in the Virginia portion of the Charlotte belt.

INTRODUCTION

The southern Appalachian Piedmont (Figure 1) is one of the last and largest areas of poorly understood geology in the United States. Much of the area has been previously examined on a reconnaissance basis only, with only a small percentage of detailed, 1:62,500 or 1:24,000 scale mapping. The Piedmont consists of several geologic belts that were originally part of the volcanic arc Carolinia that collided with North America during the Late Cambrian to Middle Ordovician Taconic Orogeny (Glover, 1989). These belts are primarily the Charlotte belt and the Carolina slate belt (Figure 1), but include smaller belts such as the Kings Mountain, Kiokee, Belair, Raleigh, and Eastern slate belts. This paper concentrates on the Charlotte belt and part of the adjacent Carolina slate belt (Figure 1).

Since the early work of Laney (1917) in the adjacent area to the southeast of the present study, the Carolina slate belt (Figure 1) has been the focus of several studies (e.g., Sundelius, 1970 and references therein; Tobisch and Glover, 1971; Hadley, 1973; Bland and Blackburn, 1980; Black, 1980; Kreisa, 1980; Harris and Glover, 1985, 1988). This is because its relatively low metamorphic grade (greenschist) and lack of major deformation make it amenable to stratigraphic and chemical investigations that are difficult in the amphibolite grade Charlotte belt that has undergone wholesale recrystallization and deformation of the original lithologies. Moreover, because of the flat topography and deep weathering of the Piedmont, fresh rock is essentially absent except along streams. Road cuts are rare because the gentle relief of the area makes them unnecessary. As a result, the Charlotte belt, along with the Inner Piedmont belt (Figure 1) farther southwest, ranks as one of the least studied of all Appalachian belts. Hatcher and others (1980) noted this paucity of literature on the Charlotte belt country rock and, accordingly, devoted only a single paragraph of their geologic synthesis of the southern Appalachians to the Charlotte belt.

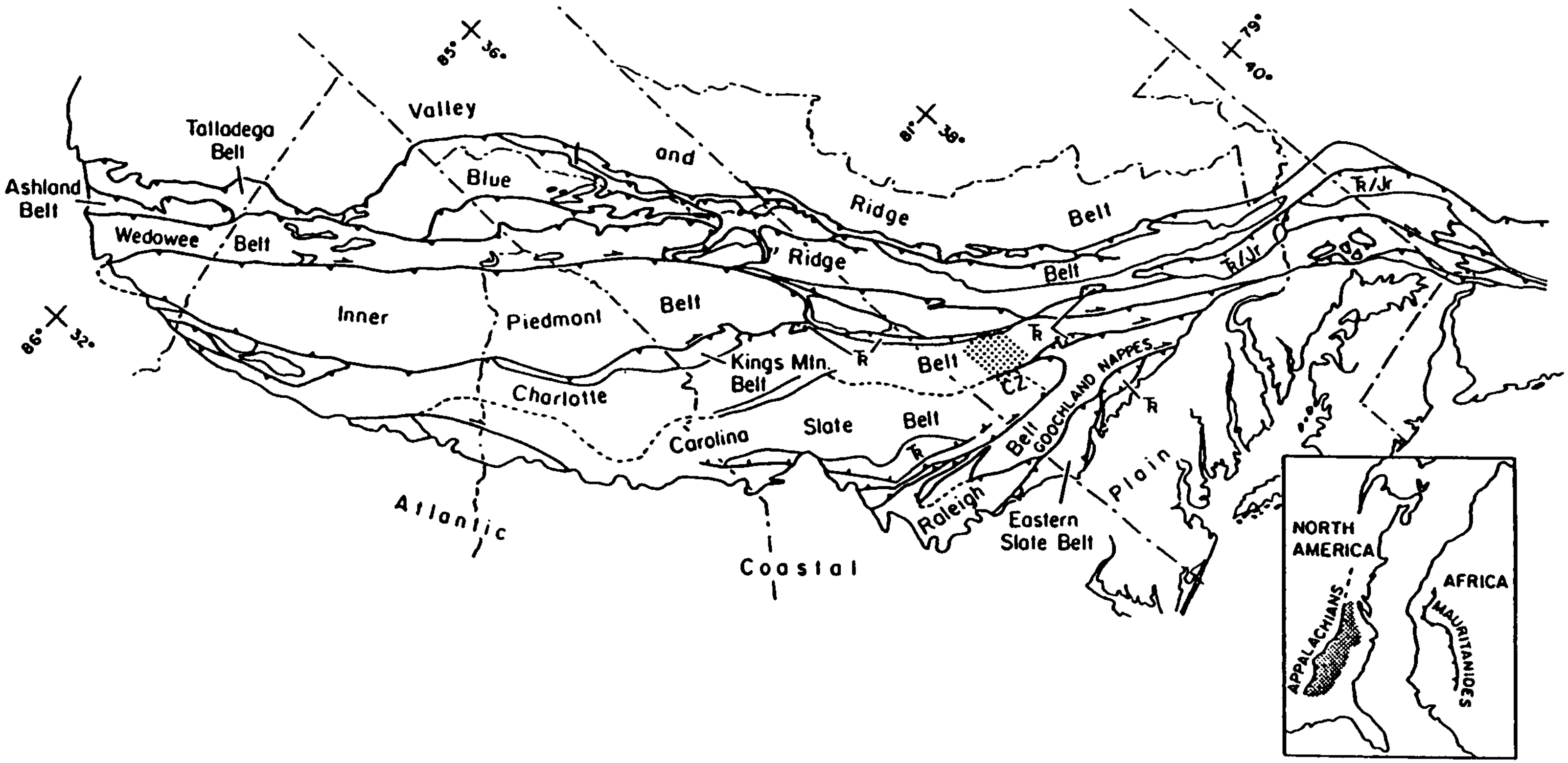

Figure 1: Tectonic map of the southern Appalachians showing location of major lithotectonic belts. Shaded area in inset gives location with respect to eastern North America. CZ is Clover shear zone. Tr and Jr are Triassic and Jurassic, respectively. Dotted enclosure is study area in Figure 2. Other names are self-explanatory. Map from Glover (1989).

Furthermore, many of the existing detailed studies in the Charlotte belt (e.g., Fullagar, 1971; Butler and Fullagar, 1978) treat the intrusive rocks rather than the host into which those rocks were intruded. The relative lack of study of the Charlotte belt host is somewhat surprising, considering that its northwestern boundary is recognized as the Taconic suture (Glover and others, 1983; Glover, 1989). Its regional extent of over 800 km, stretching from near Arvonia, Virginia where it is overlapped by coastal plain sediments in Georgia (Figure 1), indicates that it is an important element of Piedmont geology and deserving of more attention than it has heretofore received.

The purpose of this paper is to show that a mappable volcanic/sedimentary stratigraphy exists in the Virginia Charlotte belt, and to further show that this stratigraphy is contiguous with and mappable into the adjacent Carolina slate belt.

PREVIOUS WORK

Figure 1 shows the Charlotte belt and the location of the study area (dotted pattern). within the tectonic framework of the southern Appalachians. The earliest work in the area was that of Laney (1917) who defined the Hyco, Aaron, Virgilina sequence in the adjacent Carolina slate belt. He believed a fault or unconformity formed the Charlotte belt/Carolina slate belt boundary.

In 1955, P. B. King, building on earlier work, divided the southern Appalachian Piedmont into a number of northeast-trending belts, of which the Charlotte belt and Carolina slate belt are two. He postulated that slate belt equivalents might occur in the Charlotte belt. Glover and Sinha (1973) concluded that the Charlotte belt consisted of higher metamorphic grade rock equivalent to the slate belt.

Mapping across nearly the entire Virginia Charlotte belt along the Virginia-North Carolina boundary has been accomplished by Tobisch and Glover (1969, 1971), Henika (1977), and Kreisa (1980). Tobisch and Glover (1969) found that the Charlotte belt/Carolina slate belt boundary was primarily an isograd. Tobisch and Glover (1971) noted that the slate belt seemed to grade into the Charlotte belt gneisses, but made no detailed stratigraphic correlations. Harris and Glover (1988) considered that the high metamorphic grade Charlotte belt rocks were probably equivalent to lower grade rocks in the slate belt.

To the southwest, in South Carolina, McCauley (1961) noted that the Charlotte belt was more mafic than the Carolina slate belt and concluded that the two were not equivalent sequences at different metamorphic grade. On the other hand, Overstreet and Bell (1965) felt that because the sequence of rocks in the Kings Mountain, Charlotte, and Carolina slate belts had so many features in common, the stratigraphy probably continued across all three belts. Misra and McSween (1984) also considered these three belts to be part of the same terrane.

GENERAL GEOLOGY

The study area (Figure 2, Plate 1a) consists of a large area of sub-horizontal amphibolite grade Charlotte belt rocks bounded on both the northwest and southeast by Late Paleozoic dextral shear zones. The moderately southeast-dipping Carolina slate belt sequence lies to the southeast. The most prominent structural features on the map are the shear zones, large regional-scale northeast-trending open folds, and Triassic rift basins. A brief geologic history is as follows.

From at least 740 Ma (Glover and others, 1971) to about 600 Ma, deposition of volcanic rocks and subordinate epiclastic rocks of the older slate belt sequence (Glover, 1974) occurred upon Carolinia. During the 600 Ma Virgilina deformation (Glover and Sinha, 1973; Harris and Glover, 1985, 1988), a lull in the volcanism occurred and uplift allowed the formation of an erosion surface across the area. Subsequently, volcanism resumed, and the younger slate belt (Glover, 1974; Harris and Glover, 1985, 1988) volcanic and epiclastic rocks were deposited unconformably above the older Carolina slate belt sequence. The latter sequence is not recognized in the study area.

As the Carolinia arc collided with Laurentia in the Late Cambrian to Middle Ordovician, deep, hot infrastructural Charlotte belt material was thrust northwestward beneath the Carolina slate belt suprastructure to form a large recumbent fold nappe (Tobisch and Glover, 1971; Henika, 1977; Figure 3, Plate 1b). The exposed Charlotte belt in the study area is the

EXPLANATION

STRATIGRAPHY

Triassic	Tr	*Arkose and conglomerate*
Ordovician-Silurian	OSa	*Arvonia Formation*
Ordovician	O(?)tb	*Tanyard Branch Granitic Gneiss*
	Os	*Shelton Formation*
Cambrian	Cm	*Melrose Granite*
	C(?)ro	*Red Oak Granite*
Late Precambrian	pCv	*Virgilina Formation*
	pCa	*Aaron Formation*
	pCuh	*Upper Hyco Formation*
	pCav	*Altered volcanic rocks* A - Altered
	pCbc	*Blackwater Creek Gneiss* H - Hornblende-bearing
	pCec	*Ellis Creek Gneiss*
	pCcc	*Catawba Creek Amphibolite*
	pCsmc	*St. Matthews Church Amphibolite*
	pClh	*Lower Hyco*
	pCpel	*Pelitic schists*
	pCiv	*Intermediate volcanic rocks*

SYMBOLS

Overturned anticline

Anticlinal axis

Synclinal axis

1:24,000 quadrangle corner

Shear zone boundary

Brittle fault

Lithologic boundary

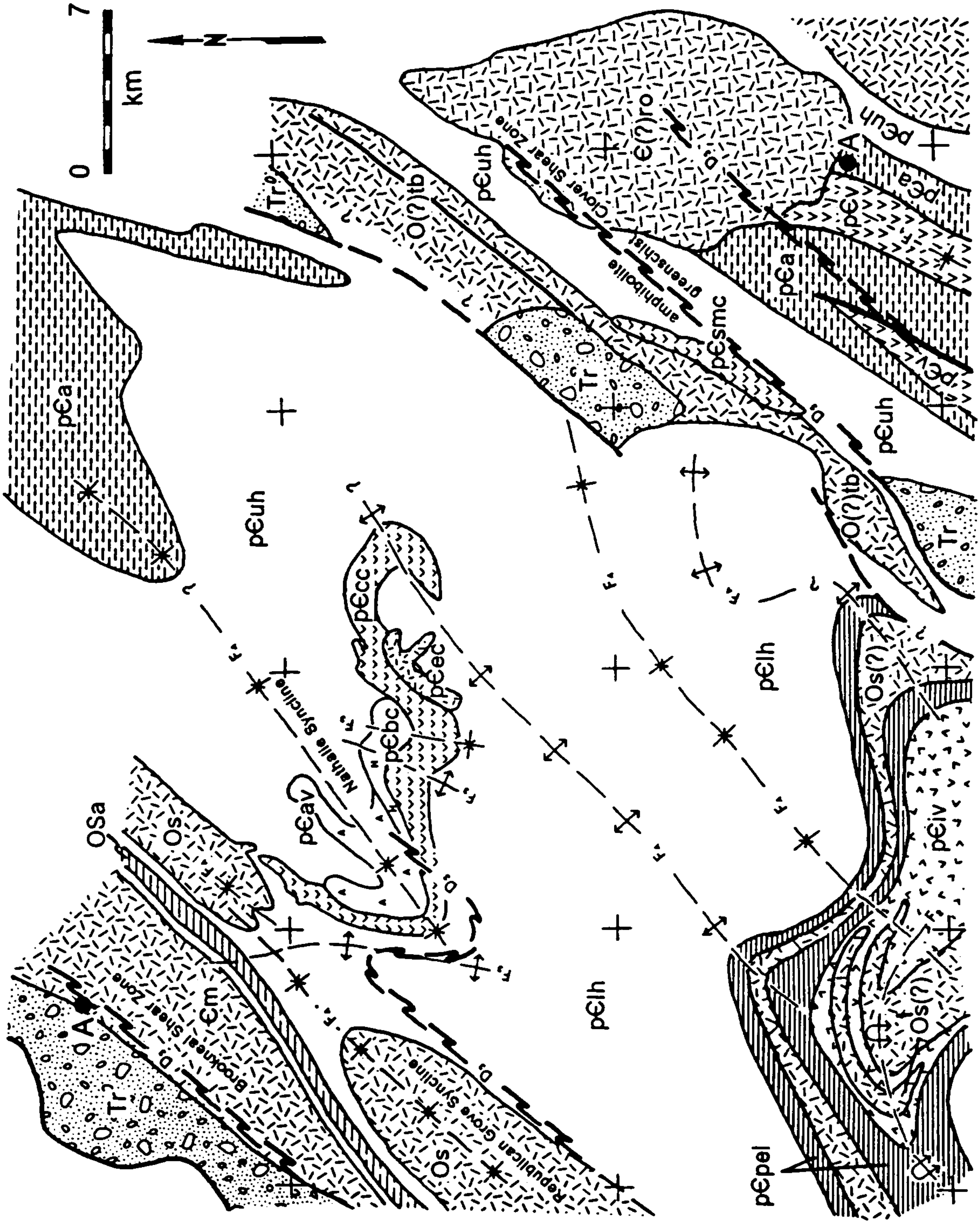

Figure 2: Geologic map of the south central Virginia Piedmont. All boundaries are approximate. Area of map is shown in Figure 1. Points A and A′ are end points of cross-section in Figure 3. Map after field mapping during this investigation, Laney (1917), VDMR (1963), Tobisch and Glover (1971), and Gates (1981). Explanation on facing page.

Cross-Section A - A'

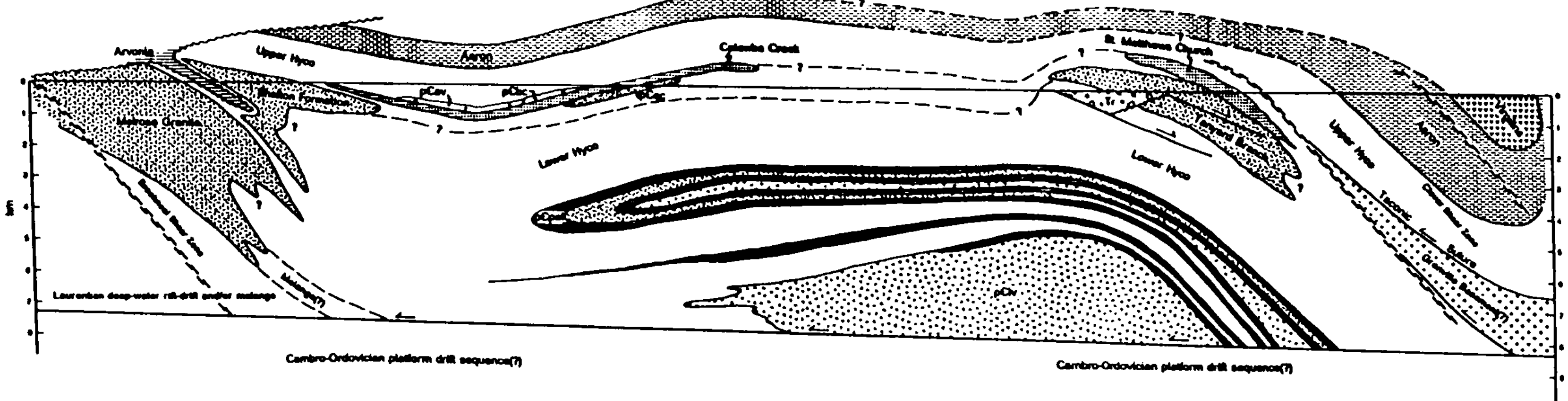

Figure 3: Cross-section across the Milton Nappe. The southeastern boundary of the Brookneal shear zone is not shown so that thin formations in the area may be more readily apparent. See Figure 2 for location of line.

upright limb of that nappe (Baird, in preparation). Deformation uplifted the area and an erosion surface occurred over Carolina slate belt lithologies. Subsequently, the Late Ordovician to Early Silurian pelitic Arvonia Formation was deposited unconformably upon the older units (Tillman, 1970).

During the Late Paleozoic, dextral shear zones affected both the northwest and southeast margins of the Charlotte belt. This shearing event was followed by a folding event that caused the formation of a series of regional scale northeast-trending antiforms and synforms throughout the area. The Charlotte belt rocks are sub-horizontal, and, on average, dip only a few degrees to the northeast. On the southeast margin of the Charlotte belt, the Carolina slate belt sequence dips moderately to the southeast. Together, the two belts comprise a gently northeast-plunging anticlinorium.

The Mesozoic rifting event is exemplified by Triassic sedimentary rocks as deposited in the Dan River, Scottsburg, Mt. Laurel, and other basins. Diabase dikes associated with the Mesozoic rifting are common throughout the area.

The central Charlotte belt is separated from the eastern Charlotte belt/Carolina slate belt by the Tanyard Branch granitic gneiss (Figure 2, Plate 1a), intruded near the Charlotte belt/Carolina slate boundary. This forms a convenient division, and the remainder of the paper will be framed in terms of sequences in these two sub-areas. In the discussion that follows, the probable Charlotte belt equivalents of Carolina slate belt rocks will be identified by their lithologic types, with the proposed name for the Charlotte belt unit following in parentheses. Justification for the correlations with slate belt units is the purpose of the paper.

CENTRAL CHARLOTTE BELT STRATIGRAPHY

The Charlotte belt of south central Virginia is principally a series of volcanic and pelitic rocks, similar to that of the more familiar Carolina slate belt. All of the rocks have been metamorphosed to amphibolite facies, and are thus meta-volcanic, meta-pelitic, etc., rocks. The prefix meta- is left off in the following discussion, but is implicit in each description.

Based on field mapping, and modal mineralogy (Table 1), whole rock chemical analysis (Table 2), and CIPW norms (Table 3) of representative samples, the dominant rock type is biotite quartz plagioclase gneiss of dacitic composition, including lesser amounts of K-feldspar plagioclase quartz gneiss of rhyolitic composition (Figure 4; Streckeisen and LeMaitre, 1979). These rocks comprise slightly more than half of the stratigraphic column of the area. Mafic units of basaltic composition represent about a fifth of the column. Graywacke type rocks make up somewhat less than a fifth of the area, whereas hydrothermally altered volcanic rocks constitute less than a tenth. Overall, the Charlotte belt rocks represent a bimodal suite of rhyodacite and basaltic volcanic rocks. The Charlotte belt lithologies have a large areal extent as ascertained from viewing the map (Figure 2, Plate 1a). This large extent may give the impression that a great thickness of these rocks is present. However, the map pattern is due primarily to the gentle northeast plunge of the units, and the total thickness of these units in the study area is only about 3.5 km.

The belt is lithologically variable and the units as described below commonly do not consist entirely of the lithology described, but contain small proportions of other lithologies as well, e.g., local rhyolite or mafic layers within a dominantly dacitic sequence. Each unit has been mapped as the dominant lithology over a given portion of the map area. Although such rock types can be easily defined, the metamorphic grade is too high and the consequent recrystallization too intense to permit identification of original features such as lapilli, flow banding, etc.

Nearly all of the Charlotte belt lithologies have been cut by small granitic to pegmatitic dikes and pods. These are more common, however, in the pelitic lithologies.

Milton Nappe Core

The core of the Milton nappe is defined here as those rocks lying stratigraphically below the lower rhyodacite unit (Lower Hyco Formation; Figure 2, Plate 1a). According to Tobisch and Glover (1971), they consist of thin layers of pelitic schist, quartzite, and local calc-silicate gneiss within quartz-feldspar gneiss. These lithologies include medium- to coarse-grained

Table 1
Modal Analyses of Selected Representative Charlotte Belt Lithologies
(Classification based on Streckeisen (1973) and Streckeisen and LeMaitre (1979))

SAMPLE	QTZ	PLAG	KSP	BIOT	CHLR	MUSC	HORN	EPID	SPHN	OPAQ
Lower Hyco Formation Rhyolite										
RB7- 5	34	39	20	2	–	3	–	1	–	–
Catawba Creek Amphibolite (Basalt) Member of Hyco Formation										
RB6- 1	10	19	–	–	–	–	53	28	tr	–
RB6- 25	–	–	–	–	–	–	42	47	1	–
RB6-423	19	–	–	–	6	–	26	47	2	–
(avg)	(10)	(6)	–	–	(2)	–	(40)	(41)	(1)	–
Ellis Creek Gneiss (Tonalite)										
RB6-182	31	54	–	7	–	–	1	5	–	1
RB6-183	22	57	–	12	–	–	13	2	–	3
RB6-191	26	49	–	–	8	–	–	5	–	–
(avg)	(26)	(53)	–	(6)	(3)	–	(5)	(4)	–	(1)
Hydrothermally Altered Volcanic Rocks										
RB6- 36	57	–	–	–	–	43	–	–	–	tr
RB6-270	74	–	–	–	–	26	–	–	–	–
RB6-380	66	–	–	–	–	34	–	–	–	–
(avg)	(66)	–	–	–	–	(34)	–	–	–	–
Upper Hyco Formation Dacite										
RB6- 14	38	38	–	10	–	–	3	12	–	–
RB6-139	46	39	–	8	–	2	–	5	–	–
RB6-140	33	54	–	11	–	2	–	1	–	–
RB6-175	37	55	tr	6	–	–	–	–	–	tr
RB6-179	37	50	–	12	–	tr	–	tr	–	–
RB6-855	48	37	–	14	–	–	–	tr	–	1
(avg)	(40)	(46)	–	(10)	–	(1)	(1)	(3)	–	–
Upper Hyco Formation Rhyolite										
RB6- 6	31	47	20	2	–	–	–	–	–	–
RB6-136	47	22	17	1	–	10	–	3	–	–
(avg)	(39)	(35)	(19)	(2)	–	(5)	–	(2)	–	–
Aaron Formation (Graywacke)										
RB6- 9	35	29	–	21	–	14	–	–	–	2
RB6- 45	23	49	–	26	–	tr	–	–	–	2
(avg)	(29)	(39)	–	(24)	–	(7)	–	–	–	(2)
St. Matthews Church Amphibolite (Basalt) Member of Hyco Formation										
RB6-684	5	31	–	tr	–	–	62	2	–	–
RB6-729	9	51	–	2	–	–	35	2	–	1
(avg)	(7)	(41)	–	(1)	–	–	(49)	(2)	–	(1)
Tanyard Branch Granitic Gneiss (Granite)										
RB6- 76	36	34	30	–	–	tr	–	–	–	–
Red Oak Granite (Granodiorite)										
RB6-100	29	49	22	–	–	–	–	–	–	tr

Table 2
Chemical analysis results of selected Charlotte belt lithologies.
Values in weight percent, except Zr in ppm.

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Zr	LOI	Total
Lower Hyco Formation Rhyolite													
RB7- 5	75.03	13.00	1.24	1.19	0.32	3.96	3.23	0.16	0.04	0.05	77	0.35	98.68
Catawba Creek Amphibolite (Basalt) Member of Hyco Formation													
RB6- 1	47.33	16.02	12.24	13.01	6.05	2.36	<0.10	0.94	0.44	0.10	42	1.31	99.86
RB6- 25	49.46	15.31	11.78	15.28	5.15	0.73	<0.10	0.76	0.18	0.09	41	1.24	100.03
RB6-423	44.84	18.58	11.38	18.95	2.98	0.46	<0.10	0.79	0.30	0.14	41	1.66	100.19
(avg)	(47.21)	(16.64)	(11.80)	(15.75)	(4.73)	(1.18)	(<0.10)	(0.83)	(0.31)	(0.11)	(41)	(1.40)	(100.03)
Upper Hyco Formation Dacite													
RB6- 14	65.66	15.12	6.46	5.57	2.08	2.92	1.28	0.29	0.11	0.08	73	0.64	100.27
RB6-140	72.68	13.60	2.93	2.01	1.02	4.09	1.90	0.22	0.04	0.07	83	0.58	99.20
RB6-175	77.42	12.20	1.71	1.20	0.22	5.27	0.26	0.25	0.03	0.05	170	0.61	99.27
RB6-179	71.04	14.59	3.73	3.39	1.05	3.75	1.31	0.43	0.09	0.11	186	0.57	100.15
RB6-590	66.40	16.11	4.86	2.61	1.52	3.94	2.19	0.85	0.07	0.12	303	0.68	99.48
RB6-855	73.39	11.91	5.99	1.65	1.14	4.29	0.90	0.49	0.10	0.09	279	0.26	100.30
(avg)	(71.06)	(13.92)	(4.28)	(2.74)	(1.17)	(4.04)	(1.31)	(0.43)	(0.07)	(0.09)	(182)	(0.55)	(99.78)

Table 2 (cont.)

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Zr	LOI	Total
Upper Hyco Formation Rhyolite													
RB6- 6	70.57	14.99	1.01	2.17	0.25	4.31	3.63	0.11	0.02	0.06	47	0.34	97.61
RB6- 80	75.27	14.05	1.02	0.98	0.15	3.40	5.10	0.09	0.02	0.06	59	0.53	100.80
RB6-136	75.13	13.67	1.54	1.58	0.24	2.76	3.77	0.14	0.03	0.06	107	0.85	99.88
(avg)	(73.66)	(14.24)	(1.19)	(1.58)	(0.22)	(3.49)	(4.17)	(0.12)	(0.03)	(0.06)	(71)	(0.58)	(99.43)
Aaron Formation (Epiclastic)													
RB6- 9	66.65	14.99	7.10	2.15	1.91	2.10	3.15	1.07	0.13	0.19	322	1.07	100.64
RB6- 45	62.41	15.87	7.74	2.78	2.21	2.39	3.27	1.23	0.12	0.26	346	1.15	99.59
(avg)	(64.53)	(15.43)	(7.42)	(2.47)	(2.06)	(2.25)	(3.21)	(1.15)	(0.13)	(0.23)	(334)	(1.11)	(100.12)
St. Matthews Church Amphibolite (Basalt) Member of Hyco Formation													
RB6-684	47.98	16.48	11.91	10.66	6.13	2.43	0.47	0.77	0.20	0.12	63	0.94	98.54
RB6-729	49.51	18.44	11.16	8.96	4.33	3.00	0.88	0.76	0.16	0.24	45	1.14	98.67
(avg)	(48.75)	(17.46)	(11.54)	(9.81)	(5.23)	(2.72)	(0.68)	(0.77)	(0.18)	(0.18)	(54)	(1.04)	(98.61)

Table 3
CIPW Norms of Selected Representative Charlotte Belt Lithologies
(Lithologies based on classification of Streckeisen and LeMaitre (1979))

SAMPLE	QUARTZ	CRDM	ORTH	AB	AN	WOLL	DIOP	HYP	HEM	IL	RUT	AP	LITH
Lower Hyco Formation													
RB7- 5	36.75	0.95	19.09	33.51	5.58	--	--	0.80	1.24	0.09	0.12	0.12	Rhyol
Catawba Creek Amphibolite Member of Hyco Formation													
RB6- 1	3.63	--	--	19.97	33.13	--	22.74	4.52	12.24	0.94	1.09	0.23	Basalt
RB6- 25	12.98	--	--	6.18	38.51	--	27.07	0.28	11.78	0.39	1.37	0.21	Basalt
RB6-423	7.11	--	--	3.89	48.64	9.32	16.01	--	11.38	0.64	1.11	0.32	Basalt
(avg)	(7.91)	(--)	(--)	(10.01)	(40.09)	(3.11)	(21.94)	(1.60)	(11.80)	(0.66)	(1.19)	(0.25)	
Upper Hyco Formation Dacite													
RB6- 14	29.56	--	7.56	24.71	24.38	--	1.68	4.40	6.46	0.24	0.41	0.19	Dacite
RB6-140	35.99	1.33	11.23	34.61	9.51	--	--	2.54	2.93	0.09	0.18	0.16	Dacite
RB6-175	43.01	1.19	1.54	44.59	5.63	--	--	0.55	1.71	0.06	0.22	0.12	Dacite
RB6-179	35.69	1.11	7.74	31.73	16.10	--	--	2.62	3.73	0.19	0.33	0.26	Dacite
RB6-590	27.58	2.80	12.94	33.34	12.16	--	--	3.79	4.86	0.15	0.77	0.28	Dacite
RB6-855	40.01	1.10	5.32	36.30	7.60	--	--	2.84	5.99	0.21	0.38	0.21	Dacite
(avg)	(35.31)	(1.26)	(7.72)	(34.21)	(12.56)	(--)	(0.28)	(2.79)	(4.28)	(0.16)	(0.38)	(0.20)	
Upper Hyco Formation Rhyolite													
RB6- 6	26.76	0.17	21.45	36.47	10.37	--	--	0.62	1.01	0.04	0.09	0.14	Rhyol
RB6- 80	33.82	1.30	30.14	28.77	4.47	--	--	0.37	1.02	0.04	0.07	0.14	Rhyol
RB6-136	41.07	2.32	22.28	23.35	7.45	--	--	0.60	1.54	0.06	0.11	0.14	Rhyol
(avg)	(33.88)	(1.26)	(24.62)	(29.53)	(7.43)	(--)	(--)	(0.53)	(1.19)	(0.05)	(0.09)	(0.14)	
St. Matthews Church Amphibolite Member of Hyco Formation													
RB6-684	4.00	--	2.78	20.56	32.68	--	13.64	9.94	11.91	0.43	1.34	0.28	Basalt
RB6-729	5.58	--	5.20	25.38	34.26	--	5.14	8.40	11.16	0.34	1.42	0.56	Basalt
(avg)	(4.79)	(--)	(5.38)	(22.97)	(33.47)	(--)	(9.39)	(9.17)	(11.54)	(0.39)	(1.38)	(0.42)	

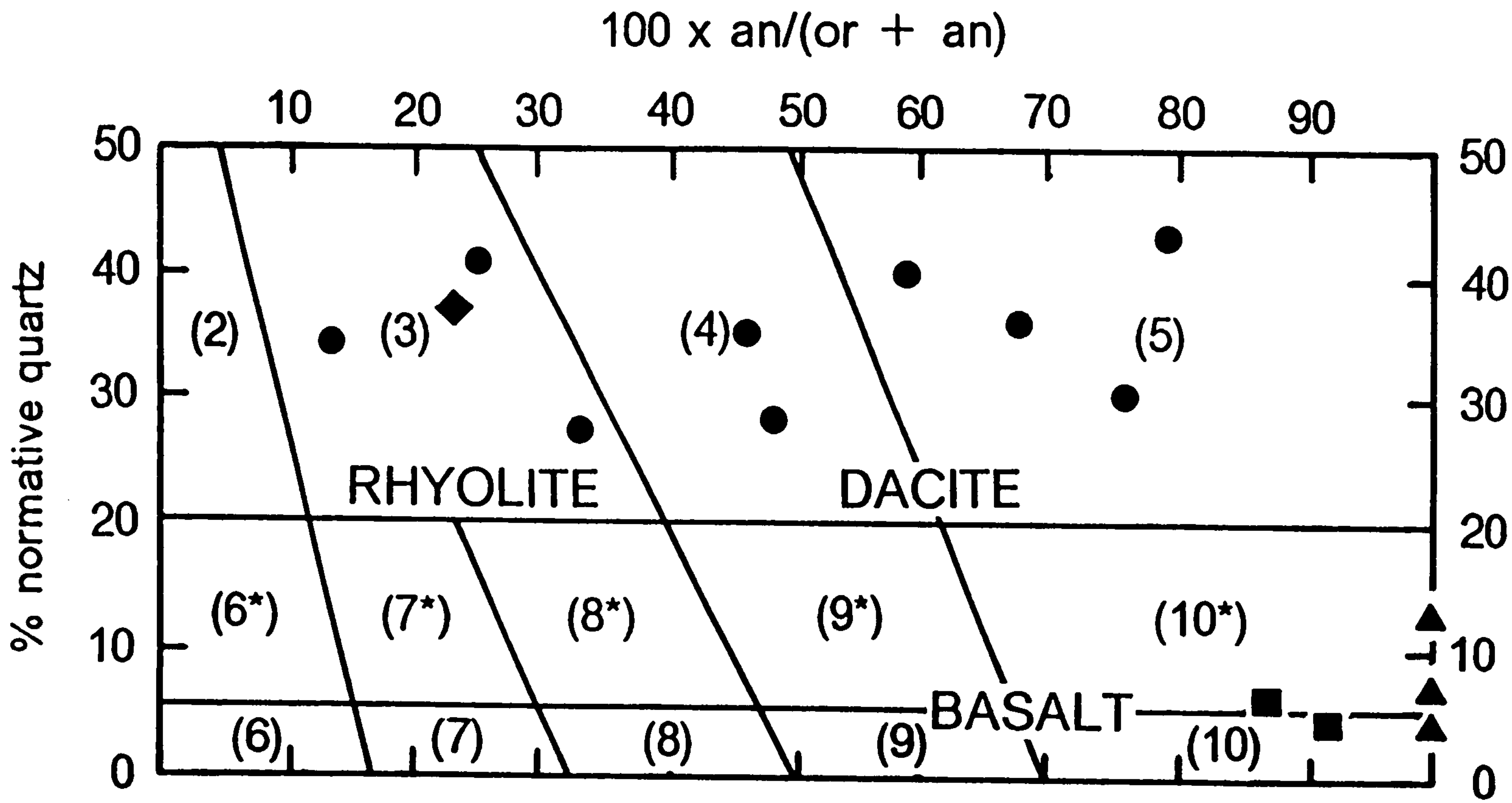

Figure 4: Volcanic rock type diagram based on CIPW normative mineralogy. Fields are as follows: (2) alkali-feldspar rhyolite, (3) rhyolite, (4)-(5) dacite, (6*) alkali-feldspar quartz trachyte, (7*) quartz trachyte, (8*) quartz latite, (9*), (10*), (9), and (10) andesite if silica > 52%; basalt if silica < 52%. Diamond - Lower Hyco Formation. Circles - Upper Hyco Formation. Triangles - Catawba Creek Amphibolite. Squares - St. Matthews Church Amphibolite. From Streckeisen and LeMaitre (1979).

granitic rock (probable Shelton Formation - see below) that has intruded the hinges of folds related to the nappe. Farther to the southwest and into North Carolina, these lithologies in turn surround an area of andesitic rock that possibly represents Goochland basement in this area. Further study is needed on this question.

Lower Rhyodacite Unit (Lower Hyco Formation)

The lower rhyodacite unit (Lower Hyco Formation) is defined as that portion of the Hyco lying stratigraphically above the pelites and other rocks of the nappe core and below the Catawba Creek Amphibolite Member (discussed below) of the Hyco Formation (Figure 2, Plate 1a). The lower rhyodacite unit (Lower Hyco) is not considered as a separate formation as distinct from the upper rhyodacite unit (Upper Hyco) because the intervening Catawba Creek Amphibolite is discontinuous, and where so the lower rhyodacite unit (Lower Hyco) is gradational into the upper rhyodacite unit (Upper Hyco; Figure 2, Plate 1a).

Type Locality. Excellent exposures of lower rhyodacite unit (Lower Hyco) volcanic rocks can be seen along most streams and tributaries near the Bannister River. Particularly good exposures may be seen along the major tributary to Bradley Creek parallel to Highway 628 and just northwest of Millstone, VA (Republican Grove Quadrangle).

Lithologic Description. The lower rhyodacite unit (Lower Hyco) volcanic rocks consist mainly of leucocratic, fine-grained (0.125-1.0 mm) dacite gneiss of pl-qtz-bt $\pm$ ms $\pm$ ep $\pm$ hb $\pm$ gt composition, with minor rhyolite of qtz-pl-ksp-ms $\pm$ bt $\pm$ ep $\pm$ gt composition. The rhyolite will be described in the discussion of the upper rhyodacite unit, in which it is more common.

The dacite commonly contains only a few percent biotite (Table 1), but varies to more than 20% biotite. The biotite is mostly brown to red-brown. Muscovite is present, but is usually quite subordinate to biotite. It is principally seen on foliation surfaces, where it is medium-grained, whereas the biotite in the matrix is fine-grained. The feldspar is mainly plagioclase of andesine composition, with local minor K-feldspar. Quartz ranges to slightly over 30%. The feldspar and quartz commonly occur as small pods, possibly porphyroblasts or relict phenocrysts. Usually, a percent or less of epidote and zoisite are present, and fine-grained almandine garnet is abundant in places. On a large scale, the unit is quite homogeneous. Despite its large map extent, the thickness of the lower rhyodacite unit (Lower Hyco) is only about 1100-1200 m because of the subhorizontal attitude of the unit.

Interpretation. The lower rhyodacite unit (Lower Hyco Formation) is interpreted as a rhyodacitic volcanic unit due to its composition and fine-grained, areally homogeneous nature and great thickness. Its locally gradational relationship with very biotitic portions interpreted as metagraywacke or pelite indicate that the unit is not a shallow intrusive. This unit is the same as that referred to by Kreisa (1980) as biotite gneiss, which he also interpreted as metavolcanic. His mica-rich gneiss is equivalent to the very biotitic portions of the lower rhyodacite unit (Lower Hyco) volcanic rocks here and has a chemical composition similar to that of graywacke.

Catawba Creek Amphibolite Member of the Hyco

Type Locality. Good exposures of the amphibolite are found along Catawba Creek and tributaries 2-3 km northeast of Nathalie, VA (Nathalie quadrangle). Excellent exposures may also be viewed along Bentley Creek about 250 m west of Highway 501 in the southwestern portion of the Brookneal quadrangle.

Lithologic Description. The Catawba Creek is a dark green to black, fine- to medium-grained (0.125-0.25 mm) hb-ep-pl-qtz$\pm$sph amphibolite, containing approximately equal proportions of amphibole and epidote (Table 1). Epidote-rich lithologies are yellowish-green with common bands of quartz. Plagioclase content is small, usually less than 10%. The amphibole is dominantly hornblende, but actinolite is present locally. The hornblende is blue-green to green in color. The unit averages 10-15% quartz. Thickness is from about 30-100 m, averaging around 70 m.

The Catawba Creek in places contains concordant layers of felsic volcanic material, and is locally interlayered with muscovite schist, and gradational with biotite schist.

Interpretation. The lack of cross-cutting relations and the fine- to medium-grained nature of the Catawba Creek, especially considering that grain size most likely increased somewhat during metamorphism, make it probable that it is a volcanic unit. Chemical analyses (Table 2) show that the rock has about 44-49% silica. Classification of the rock, based on CIPW norms, indicates that the unit was a basalt (Figure 4). The fine grain size, interlayers of muscovite schist, probably pelite, and the gradation to biotite schist, possibly of epiclastic origin, argue for an extrusive origin.

Blackwater Creek Gneiss Member of the Hyco

Type Locality. This gneiss may be seen along Blackwater Creek about one-and-a-half to two miles south-southeast of Clarkton, Virginia (Nathalie quadrangle).

Lithologic Description. The Blackwater Creek Gneiss is leucocratic when fresh, fine-grained (0.125 to 0.25 mm), with a pl-qtz-hb$\pm$bt$\pm$ep$\pm$gt assemblage. Quartz content is around 30%. It has a salt and pepper appearance like the lower rhyodacite unit (Lower Hyco) but this is due to its containing a few percent hornblende. Biotite is subordinate to almost nil. The hornblende is mostly blue-green, sometimes green and only locally brown. When biotite does occur, it is usually olive green in color, and sometimes brown. Fine almandine garnet and sphene also occur. Blackwater Creek Gneiss is about 25-30 m in thickness.

Interpretation. The Blackwater Creek Gneiss, due to its fine-grained nature and lack of cross-cutting relationships, is interpreted to have been a hornblende dacite volcanic unit.

Ellis Creek Gneiss

Type Locality. Very good and easily accessible outcrops of Ellis Creek Gneiss occur along Ellis Creek within 100 m either side of where the creek is crossed by Highway 625 (Conner Lake quadrangle).

Lithologic Description. The Ellis Creek Gneiss makes good outcrops in its area of occurrence. The Ellis Creek Gneiss is a medium to thick layered, medium-grained (0.5 to about 2 mm), leucocratic to medium gray, pl-qtz-hb-bt-ep gneiss containing around 5% each of hornblende and biotite, 50% plagioclase, a few percent epidote, and about 25% quartz (Table 1). Part of the plagioclase is altered to epidote, and some of the matrix zoisite is myrmekitic. Large, 1-2 cm, feldspar porphyroblasts, or possibly phenocrysts, are common. Locally, aplite dikes cut the gneiss. Exposures north of Highway 625 contain at least three fine-grained amphibolite xenoliths.

Interpretation. The Ellis Creek Gneiss is considered to have been a hornblende tonalite (Streckeisen, 1973) based on its coarse grain size and the presence of xenoliths of dissimilar material. Additionally, it appears to have a cross-cutting relationship with the Catawba Creek Amphibolite (Figure 2, Plate 1a). Because of its close proximity with the compositionally similar Blackwater Creek Gneiss, it is interpreted as the intrusive equivalent. As the Ellis Creek cuts the Catawba Creek Amphibolite, the mafic xenoliths are probably derived from the latter.

Hydrothermally Altered Volcanic Rocks

Type Locality. Exposures of hydrothermally altered volcanic rocks occur along Childrey Creek west of Highway 632 and along tributaries of Birch Creek, about a mile-and-a-half east of Acorn, Virginia (Nathalie Quadrangle).

Lithologic Description The material is fine-grained (0.125 to 0.25 mm) muscovite quartz schist, averaging about 2/3 quartz and 1/3 muscovite (Table 1). The unit has been sheared, and the muscovite forms excellent mica fish. Oligoclase and K-feldspar occur rarely. A small amount of biotite also occurs. Pyrite is common, and grains of chalcopyrite occur locally with the pyrite. In thin-section, fine garnet can be seen to have grown over the muscovite mica fish. These garnets are commonly color-zoned, with pinkish cores and clear rims. Along part of Childrey Creek, the rock is otherwise typical, but contains late synkinematic grains of the zinc spinel gahnite. Average thickness is about 300 m.

Interpretation. The material here is considered to be hydrothermally altered volcanic rocks, such as would be found near a volcanic vent where circulating hydrothermal waters have leached the feldspars and altered them to clay. The unit is probably equivalent to part of the upper rhyodacite unit (Upper Hyco). The gahnite may represent a concentration of zinc by the circulating waters, possibly originally introduced by fluids accompanying nearby eruptions. The sulfides probably have a similar origin. Based on the close proximity of the altered volcanic rocks to the Blackwater Creek and Ellis Creek gneisses, it is possible that the alteration may be related to Blackwater Creek volcanism.

Upper Rhyodacite Unit (Upper Hyco Formation)

Type Locality. The upper rhyodacite unit (Upper Hyco) volcanic rocks are divided into two dominant lithologies (discussed below), a pl-qtz-bt ± ms ± ep ± hb ± gt gneiss, and a qtz-pl-ksp-ms ± bt ± ep ± gt gneiss. The former lithology may be seen on outcrops 200-250 m south of Highway 634 along Little Childrey Creek (Nathalie quadrangle), whereas the latter can be viewed in a small roadcut along Highway 612 about 300 m west of Saxe, Virginia (Saxe quadrangle). Excellent exposures of upper rhyodacite unit (Upper Hyco) volcanic rocks can be seen along most streams and tributaries near the Roanoke River and along any of the several tributaries to Hunting Creek just north of Conner Lake (Conner Lake quadrangle). Jonas (1932) grouped much of this unit into the Columbia granite.

Lithologic Description. On outcrop the upper rhyodacite unit (Upper Hyco) volcanic rocks are quite variable. The two principal lithologies occur throughout the outcrop area of the upper rhyodacite unit (Upper Hyco) volcanic rocks, and do not represent discrete mappable units. The biotite quartz plagioclase gneiss, however, predominates. The thickness of the upper rhyodacite unit (Upper Hyco) is around 900-1000 m.

The biotite quartz plagioclase gneiss (dacite) is predominant and is composed of fine- to medium-grained (0.125 to 0.5 mm), but mainly fine, light gray to dark gray biotite gneiss. The color change is due to higher biotite content, to about 10% (Table 1), in the darker rocks. Locally, some of the more biotitic outcrops exhibit 2-15 mm feldspar porphyroblasts within a fine-grained matrix.

In thin section, the biotite ranges in color from green or olive green to brown to distinctly red-brown. Locally, there is some alteration to chlorite. A small amount of muscovite can also be seen microscopically. Hornblende is present locally. The feldspar is nearly always plagioclase, usually oligoclase with local albite. Samples from about a fourth of the localities, exhibit relict plagioclase phenocrysts. In places, the plagioclase is somewhat altered to zoisite or sericite. Minor K-feldspar occurs in about 5% of the samples, but overall it is quite rare. Quartz averages about 40% of the rock. Accessory opaques are usually ilmenite, with rutile, and pyrite, with chalcopyrite.

The lighter colored gneisses are the most resistant to weathering, and provide some of the best outcrops in the area. The more biotitic gneisses are readily weathered and outcrops are increasingly poor with increasing biotite content. Stream beds usually provide fresh rock, but upland cuts, such as along railroad tracks, are in saprolite. Iron oxide-coated slickensides with random attitudes are seen locally in the saprolite, but not in the fresh rock. The dacites of the upper rhyodacite unit (Upper Hyco) is more variable in biotite content than the dacites of the lower rhyodacite unit (Lower Hyco Formation), ranging from only a few percent biotite, which is conspicuous due to the leucocratic nature of the rock, to over 30% biotite where the rock becomes distinctly schistose. Usually, a few percent epidote or zoisite are present, and fine-grained almandine garnet is abundant locally.

Aplite dikes are common in this lithology in the area northeast of Brookneal. Many are concordant with the foliation. Others are variably oriented, and are either boudined, thickened or folded. Coarser pegmatitic pods are also common.

The K-feldspar plagioclase quartz lithology (rhyolite) of the upper rhyodacite unit (Upper Hyco) is light tan colored when fresh. The grain size is fine to medium (0.125-0.5 mm), with fine predominating. Biotite averages less than 5% (Table 1), hence the leucocratic nature of the rock. Where present, biotite is usually brown, but ranges from green to red-brown. Locally, the biotite is altered to chlorite. Muscovite is usually present in amounts subequal to that of the biotite, somewhat coarser-grained than the rest of the rock, and defines a weak lineation on foliation surfaces. Overall, the rock is relatively mica-poor. About 2/3 of the samples contain microcline. About 1/4 of the lithology contains mm or so sized grains of feldspar that may be relict phenocrysts. Plagioclase in the gneiss averages about 35% and is commonly speckled with zoisite altered from the plagioclase. Quartz is slightly more abundant at about 39%. A percent or two epidote is typical and garnet is present locally.

Interpretation. Like the lower rhyodacite unit (Lower Hyco), the upper rhyodacite unit (Upper Hyco) Formation is also interpreted as a rhyodacitic (Figure 4) volcanic unit due to its fine-grained nature. Its gradational relationship with very biotitic portions, interpreted as possible metagraywacke, indicates that the unit is not a shallow intrusive.

All samples selected from the biotite quartz plagioclase gneiss fall within the compositional range of dacite (Figure 4).

The majority of the aplitic dikes appear to be pre- or synkinematic. They are interpreted as preserved in various stages of transposition and becoming conformable to layering due to deformation.

Figure 4 indicates that the K-feldspar plagioclase quartz gneisses are all rhyolites. Their leucocratic nature, due to the low biotite content, is a rapid, usually accurate method of discriminating rhyolites from dacites in the field in this area.

Epiclastic Unit (Aaron Formation)

Type Locality. The epiclastic unit (Aaron Formation) is exposed along Cub Creek just southwest of Phenix, Virginia (Aspen quadrangle). It is also found in Norfolk and Western railroad cuts to the southeast of Phenix.

Lithologic Description. The epiclastic unit (Aaron Formation) is a medium to dark gray pl-qtz-bt-ms $\pm$ gt schist containing about 24% biotite, 7% muscovite, 29% quartz, and 39% plagioclase of andesine composition. It is usually coarse- to locally very coarse-grained (0.5-2.0 mm), and commonly contains 0.5 cm or so, porphyroblastic grains of feldspar in the matrix. Almandine garnet occurs in many of the exposures. The biotite is generally brown to red-brown. The unit is up to 1100 m in thickness in the area.

The epiclastic unit (Aaron Formation) appears gradational with biotitic portions of the upper rhyodacite unit (Upper Hyco Formation). Like those rocks, the Aaron has common aplite and pegmatite dikes that are in varying degrees of conformity with the foliation. Locally, there are thin layers of hornblende amphibolite, some partially retrograded to epidote. Coarse hornblendite occurs at one locality. Table 2 indicates that the epiclastic unit (Aaron Formation) has the highest Fe, Ti, and Zr of all the non-mafic samples analyzed.

Part of this unit was included in the Wissahickon Formation by Jonas (1932).

Interpretation. Due to the aluminous, micaceous nature of the Aaron Formation, its protolith is interpreted to have been a fine-grained sedimentary unit, representing epiclastic material or distal products from volcanic eruptions. It commonly contains various admixtures of less biotitic volcanic material. The local mafic layers are interpreted as small sills or dikes that possibly served as feeders for the overlying Virgilina Formation. The higher Fe, Ti, and Zr (Table 2) may be indicative of the concentration of the heavy mineral fraction during weathering, transportation, and redeposition, consistent with the interpreted epiclastic origin for this unit.

Shelton Formation

The Shelton is a coarse-grained granite gneiss that is strongly sheared in all exposures examined. It is a classic L-tectonite, exhibiting a strong subhorizontal mineral lineation and only a very weak southeast-dipping mylonitic foliation. The lineation is defined by extremely elongated grains of quartz and feldspar. In weathered stream bed exposures, the elongated minerals break out into pencil-shaped and sized fragments, with a "rotted log" appearance. Locally, the rock is deeply incised by steep-sided streams. The Shelton is quartzofeldspathic, with little mica. One phase within the Shelton, however, is very biotitic with coarse grains of feldspar in the matrix.

As also noted by Tobisch and Glover (1971) and Henika (1977, 1980), the Shelton is exposed in the core of synformal and antiformal structures. The Shelton as mapped here is contiguous with portions of the Shelton as defined by Jonas (1932).

Arvonia Formation

The Arvonia is a silver-gray graphitic quartz muscovite schist of probable pelitic protolith. Gates (in Gates and others, 1986) extended the Arvonia formation southwest as far as Brookneal, Virginia. This study has mapped it another 15 km to the southwest where it is inferred to be overlapped by sediments of the Danville Triassic basin. Where it crops out, the Arvonia forms steep-sided stream cuts and is usually fresh and well-exposed. It forms steep, jagged cliffs over streams near the Roanoke River. The Arvonia is presently preserved only in a strip on the far northwestern edge of the map area. Its thickness is up to about 70 m.

EASTERN CHARLOTTE BELT AND CAROLINA SLATE BELT STRATIGRAPHY

Many of the units of this area, such as the Hyco, Aaron, and Virgilina formations of the Carolina slate belt, have been adequately described elsewhere (Tobisch and Glover, 1971; Glover and Sinha, 1973; Kreisa, 1980; Harris and Glover 1985, 1988), therefore, they will be only briefly summarized here. The Hyco Formation has not previously been recognized as a Charlotte belt unit. The correlation between the two belts proposed here is based on similar stratigraphic and lithologic succession in the central Charlotte belt and eastern Charlotte belt/Carolina slate belt, but the two cannot be physically connected in this area due to the intervening Tanyard Branch Granitic Gneiss. The Hyco of the Carolina slate belt, however, has been mapped directly across the Charlotte belt/Carolina slate belt boundary and into the Charlotte belt for some 2-3 km before reaching the Tanyard Branch. This directly correlatable portion of Charlotte belt Hyco, as well as all of the Carolina slate belt Hyco, is part of the Upper Hyco Formation as defined here.

Minor lithologies of an intrusive nature are of limited areal extent and do not represent mappable stratigraphy.

St. Matthews Church Amphibolite Member of the Hyco

Type Locality. The St. Matthews Church Amphibolite is named for exposures along Clover Creek just northeast of St. Matthews Church on Highway 92 in Clover, VA, and for exposures along Opossum Branch of Difficult Creek about two kilometers south of the church.

Lithologic Description. The rock mapped as St. Matthews Church Amphibolite consists of two lithologies. These lithologies are interlayered along strike, and thus cannot be separated by mapping. The thickness of the unit is from 500-1000 m, and averages about 725 m.

The dominant lithology is a fine- to medium-grained (0.125-0.25 mm) hb-pl-qtz-ep$\pm$bt amphibolite containing as much as 50% hornblende, 40% plagioclase, and 10% quartz (Table 1). It is dark green to black, with a few 1 mm or so leucocratic feldspars in the matrix giving the rock a speckled appearance. Locally, some of the amphibole is altered to epidote and zoisite. It weathers to a bright red punky saprolite. Soils over this lithology are dominantly red. The CIPW norms for two samples of St. Matthews Church Amphibolite plot as basalts (Figure 4).

The subordinate lithology is quite similar to the Blackwater Creek Gneiss. It is a leucocratic pl-qtz-hb$\pm$bt$\pm$ep gneiss, with a salt and pepper appearance due to the few percent hornblende contained therein. It contains almost no biotite. It is fine-grained (0.125 to 0.25 mm), and commonly contains epidote and zoisite. Fine almandine garnet occurs locally.

Interpretation. The fine- to medium-grained nature of the St. Matthews Church Amphibolite make it likely that the lithologies present represent original basaltic and hornblende dacitic volcanic units, respectively. Although the St. Matthews is in a similar stratigraphic position with the Catawba Creek Amphibolite, the two members do not map out as a continuous unit. The cross-section (Figure 3, Plate 1b) illustrates possible equivalence between the Catawba Creek and St. Matthews Church amphibolites. Alternatively, the Catawba Creek may be a somewhat older member than the St. Matthews. The present data allow for either interpretation. It is clear, however, that both occur within a narrow stratigraphic interval within the Hyco.

Upper Hyco Formation (Charlotte Belt)

The Upper Hyco Formation of the Carolina Slate belt is stratigraphically continuous across the traditional Charlotte belt/Carolina slate belt boundary (Laney, 1917; Virginia Division of Mineral Resources, 1963) and into the Charlotte Belt. It experiences little change, other than an increase from greenschist to amphibolite metamorphic grade. Tobisch and Glover (1971) also noted that the Hyco was gradational with Charlotte belt gneisses.

Locality. The higher metamorphic grade portion of the Hyco Formation is seen along the tributary to Difficult Creek a couple of kilometers northeast of Scottsburg, Virginia (Scottsburg quadrangle), and along Clover Creek just northeast of the exposures of St. Matthews Church Amphibolite (Clover quadrangle). Both of these streams cross the Carolina slate belt/Charlotte belt boundary, and the continuity of the Hyco into the Charlotte belt with accompanying increase in metamorphic grade may be seen.

Lithologic Description. The Charlotte belt Hyco is comprised mainly of tan-colored qtz-pl-ksp-ms $\pm$ bt $\pm$ ep $\pm$ gt rock containing 30-40% quartz, with the remainder as feldspar. It contains very little mica, dominantly a small amount of coarse-grained (0.5-1.0 mm) muscovite on foliation surfaces, with local, disseminated, fine (0.125-0.25 mm) biotite. Small, scattered almandine garnets are commonly found. At least a 1000 m section of Hyco is present in the Charlotte belt.

Interpretation. The Charlotte belt Hyco is also interpreted as a rhyodacitic volcanic unit, equivalent to its lower grade slate belt portion. Rhyolites appear to be more common in the section examined.

Upper Hyco Formation (Carolina Slate Belt)

The Upper Hyco Formation of the Carolina slate belt is dominantly a rhyodacitic volcanic sequence. It was originally named the Hyco quartz porphyry by Laney (1917), but was changed to the Hyco Formation by Kreisa (1980) who noted that the sequence includes other lithologies as well. Other work (Baird, in preparation) indicates that this area of slate belt Hyco was metamorphosed at least as high as garnet zone during the Taconic orogeny. In the map area, all of the slate belt Hyco lies within the area overprinted by the late Paleozoic greenschist grade Clover shear zone (Baird, 1988) and, as such, has undergone some degree of shearing and recrystallization. Because of this, original depositional features are rare in the slate belt of this area as well.

Petrographic work, however, does show the common presence of relict plagioclase phenocrysts, commonly rotated during shearing, in a fine-grained pl-qtz-ms-chl-ep $\pm$ bt matrix. The coarser grains are not likely to be porphyroblasts, as the rock is sheared, and porphyroblastic mineral growth is inhibited during active shearing (Bell and others, 1986). The protolith was probably a porphyritic crystal tuff. If any lithic fragments were originally present, they have since been recrystallized.

Aaron Formation

The Aaron Formation was originally named the Aaron Slate by Laney (1917). Kreisa (1980) renamed the unit the Aaron Formation because it included lithologies other than slate. Like the Hyco, the Aaron has also been subjected to the shearing event. In some places, however, it is still relatively undeformed and exhibits a fine laminated appearance that petrographic work shows to be grading, probably representing the distal product of turbidity currents. The Aaron has a distinct slaty appearance and a phyllitic sheen. Typical Aaron is a greenish- silver to gray pl-qtz-ms-chl-ep $\pm$ bt slate when fresh and light tan when weathered. The Aaron in this area is about 1700-1800 m thick. The most important point for this discussion is that the Aaron is dominantly an epiclastic unit overlying the rhyodacitic Hyco. More detail on the Aaron may be found in Laney (1917), Glover and Sinha (1973), Kreisa (1980), and in Harris and Glover (1985, 1988).

Virgilina Formation

Laney (1917) termed this unit the Virgilina Greenstone, an apparent member within the Aaron which occurred both above and below his Virgilina Greenstone. Kreisa (1980) did away altogether with the term Virgilina Greenstone, calling Laney's Aaron-Virgilina-Aaron sequence simply the Aaron Formation, and referring to the tripartite sequence as members within the Aaron Formation. Harris and Glover (1985, 1988) proposed the name Aaron Formation for the lower member and included the two upper members into the Virgilina Formation.

On outcrop, the Virgilina is a greenish-gray ep-chl-qtz-pl greenstone. Because of the shearing and retrograde event, little of what could be called original texture or mineralogy remains. Much of it now consists of epidote and minor chlorite. Quartz veins are common throughout. Locally, samples are observed with greenish-gray patches of chlorite on the foliation surfaces that are interpreted as flattened lapilli. The entire thickness of Virgilina has not been examined in this study.

Tanyard Branch Granitic Gneiss

Type Locality. Exposures of the Tanyard Branch Granitic Gneiss are found along Tanyard Branch just southwest of Clover, VA (Clover quadrangle).

Lithologic Description. The Tanyard Branch is a fine-grained (0.5-2.0 mm) granitic gneiss containing 30-40% quartz, a trace of muscovite, Commonly, it has a small amount of disseminated biotite. It is massive in places, but usually has at least a weak foliation. with subequal proportions of plagioclase and microcline. In the vicinity of the Triassic basins, the plagioclase is commonly altered and usually exhibits a cataclastic texture.

Interpretation. The Tanyard Branch is interpreted as a granite (Streckeisen, 1973) due to its being much coarser-grained than the surrounding volcanic rocks, and because of its granitic appearance. Because the Tanyard Branch cuts the previously-existing Hyco Formation, it must be younger than the Hyco.

OTHER UNITS

Mafic Intrusives

Scattered throughout the Charlotte belt are found local mafic intrusives, too small to illustrate on the geologic map, and interpreted to be small dikes or sills. They are somewhat more common in the northeast part of the area. They are coarse- to very coarse-grained (1.0-10.0 mm), and grade from gabbroic rocks to hornblendite. The hornblendite is usually the coarser-grained rock. Outcrop quality is from good fresh crops to clayey saprolite. Foliation is usually weak. Locally, the gabbroic material may be seen to be interlayered with fine-grained, mafic, probably volcanic material.

Granitic/Pegmatitic Dikes

Granitic to pegmatitic dikes, as well as small pods and segregations are common throughout all the lithologies. They are, however, more common in more biotitic lithologies such as the upper rhyodacite unit (Upper Hyco) and the epiclastic unit (Aaron Formation). The mineralogy is mainly microcline, somewhat subordinate plagioclase, and 30% or more quartz. The lithology is dominantly mica-poor, but the mica present is nearly always muscovite. Foliation is usually weak to non-existent. Grain size is coarse to pegmatitic, and commonly grades from one to the other in the same exposure. Locally, xenoliths of foliated metamorphic rock are found. Where present as dikes, they are mainly sub-vertical, and exhibit a weak preferred orientation. Granitic dikes are oriented at a NNE trend, whereas pegmatite dikes are usually about NW, indicating that the two may not be related. These dikes commonly form small waterfalls across streams where less resistant country rock weathers away, leaving the dikes in relief.

Triassic Rocks

Diabase Dikes. Diabase dikes have been observed only in the Charlotte belt. Locally, they are seen to cross streams, but more commonly are identified by the appearance of float blocks in the streams and adjacent hillsides. Float ranges in size from small cobbles to boulders a meter or more across. The dikes strongly deflect a compass needle within a meter's distance. The rock is usually very fresh, even when present as float. On a weathered surface, the material is medium gray, and commonly pitted. Locally, the weathered surfaces show a distinct layering that cannot be seen on a broken surface. On a fresh surface the rock is black and very fine- to medium-grained. Randomly oriented blades of plagioclase give the rock a sub-ophitic texture. On average, the dikes are oriented about NNW.

Sandstone and Conglomerate. Several Triassic basins are present along both boundaries of the Charlotte belt. Only one of these, the Mount Laurel basin north of Clover, Virginia (middle of three southeastern basins in Figure 2, Plate 1a), was traversed during mapping. The rocks there consist of red arkosic sandstone and conglomerate. They are poorly-sorted, with a wide range of material from sand-sized to clasts up to over 0.5 m. The clasts average about 2-10 cm for their long axes. Long axes of the clasts generally lie within the same bedding plane, but show no preferred orientation. Although the outcrops observed are very weathered, the clasts mainly consist of foliated metamorphic rocks.

STRATIGRAPHIC ORDER

Based on isotopic dating and preserved sedimentary structures such as graded beds, work done in the Carolina slate belt by others (e.g., Glover and Sinha, 1973; Harris and Glover, 1985, 1988) has shown that it is principally an upright sequence. The boundary between the two consists in part of a shear zone (the Clover shear zone) across which the grade increases from greenschist in the Carolina slate belt to amphibolite in the Charlotte belt. Because the movement along the zone is late in the sequence of deformational events, and because shearing is principally along strike and distributed more or less evenly across the 5.4 km width of the zone, there do not appear to be significant changes in the original relationships between any two adjacent units affected by the zone. As indicated above, the Carolina slate belt Hyco continues across the Charlotte belt/Carolina slate belt boundary and on into the Charlotte belt. Because of this continuity, and because the slate belt sequence is fundamentally an upright sequence, the stratigraphy of the Charlotte belt is considered as upright as well, and therefore as lying stratigraphically and conformably beneath the slate belt sequence (Figure 3, Plate 1b). Based on this, the rock sequence will now be ordered from oldest to youngest.

Central Charlotte Belt

Tobisch and Glover (1971) studied the rocks immediately south and southeast of the present mapping area. Part of the rocks they mapped constitute the core of the Milton nappe (Figure 2, Plate 1a). The sequences described in this paper are younger than and overlie the nappe core. The stratigraphic column for the central Charlotte belt is shown in Figure 5a. The lower rhyodacite unit (Lower Hyco) is the oldest unit of the study area and consists dominantly of rhyodacitic volcanic rocks. The next youngest unit to the northeast is the Catawba Creek Amphibolite, interpreted as basalt flows or tuffs within the Hyco. It can be traced across a couple of quadrangles, but eventually pinches out to the east.

Two units of even more limited extent intervene between the Catawba Creek Amphibolite and the upper rhyodacite unit (Upper Hyco Formation). These are approximately coeval and are apparently younger than the Catawba Creek Amphibolite. To the west is the Blackwater Creek Gneiss, an intermediate hornblende-bearing volcanic unit (Figure 2, Plate 1a). To the east, and intrusive into the Catawba Creek, is the Ellis Creek Gneiss, an intermediate hornblende-containing gneiss. The latter contains mafic xenoliths of probable Catawba Creek Amphibolite, and is interpreted as the intrusive equivalent of the Blackwater Creek Gneiss. The upper rhyodacite unit (Upper Hyco Formation) is the next unit to the northwest. It is similar to the lower rhyodacite unit (Lower Hyco) volcanic rocks, but when both are considered as a whole, there is a secular increase in biotite content to the northeast. Overlying the upper rhyodacite unit (Upper Hyco Formation) is the epiclastic unit (Aaron Formation). The entire portion of Charlotte belt from that mapped by Tobisch and Glover (1971) through the Aaron Formation is considered as a continuous conformable sequence.

Eastern Charlotte Belt/Carolina Slate Belt

The oldest rock examined in this area is the Charlotte belt Hyco that lies just below the Carolina slate belt Hyco. Glover and others (1971) reported a date of 740 Ma for Charlotte belt rocks that lay just below the Charlotte belt/Carolina slate belt boundary and which are probably equivalent to the Charlotte belt Hyco here. Within the lower section of the Charlotte belt

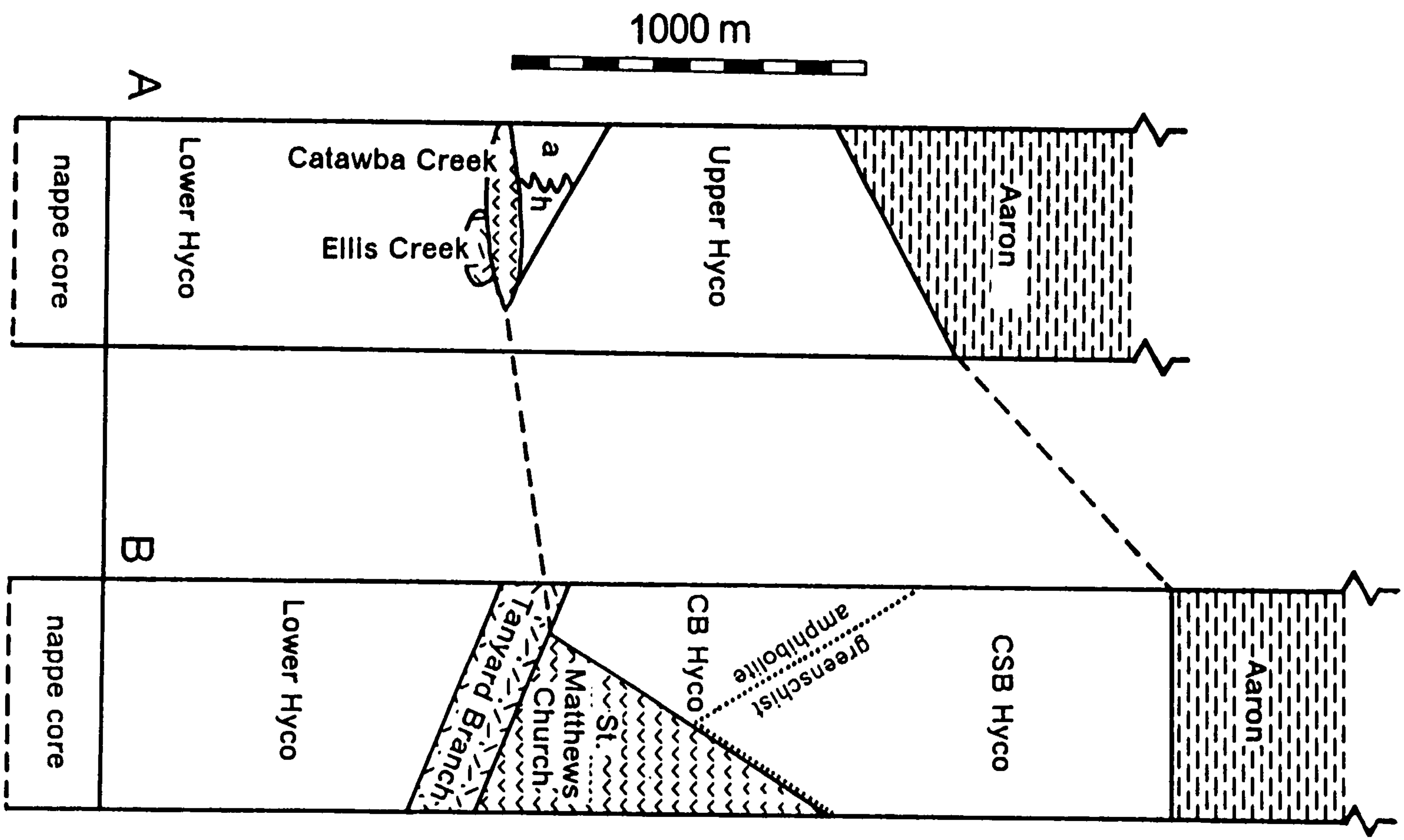

Figure 5: Stratigraphic columns and correlations between (a) the central Charlotte belt and (b) the eastern Charlotte belt and Carolina slate belt. Compare with cross-section in Figure 3.

Hyco is the St. Matthews Church Amphibolite. It is similar both chemically and in appearance to the Catawba Creek Amphibolite. The slate belt Hyco lying immediately above is bracketed to be at least 650 ± 30 ma (U-Pb, McConnell and Glover, 1982). This represents the age of the Flat River Complex intrusive into the lower part of the slate belt Hyco. Near the top of the slate belt Hyco, the volcanic rocks have been dated at 620 ± 30 Ma (U-Pb, Glover and Sinha, 1973). Stratigraphically slightly above this, metazoan imprints occur (Cloud and others, 1976). Lying above and to the southeast are the younger Aaron and Virgilina formations, respectively. Separating the Virgilina from the overlying Uwharrie Formation of the young slate belt sequence is the Virgilina unconformity. Since the Virgilina deformation occurred at about 600 Ma (Glover and Sinha, 1973; Harris and Glover, 1985, 1988), the top of the Virgilina Formation can be no younger than about 600 Ma. Correlations proposed between central Charlotte belt stratigraphy and that of the eastern Charlotte belt/Carolina slate belt stratigraphy are shown in Figure 5.

The Red Oak Granite cuts, and is therefore later than, the older slate belt sequence as represented in this area. It may be related to young slate belt volcanism. It is itself cut by Alleghanian shearing of the Clover shear zone (Baird, in preparation).

The Shelton Formation has been dated by Kish and others (1979) as 425 Ma. Considering the cooling history of a hot metamorphosed terrane, the date of the actual intrusion may be more like 450 Ma. This would make it a late Taconic granite, and is mapped by Henika (1980) as intrusive into the core of the nappe described by Tobisch and Glover (1971). This age probably indicates that the intrusion was syn-kinematic, accompanying the nappe thrusting. Buoyancy from such a hot intrusion may have aided the nappe thrusting. The Tanyard Branch also is younger than older slate belt volcanism, and may be related to the Shelton.

Unconformably overlying the volcanic sequences is the Ordovician-Silurian Arvonia Formation (Tillman, 1970). The Arvonia Formation was mapped as far southwest as Brookneal, Virginia by Gates (Gates and others, 1986), and present mapping has extended it some 15 km farther to the southwest, where it is inferred to be overlapped by sediments of the Danville Triassic basin.

DISCUSSION

Principally because of the intrusive nature of the Tanyard Branch Granitic Gneiss separating the central Charlotte belt from the eastern Charlotte belt/Carolina slate belt (Figure 2, Plate 1a), lithologic sequences of the two areas cannot be physically connected by mapping. The upper rhyodacite unit (Upper Hyco) of the central Charlotte belt, however, is interpreted as the probable equivalent of the Hyco in the eastern Charlotte belt/Carolina slate belt. The lower rhyodacite unit (Lower Hyco) of the Charlotte belt is interpreted to be older than and to lie beneath both the upper rhyodacite unit (Upper Hyco) of the central Charlotte belt and the Hyco of the eastern Charlotte belt/Carolina slate belt. The upper rhyodacite unit (Upper Hyco) is interpreted as the equivalent of the Charlotte belt and Carolina slate belt Hyco, thus it is recommended that these units now be referred to as Upper Hyco as well. Glover and others (1971) obtained a date of 740 Ma on Charlotte belt rocks that lie just below the base of the Hyco. These rocks correspond to the upper part of the lower rhyodacite unit (Lower Hyco), which indicates that most of the lower rhyodacite unit (Lower Hyco) gneisses must be older than this. Slightly northwest of the Charlotte belt/Carolina slate belt boundary, there is a broad structural flexure where the sub-horizontal rocks of the central Charlotte belt bend into the moderately southeast-dipping rocks of the eastern Charlotte belt/Carolina slate belt.

Based on the stratigraphy as outlined in this paper, and on the fundamental recumbent fold nappe structure of the Charlotte belt/Carolina slate belt (Tobisch and Glover, 1971; Henika, 1977, 1980; Baird, in preparation), it has been possible to construct a cross-section across these belts that illustrates the correlations between stratigraphies (Figure 3, Plate 1b). In this construction, part of the Charlotte belt area mapped by Tobisch and Glover (1971; southwestern portion of Figure 2, Plate 1a) is the core of the Milton nappe. The Hyco Formation has been folded around the nappe core, and should thus be found in the Charlotte belt of northeastern North Carolina.

Correlations with the most confidence are those of the Aaron and Hyco Formations. The similarity of sequence of rock north from the nappe core with that east from the core into the

Carolina slate belt suggests that this is a viable correlation. The equivalence of the Catawba Creek and the St. Matthews Church amphibolites is somewhat more debatable. If not part of the same flow, they are, however, both part of middle Hyco volcanism, with the St. Matthews possibly being slightly younger than the Catawba Creek. Similarly, the Shelton and the Tanyard Branch were perhaps never physically connected, but still may be part of the same intrusive episode.

CONCLUSIONS

The lithology of the Charlotte belt is that of a volcanic arc. The area can be divided into two parts, the central Charlotte belt and the eastern Charlotte belt/Carolina slate belt, separated by the intervening Tanyard Branch Granitic Gneiss. A lower rhyodacite unit (Lower Hyco) underlies the sequence of both areas. In the central Charlotte belt, the sequence above the lower rhyodacite (Lower Hyco) is (1) basaltic volcanic rocks (Catawba Creek Amphibolite Member of the Hyco), (2) an upper rhyodacite unit (Upper Hyco), and (3) an epiclastic unit (Aaron Formation). This sequence is concordant with the sequence in the eastern Charlotte belt/Carolina slate belt of (1) basaltic volcanic rocks (St. Matthews Church Amphibolite Member of the Hyco), (2) more rhyodacites (Upper Hyco), and (3) an epiclastic unit (Aaron). This correspondence of lithologies is consistent with and expected from the interpretation of the Charlotte belt/Carolina slate belt as part of a large recumbent fold nappe.

Because of the nature of the nappe structure and the correspondence in stratigraphic sequence between the two belts, it is concluded that stratigraphic equivalence exists between the Charlotte belt and the Carolina slate belt.

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THE CHARLOTTE BELT, SOUTH CENTRAL VIRGINIA:

PART II. VOLCANIC ARC TECTONIC SETTING

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THE CHARLOTTE BELT, SOUTH CENTRAL VIRGINIA: PART II. VOLCANIC ARC TECTONIC SETTING

ABSTRACT

The Carolina slate belt is already established as a volcanic arc sequence. New chemical analyses of Charlotte belt rocks from south central Virginia, together with analyses of Carolina slate belt rocks from the literature from adjacent areas, are compared. It is found that there are no significant differences between Charlotte belt and Carolina slate belt rocks, and that both sequences developed in the near-vent area of a volcanic arc over thin to normal thickness continental crust.

Supporting these conclusions are (1) bi-modal silica frequency, with a predominance of felsic end member rocks, (2) calc-alkalic indices between 60 and 64%, (3) calc-alkaline differentiation trend, (4) predominance of metaluminous to peraluminous rocks, and (5) major and trace element discriminant analyses indicative that the metabasalts are predominantly low-K tholeiites, with lesser amounts of calc-alkaline basalts.

INTRODUCTION AND PREVIOUS WORK

Detailed geologic mapping across the Charlotte belt and into the Carolina slate belt in south-central Virginia (dotted pattern in Figure 1) confirms that the Charlotte belt and the older Carolina slate belt represent a continuous stratigraphic sequence (Tobisch and Glover, 1971; Glover and Sinha, 1973; (Baird, Part I). The study area is detailed on the geologic map in Figure 2 (Plate 1a). The two belts have traditionally been regarded as representing two distinct lithotectonic belts and have been distinguished from one another by the fact that the Carolina slate belt is mainly greenschist volcanic rocks, as compared with amphibolite grade material in the Charlotte belt. The Charlotte belt is often characterized in the literature as "high grade gneisses" or "layered gneisses." Most of the early work (1950-1970) in the Charlotte belt placed an emphasis on the Paleozoic granitoid rocks intrusive into the Charlotte belt, and tended to subordinate the host rock and its geologic history. The Charlotte belt was,

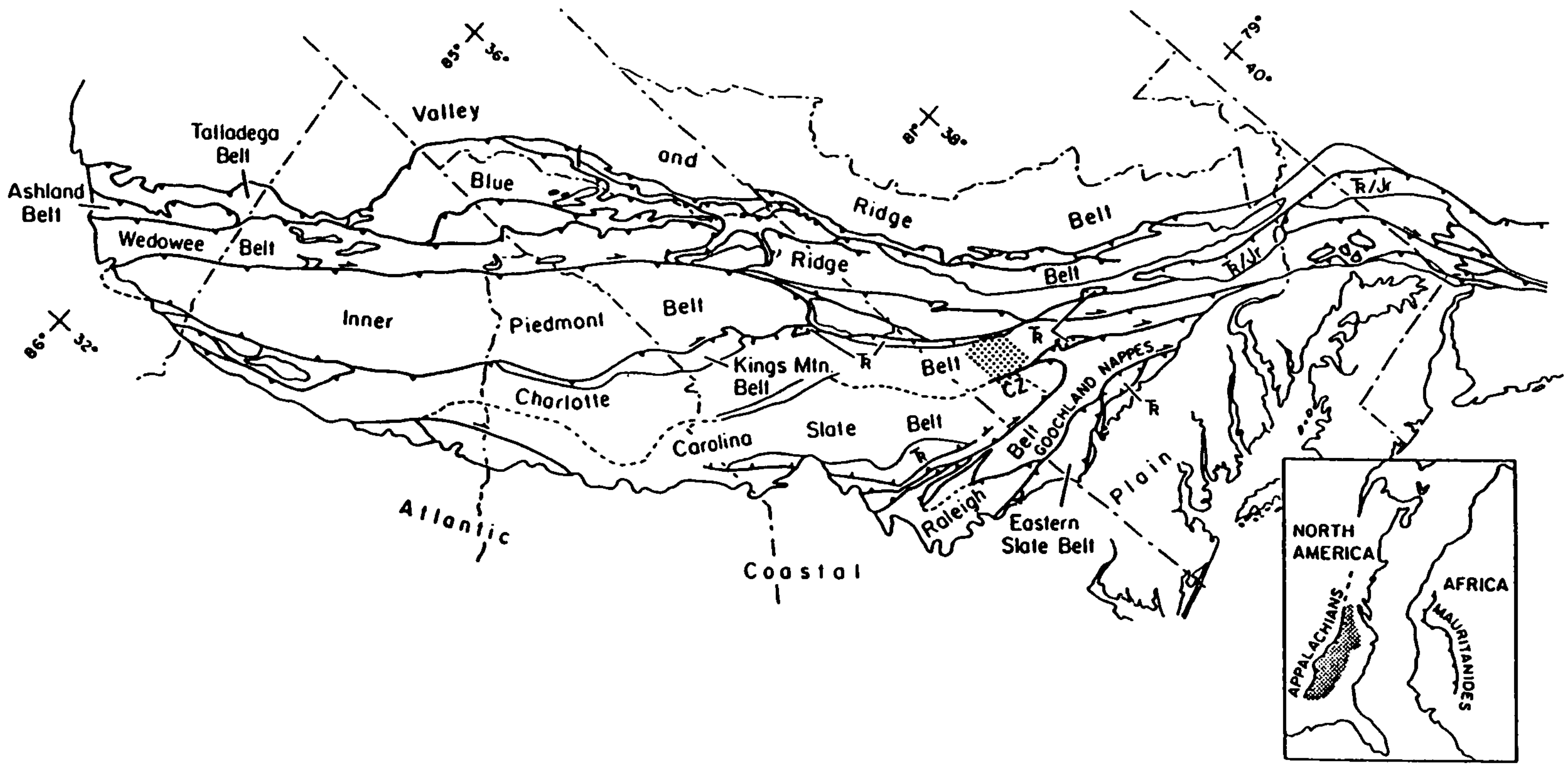

Figure 1: Tectonic map of the southern Appalachians showing location of major lithotectonic belts. Shaded area in inset gives location with respect to eastern North America. CZ is Clover shear zone. Tr and Jr are Triassic and Jurassic, respectively. Dotted enclosure is study area in Figure 2. Other names are self-explanatory. Map from Glover (1989).

EXPLANATION

STRATIGRAPHY

Triassic	Tr	*Arkose and conglomerate*
Ordovician-Silurian	OSa	*Arvonia Formation*
Ordovician	O(?)tb	*Tanyard Branch Granitic Gneiss*
	Os	*Shelton Formation*
Cambrian	Cm	*Melrose Granite*
	C(?)ro	*Red Oak Granite*
Late Precambrian	pCv	*Virgilina Formation*
	pCa	*Aaron Formation*
	pCuh	*Upper Hyco Formation*
	pCav	*Altered volcanic rocks* A - Altered
	pCbc	*Blackwater Creek Gneiss* H - Hornblende-bearing
	pCec	*Ellis Creek Gneiss*
	pCcc	*Catawba Creek Amphibolite*
	pCsmc	*St. Matthews Church Amphibolite*
	pClh	*Lower Hyco*
	pCpel	*Pelitic schists*
	pClv	*Intermediate volcanic rocks*

SYMBOLS

Overturned anticline

Anticlinal axis

Synclinal axis

1:24,000 quadrangle corner

Shear zone boundary

Brittle fault

Lithologic boundary

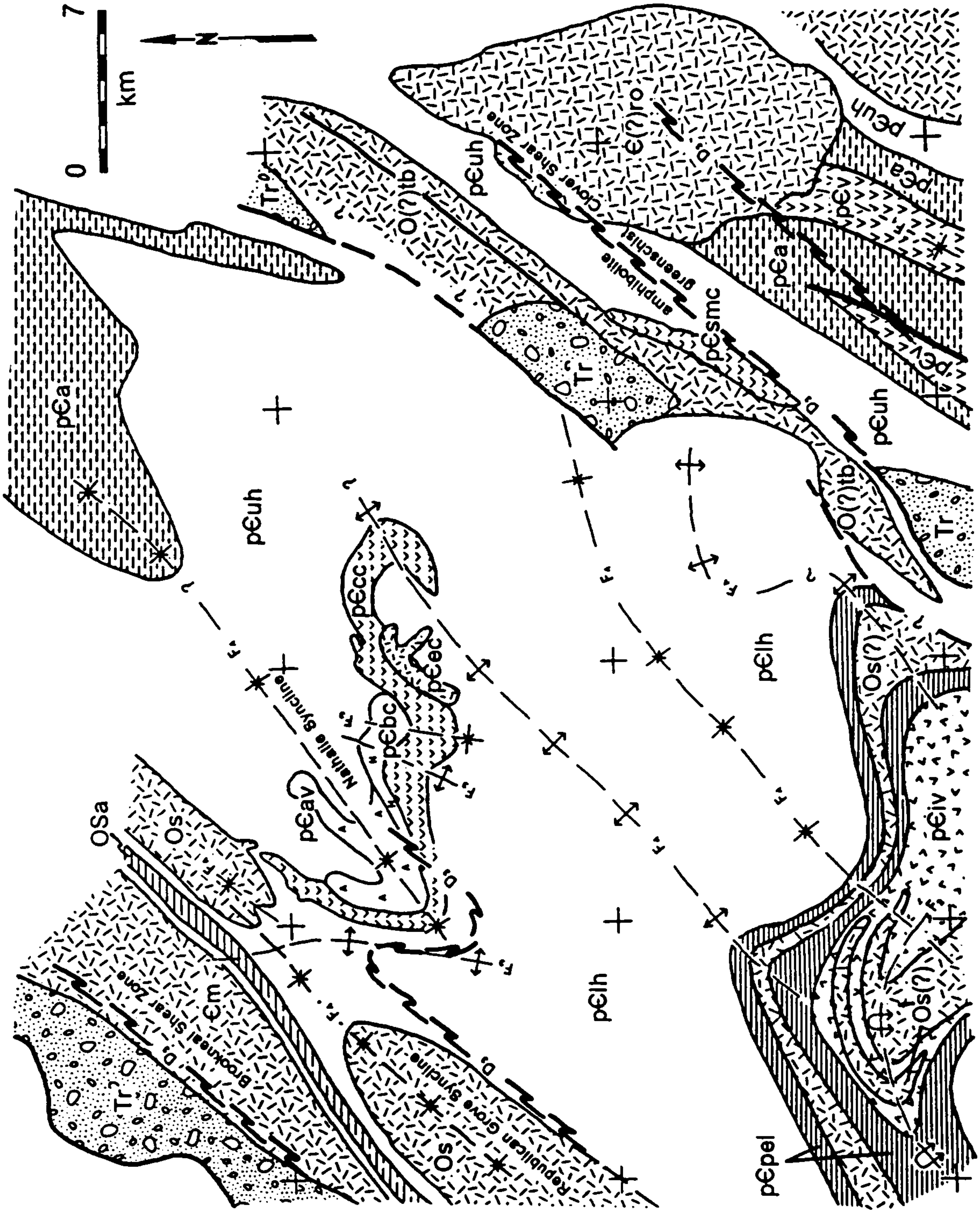

Figure 2: Geologic map of the south central Virginia Piedmont. All boundaries are approximate. Area of map is shown in Figure 1. Map after field mapping during this investigation, Laney (1917), VDMR (1963), and Tobisch and Glover (1971). Explanation on facing page.

in fact, originally distinguished by the preponderance of plutonic rocks in certain parts of the belt (King, 1955). Various origins have been proposed for the Carolina slate belt and the Charlotte belt, principally for the slate belt, but few studies have treated both belts as a unit.

Glover and Sinha (1973) found that slate belt rocks were similar to rocks from volcanic arcs that had developed over continental crust. They postulated that slate belt volcanism resulted from eastward subduction beneath the volcanic arc, and that the western margin of the Kings Mountain/Charlotte/Carolina slate belt terrane is a possible locus of the Taconic suture. Based on trace-element discriminant analysis, Bland and Blackburn (1980) proposed that greenstones in the older Carolina slate belt are calc-alkaline basalts, with a mature volcanic arc origin. Citing silica contents over 65% for the older slate belt felsic volcanic rocks, Na + K commonly > 5%, and FeO* > 2%, they also argued for development of the arc over continental-type crust. Considering the the high rhyodacite content of the slate belt rocks, and an average calc-alkalinity of 42%, Black (1980) calculated that crustal thickness was probably in the 20-40 km range. Concluding that most slate belt volcanic rocks were deposited underwater, Black (1980) postulated that either the crust was thin enough to be at isostatic equilibrium below sea level, or the relative sea level stand was high at the time.

Bland and Blackburn (1980) considered the younger slate belt basalts and concluded that they were low-K tholeiites, indicative of either an immature volcanic arc, or the trench side of a mature arc (Bland and Blackburn, 1980).

BRIEF TECTONIC HISTORY

During and prior to the time of the Late Proterozoic rifting of Laurentia, Carolinia was a volcanic arc accumulating volcanic rocks of the Charlotte belt and older Carolina slate belt sequence due to east-dipping (present-day coordinates) subduction of ocean crust beneath it. Glover and others (1971) reported a 740 Ma date for Charlotte belt rocks gradational into the Carolina slate belt sequence indicating that Carolinia volcanism initiated prior to that time. Because arc volcanic rocks are not found in the Late Precambrian-Cambrian Lynchburg-

Evington rift-drift sequence, it is unlikely that Carolinia is the fragment that rifted off of Laurentia during the Late Precambrian.

Possibly as a result of a shift to more oblique subduction beneath Carolinia, a strike-slip basin, analogous to that along modern Sumatra, formed. This basin was filled with epiclastic and volcanic rocks of the Aaron Formation. Overlying the Aaron are the basalts of the Virgilina Formation, extruded during this basin forming event (Glover, 1989). Related to this event, at around 600 Ma., Carolinia experienced the Virgilina deformation, which resulted in tight folding and broad upwarping of the area and the formation of an erosion surface (Glover and Sinha, 1973; Harris and Glover, 1985, 1988). Subsequently, Carolinia began drifting toward the eastern margin of the Laurentian craton. Subsidence allowed for the deposition of the younger Carolina slate belt sequence unconformably upon the older rocks.

Bentonites within the Ordovician carbonates of the Laurentian shelf record the approach of Carolinia. Taconic collision of Carolinia caused the northwestward thrusting of the infrastructural Milton nappe (Baird, Part I) beneath the suprastructural slate belt rocks. The result was an area of greenschist grade Carolina slate belt volcanic rocks with a moderate southeast dip juxtaposed against an area of sub-horizontal amphibolite-grade Charlotte belt volcanic rocks. At that time, the Charlotte belt was a large recumbent fold nappe, with the structure of the Charlotte belt and that of the Carolina slate belt grading into one another (Tobisch and Glover, 1969, 1971; Henika, 1977).

Approach of Africa toward North America during the Late Paleozoic caused local compression, transform movement, and tension along the North American margin (Ferrill and Thomas, 1988). Subduction activity was probably insignificant at the time. Late Paleozoic plutons are typical of crustal shortening and are not subduction related (Glover, 1989). Approach of the two continents resulted in the formation of the northeast-trending dextral eastern Piedmont fault system (Hatcher and others, 1977; Bobyarchick, 1981). At that time, the Brookneal shear zone (Gates and others, 1986) in the northwest portion of the study area, and the newly-described (Baird, 1988) Clover shear zone, in the southeast section, formed.

Final docking and suturing of the continents resulted in the imposition of a series of large northeast-trending folds upon the Charlotte belt portion of Carolinia, producing its present-day anticlinorial structure on the upright limb of the fold nappe.

Finally, Mesozoic rifting caused the formation of several Triassic basins in the area, and related diabase dikes are common.

CAROLINIAN TECTONIC SETTING

Because of the high grade of metamorphism and consequent recrystallization of the volcanic rocks described, no textural characteristics other than local relict phenocrysts remain to be used in helping determine the original tectonic setting of the Charlotte belt. To aid in making this determination, several chemical methods were employed. For major element discrimination, these include (1) silica frequency distribution, (2) calc-alkalic index, (3) iron enrichment trend, (4) alumina saturation, and (5) basalt chemistry. Trace element chemistry is also utilized in the characterization of the basalts. Major element analyses are again used for determination of the location of the Charlotte belt volcanic rocks with respect to the trench, the crustal thickness beneath the Carolinia arc, and the type of volcanic arc represented by Carolinia.

Data for the Charlotte belt will be compared with the tectonic setting of the older Carolina slate belt sequence as ascertained from the available geochemistry for that belt in the literature. Fifteen new Charlotte belt analyses (Tables 1-4) are presented here. In addition, 10 more analyses of Charlotte belt rocks in Charlotte belt south of the study area were used from Kreisa (1980). A total of 95 Carolina slate belt chemical analyses were compiled for the Virgilina area of Virginia and North Carolina (Bland, 1979, Kreisa, 1980), and for Granville (Hadley, 1973), Orange (Wilson and Allen, 1968; Black, 1977; Bland, 1979; Newton, 1983), Chatham, and Moore (Green and others, 1982) counties in North Carolina. These areas were chosen because they represent the most northerly analyses, i.e., relatively close to the study area in south central Virginia, as well as being near the Charlotte belt/slate belt

Table 1
Modal Analyses of Selected Representative Charlotte Belt Lithologies
(Classification based on Streckeisen (1973) and Streckeisen and LeMaitre (1979))

SAMPLE	QTZ	PLAG	KSP	BIOT	CHLR	MUSC	HORN	EPID	SPHN	OPAQ
Lower Hyco Formation Rhyolite										
RB7- 5	34	39	20	2	--	3	--	1	--	--
Catawba Creek Amphibolite (Basalt) Member of Hyco Formation										
RB6- 1	10	19	--	--	--	--	53	28	tr	--
RB6- 25	--	--	--	--	--	--	42	47	1	--
RB6-423	19	--	--	--	6	--	26	47	2	--
(avg)	(10)	(6)	--	--	(2)	--	(40)	(41)	(1)	--
Ellis Creek Gneiss (Tonalite)										
RB6-182	31	54	--	7	--	--	1	5	--	1
RB6-183	22	57	--	12	--	--	13	2	--	3
RB6-191	26	49	--	--	8	--	--	5	--	--
(avg)	(26)	(53)	--	(6)	(3)	--	(5)	(4)	--	(1)
Hydrothermally Altered Volcanic Rocks										
RB6- 36	57	--	--	--	--	43	--	--	--	tr
RB6-270	74	--	--	--	--	26	--	--	--	--
RB6-380	66	--	--	--	--	34	--	--	--	--
(avg)	(66)	--	--	--	--	(34)	--	--	--	--
Upper Hyco Formation Dacite										
RB6- 14	38	38	--	10	--	--	3	12	--	--
RB6-139	46	39	--	8	--	2	--	5	--	--
RB6-140	33	54	--	11	--	2	--	1	--	--
RB6-175	37	55	tr	6	--	--	--	--	--	tr
RB6-179	37	50	--	12	--	tr	--	tr	--	--
RB6-855	48	37	--	14	--	--	--	tr	--	1
(avg)	(40)	(46)	--	(10)	--	(1)	(1)	(3)	--	--
Upper Hyco Formation Rhyolite										
RB6- 6	31	47	20	2	--	--	--	--	--	--
RB6-136	47	22	17	1	--	10	--	3	--	--
(avg)	(39)	(35)	(19)	(2)	--	(5)	--	(2)	--	--
Aaron Formation (Graywacke)										
RB6- 9	35	29	--	21	--	14	--	--	--	2
RB6- 45	23	49	--	26	--	tr	--	--	--	2
(avg)	(29)	(39)	--	(24)	--	(7)	--	--	--	(2)
St. Matthews Church Amphibolite (Basalt) Member of Hyco Formation										
RB6-684	5	31	--	tr	--	--	62	2	--	--
RB6-729	9	51	--	2	--	--	35	2	--	1
(avg)	(7)	(41)	--	(1)	--	--	(49)	(2)	--	(1)
Tanyard Branch Granitic Gneiss (Granite)										
RB6- 76	36	34	30	--	--	tr	--	--	--	--
Red Oak Granite (Granodiorite)										
RB6-100	29	49	22	--	--	--	--	--	--	tr

Table 2
Chemical analysis results of selected Charlotte belt lithologies.
Values in weight percent, except Zr in ppm.

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Zr	LOI	Total
Lower Hyco Formation Rhyolite													
RB7- 5	75.03	13.00	1.24	1.19	0.32	3.96	3.23	0.16	0.04	0.05	77	0.35	98.68
Catawba Creek Amphibolite (Basalt) Member of Hyco Formation													
RB6- 1	47.33	16.02	12.24	13.01	6.05	2.36	<0.10	0.94	0.44	0.10	42	1.31	99.86
RB6- 25	49.46	15.31	11.78	15.28	5.15	0.73	<0.10	0.76	0.18	0.09	41	1.24	100.03
RB6-423	44.84	18.58	11.38	18.95	2.98	0.46	<0.10	0.79	0.30	0.14	41	1.66	100.19
(avg)	(47.21)	(16.64)	(11.80)	(15.75)	(4.73)	(1.18)	(<0.10)	(0.83)	(0.31)	(0.11)	(41)	(1.40)	(100.03)
Upper Hyco Formation Dacite													
RB6- 14	65.66	15.12	6.46	5.57	2.08	2.92	1.28	0.29	0.11	0.08	73	0.64	100.27
RB6-140	72.68	13.60	2.93	2.01	1.02	4.09	1.90	0.22	0.04	0.07	83	0.58	99.20
RB6-175	77.42	12.20	1.71	1.20	0.22	5.27	0.26	0.25	0.03	0.05	170	0.61	99.27
RB6-179	71.04	14.59	3.73	3.39	1.05	3.75	1.31	0.43	0.09	0.11	186	0.57	100.15
RB6-590	66.40	16.11	4.86	2.61	1.52	3.94	2.19	0.85	0.07	0.12	303	0.68	99.48
RB6-855	73.39	11.91	5.99	1.65	1.14	4.29	0.90	0.49	0.10	0.09	279	0.26	100.30
(avg)	(71.06)	(13.92)	(4.28)	(2.74)	(1.17)	(4.04)	(1.31)	(0.43)	(0.07)	(0.09)	(182)	(0.55)	(99.78)

Table 2 (cont.)

SAMPLE	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	TiO_2	MnO	P_2O_5	Zr	LOI	Total
Upper Hyco Formation Rhyolite													
RB6- 6	70.57	14.99	1.01	2.17	0.25	4.31	3.63	0.11	0.02	0.06	47	0.34	97.61
RB6- 80	75.27	14.05	1.02	0.98	0.15	3.40	5.10	0.09	0.02	0.06	59	0.53	100.80
RB6-136	75.13	13.67	1.54	1.58	0.24	2.76	3.77	0.14	0.03	0.06	107	0.85	99.88
(avg)	(73.66)	(14.24)	(1.19)	(1.58)	(0.22)	(3.49)	(4.17)	(0.12)	(0.03)	(0.06)	(71)	(0.58)	(99.43)
Aaron Formation (Epiclastic)													
RB6- 9	66.65	14.99	7.10	2.15	1.91	2.10	3.15	1.07	0.13	0.19	322	1.07	100.64
RB6- 45	62.41	15.87	7.74	2.78	2.21	2.39	3.27	1.23	0.12	0.26	346	1.15	99.59
(avg)	(64.53)	(15.43)	(7.42)	(2.47)	(2.06)	(2.25)	(3.21)	(1.15)	(0.13)	(0.23)	(334)	(1.11)	(100.12)
St. Matthews Church Amphibolite (Basalt) Member of Hyco Formation													
RB6-684	47.98	16.48	11.91	10.66	6.13	2.43	0.47	0.77	0.20	0.12	63	0.94	98.54
RB6-729	49.51	18.44	11.16	8.96	4.33	3.00	0.88	0.76	0.16	0.24	45	1.14	98.67
(avg)	(48.75)	(17.46)	(11.54)	(9.81)	(5.23)	(2.72)	(0.68)	(0.77)	(0.18)	(0.18)	(54)	(1.04)	(98.61)

Table 3
CIPW Norms of Selected Representative Charlotte Belt Lithologies
(Lithologies based on classification of Streckeisen and LeMaitre (1979))

SAMPLE	QUARTZ	CRDM	ORTH	AB	AN	WOLL	DIOP	HYP	HEM	IL	RUT	AP	LITH
Lower Hyco Formation													
RB7- 5	36.75	0.95	19.09	33.51	5.58	--	--	0.80	1.24	0.09	0.12	0.12	Rhyol
Catawba Creek Amphibolite Member of Hyco Formation													
RB6- 1	3.63	--	--	19.97	33.13	--	22.74	4.52	12.24	0.94	1.09	0.23	Basalt
RB6- 25	12.98	--	--	6.18	38.51	--	27.07	0.28	11.78	0.39	1.37	0.21	Basalt
RB6-423	7.11	--	--	3.89	48.64	9.32	16.01	--	11.38	0.64	1.11	0.32	Basalt
(avg)	(7.91)	(--)	(--)	(10.01)	(40.09)	(3.11)	(21.94)	(1.60)	(11.80)	(0.66)	(1.19)	(0.25)	
Upper Hyco Formation Dacite													
RB6- 14	29.56	--	7.56	24.71	24.38	--	1.68	4.40	6.46	0.24	0.41	0.19	Dacite
RB6-140	35.99	1.33	11.23	34.61	9.51	--	--	2.54	2.93	0.09	0.18	0.16	Dacite
RB6-175	43.01	1.19	1.54	44.59	5.63	--	--	0.55	1.71	0.06	0.22	0.12	Dacite
RB6-179	35.69	1.11	7.74	31.73	16.10	--	--	2.62	3.73	0.19	0.33	0.26	Dacite
RB6-590	27.58	2.80	12.94	33.34	12.16	--	--	3.79	4.86	0.15	0.77	0.28	Dacite
RB6-855	40.01	1.10	5.32	36.30	7.60	--	--	2.84	5.99	0.21	0.38	0.21	Dacite
(avg)	(35.31)	(1.26)	(7.72)	(34.21)	(12.56)	(--)	(0.28)	(2.79)	(4.28)	(0.16)	(0.38)	(0.20)	
Upper Hyco Formation Rhyolite													
RB6- 6	26.76	0.17	21.45	36.47	10.37	--	--	0.62	1.01	0.04	0.09	0.14	Rhyol
RB6- 80	33.82	1.30	30.14	28.77	4.47	--	--	0.37	1.02	0.04	0.07	0.14	Rhyol
RB6-136	41.07	2.32	22.28	23.35	7.45	--	--	0.60	1.54	0.06	0.11	0.14	Rhyol
(avg)	(33.88)	(1.26)	(24.62)	(29.53)	(7.43)	(--)	(--)	(0.53)	(1.19)	(0.05)	(0.09)	(0.14)	
St. Matthews Church Amphibolite Member of Hyco Formation													
RB6-684	4.00	--	2.78	20.56	32.68	--	13.64	9.94	11.91	0.43	1.34	0.28	Basalt
RB6-729	5.58	--	5.20	25.38	34.26	--	5.14	8.40	11.16	0.34	1.42	0.56	Basalt
(avg)	(4.79)	(--)	(5.38)	(22.97)	(33.47)	(--)	(9.39)	(9.17)	(11.54)	(0.39)	(1.38)	(0.42)	

Table 4
Minor and trace element analysis results for Charlotte belt mafic rocks
Values in ppm

SAMPLE	Ba	Sr	Y	Sc	Be	Co	Cr	Cu	Ni	V	Zn	Th	Mo
Catawba Creek Amphibolite (Basalt) Member of Hyco Formation													
RB6- 1	59	352	22	39	<1	62	70	40	10	350	380	<30	<10
RB6- 25	15	313	20	34	<1	44	390	<5	100	240	50	<30	<10
RB6-423	573	41	24	31	<1	40	400	<5	60	210	85	<30	<10
St. Matthews Church Amphibolite (Basalt) Member of Hyco Formation													
RB6-684	116	293	26	43	<1	54	120	90	30	350	80	<100	<10
RB6-729	175	519	16	31	<1	42	75	110	20	350	70	100	<10

boundary. If the two belts indeed have stratigraphic (Baird, Part I), or even temporal, equivalence, then their chemistry and tectonic setting should be similar.

Alteration of the Volcanic Rocks

It is necessary to use caution when interpreting the tectonic implications of any set of chemical analyses. Submarine volcanic rocks are especially susceptible to alteration after eruption. Most of the major elements are mobile to very mobile in this situation, with the exception of Al_2O_3, and TiO_2 (Pearce, 1976). Up to low grade metamorphism, this also remains true. Although the Charlotte belt rocks in the study area are at amphibolite grade, they appear to have been no more affected than their greenschist grade slate belt equivalents. This is perhaps because there is less pervasive fluid at higher levels of metamorphism than at lower. Figure 3 (Hamilton, 1988) shows the basalt to rhyolite rock sequence and the equivalent sequence of spilites and keratophyres on CaO v. SiO_2 and Na_2O+K_2O v. SiO_2 diagrams. On these diagrams are plotted the data for the Charlotte belt and the Carolina slate belt. Sodium is the most likely element to be added to volcanic rocks during alteration on the sea floor. Neither the Charlotte belt nor the Carolina slate belt rocks appear to have been much affected in this way. With regard to CaO, however, the Charlotte belt rocks are somewhat affected, whereas the slate belt rocks are more so. Because of the lack of added sodium, the slate belt rocks may exhibit this effect due to metamorphism rather than seawater exchange. That the mafic rocks are more affected than the felsic may be due to loss of Ca from the mafic rocks during greenschist metamorphism and the formation of epidote veins. The implications of the Ca loss will be discussed below.

With the above caveats in mind, the results of the analyses are used to make statements concerning the type of volcanic arc, whether early intraoceanic, mature arc, or continental margin arc.

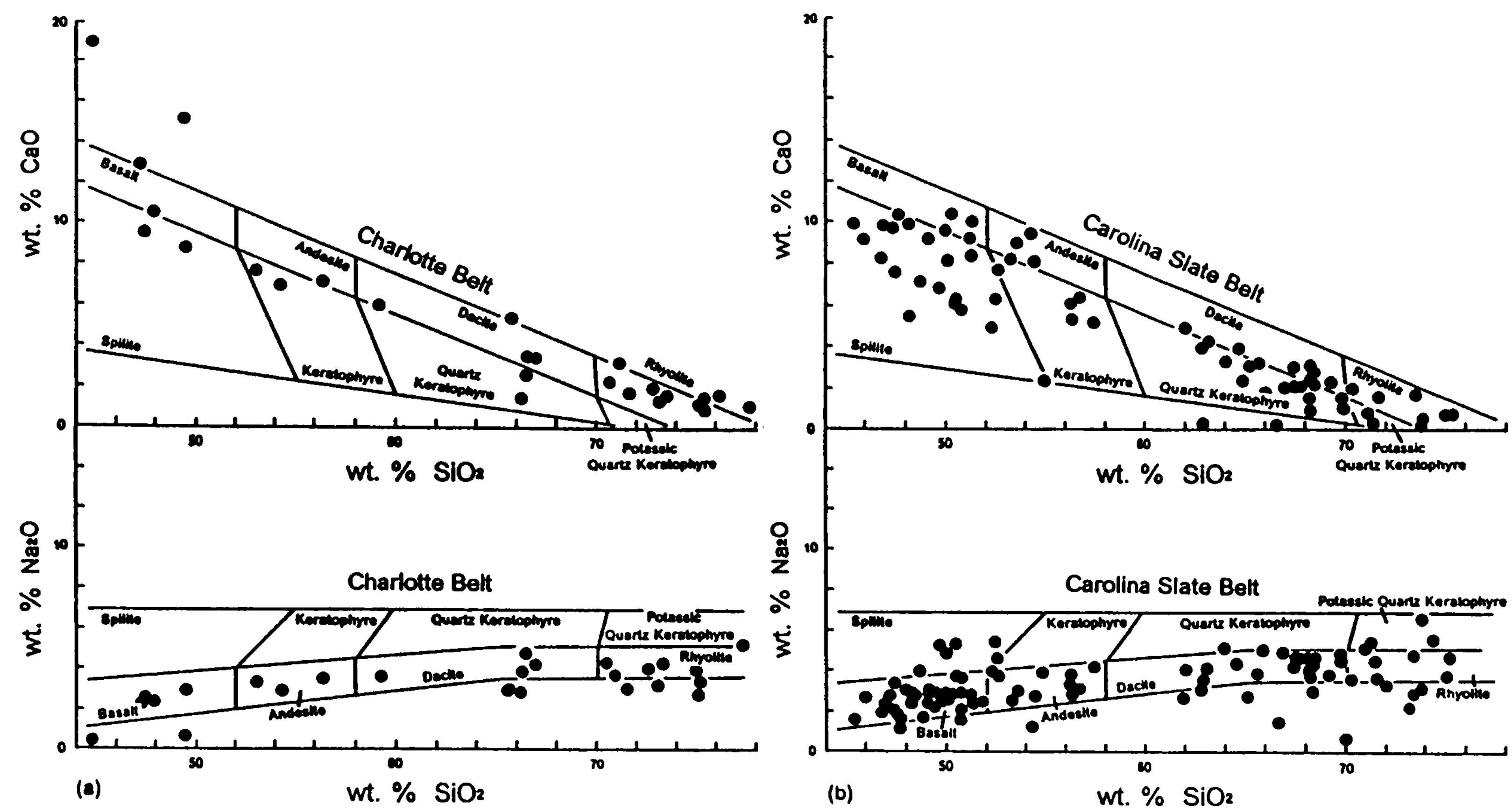

Figure 3: Volcanic rock alteration diagram. (a) Charlotte belt. (b) Carolina slate belt. See text for discussion. From Hamilton (1988).

Silica Frequency Distribution

Charlotte Belt. CIPW norms (Table 3) plotted on the classification diagram of Streckeisen and LeMaitre (1979; Figure 4) indicate that the rock suite here consists of basalts and rhyodacites. Geologic mapping in the area shows that basalt is the minor phase, comprising about 20% of the stratigraphic column in this part of the Charlotte belt (see above). Rhyodacites make up about 60% of the column. The sequence here is thus a bimodal, rhyodacite > basalt sequence. From field examination, it is apparent that the bulk of the Charlotte belt consists of a monotonous sequence of fine-grained gneisses of rhyodacitic composition. This is consistent with the findings of Tomblin (1979) who, in a study of the modern Lesser Antilles, noted a tendency for dacites to erupt in large volumes with little change in chemical composition.

Kreisa's (1980) data, on the other hand, show that, unlike in the study area, his hornblende gneisses were andesites, except for one basalt. This may indicate that the Charlotte belt laterally becomes more andesitic to the southwest, as noted by Newton (1983). This is the only difference noted between the two sets of Charlotte belt analyses. Both data sets include samples with silica as high as 76-78%.

Carolina Slate Belt. It is apparent that a good number of the 95 Carolina slate belt analyses fall within the 53-65% silica range of andesites. Although the analyses from the literature are not necessarily in proportion to the actual volume of a given rock type in an area, the fact that andesites occur in both belts to the southwest of the study area suggests a southwestward trend toward increasing proportion of andesites. Silica ranges to nearly 76% for some samples.

Calc-Alkalic Index

Peacock (1931) developed a silica variation diagram in which CaO and $Na_2O + K_2O$ were plotted against silica for a suite of rocks. With increasing silica, CaO decreases, whereas $Na_2O + K_2O$ increases. Curves can be drawn through the CaO and $Na_2O + K_2O$ points, re-

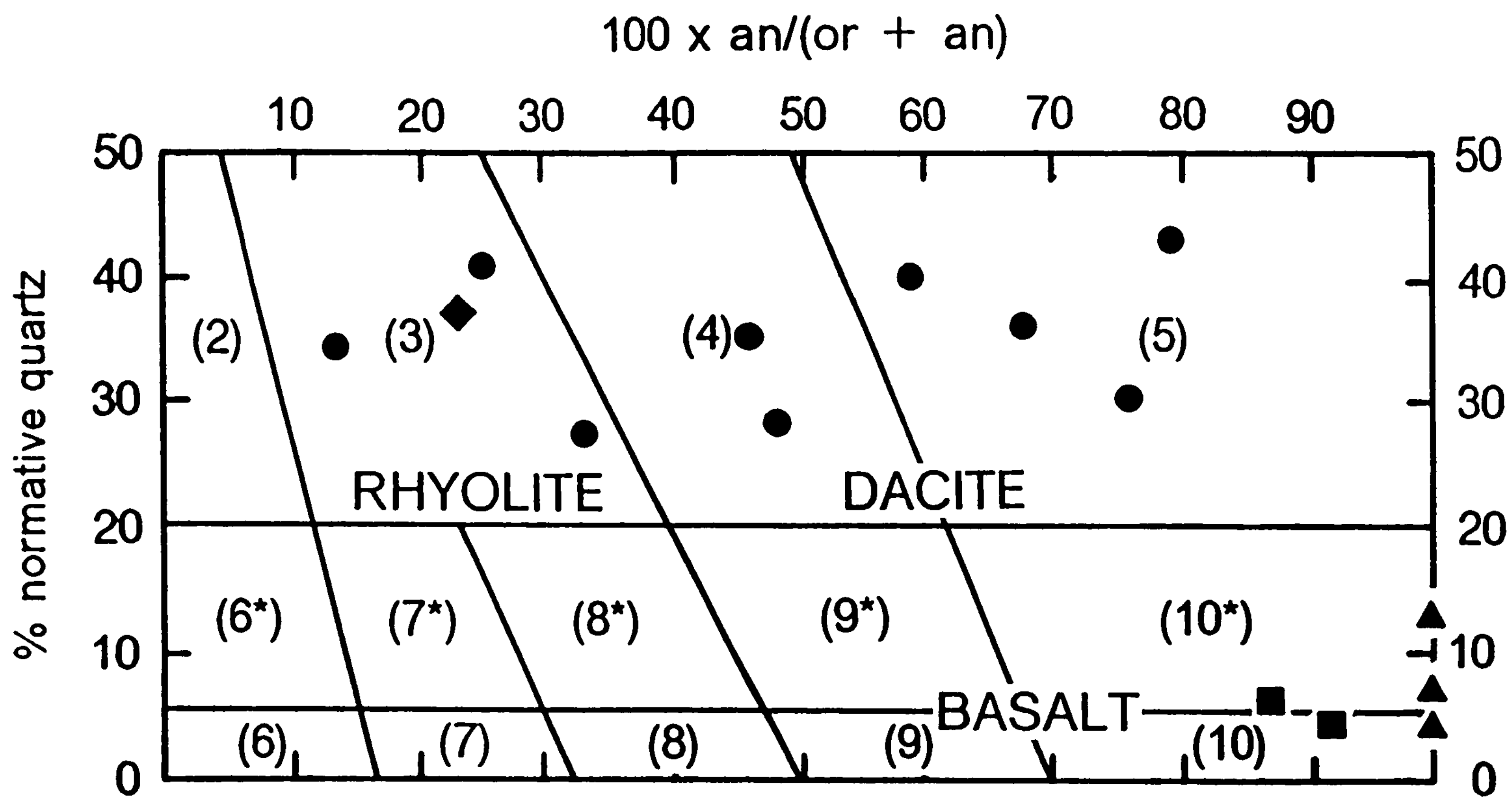

Figure 4: Volcanic rock type diagram based on CIPW normative mineralogy. Fields are as follows: (2) alkali-feldspar rhyolite, (3) rhyolite, (4)-(5) dacite, (6*) alkali-feldspar quartz trachyte, (7*) quartz trachyte, (8*) quartz latite, (9*), (10*), (9), and (10) andesite if silica > 52%; basalt if silica < 52%. Diamond - Lower Hyco Formation. Circles - Upper Hyco Formation. Triangles - Catawba Creek Amphibolite. Squares - St. Matthews Church Amphibolite. From Streckeisen and LeMaitre (1979).

spectively. The silica concentration for the point at which the two curves intersect is the calc-alkalic index for the rock suite. An index in the range 50-54% silica is typical of rifting environments, whereas the range 60-64% is characteristic of compressional tectonics. Values in the 55-59% range are generally non-classifiable.

Charlotte Belt. Figure 5a shows the Charlotte belt data plotted on a Peacock diagram. The intersection at about 64% silica is indicative of a volcanic arc tectonic regime.

Carolina Slate Belt. Figure 5b illustrates the trend of the Carolina slate belt data. The trend is similar to that of the Charlotte belt, and gives a calc-alkaline index of 60%, also indicative of the volcanic arc environment. If the Charlotte belt rocks are closely related to the slate belt rocks, the question must be asked as to why is there even this much apparent difference. As Figure 3 showed, neither belt of rocks seems to have been much affected by alteration. The slate belt rocks, however, do appear to have undergone some loss of calcium. The result of such a loss would be to lower the CaO v. SiO_2 line relative to the $Na_2O + K_2O$ line causing the intersection of the two to occur at a lower calc-alkaline index. This being the case, the true intersection would probably more correspond to that exhibited by the Charlotte belt rocks.

Iron Enrichment Trend

Iron enrichment trend is an especially important characteristic in determining original tectonic setting. There are two basic end-member trends, with a spectrum in-between. The Fenner, or Skaergaard, trend is characteristic of volcanic rocks that differentiated in a dry environment with low oxidation state, such as that typical of extension. In this case, there is a trend toward iron enrichment as iron-poor phases crystallize from the magma. Eventually, the iron is incorporated in later crystallizing phases (see Figure 6, inset). The Bowen, or calc-alkaline trend is characteristic of wet environments with high oxidation states, such as those associated with compressional tectonics. In this instance, the iron may early on increase somewhat in the melt, but then comes out early in oxide phases, and relatively little iron-enrichment occurs (Figure 6, inset).

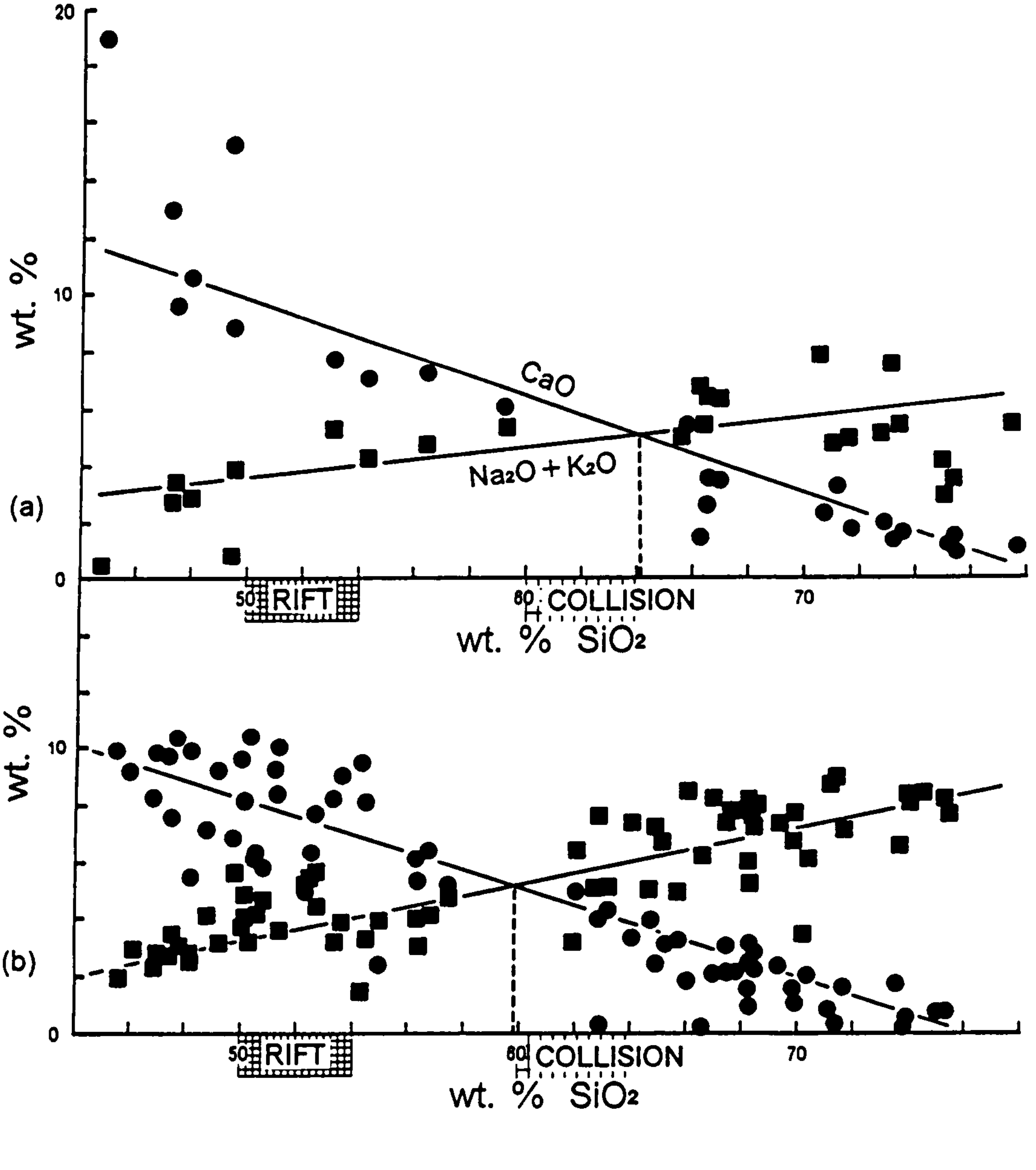

Figure 5: Calc-alkalinity diagram. Squares - $Na_2O + K_2O$ v. SiO_2. Circles - CaO v. SiO_2. An index in the range 50-54% silica is typical of rifting environments, whereas the range 60-64% is characteristic of compressional tectonics. Values in the 55-59% range are generally non-classifiable. (a) Charlotte belt data. (b) Carolina slate belt data. From Peacock (1931).

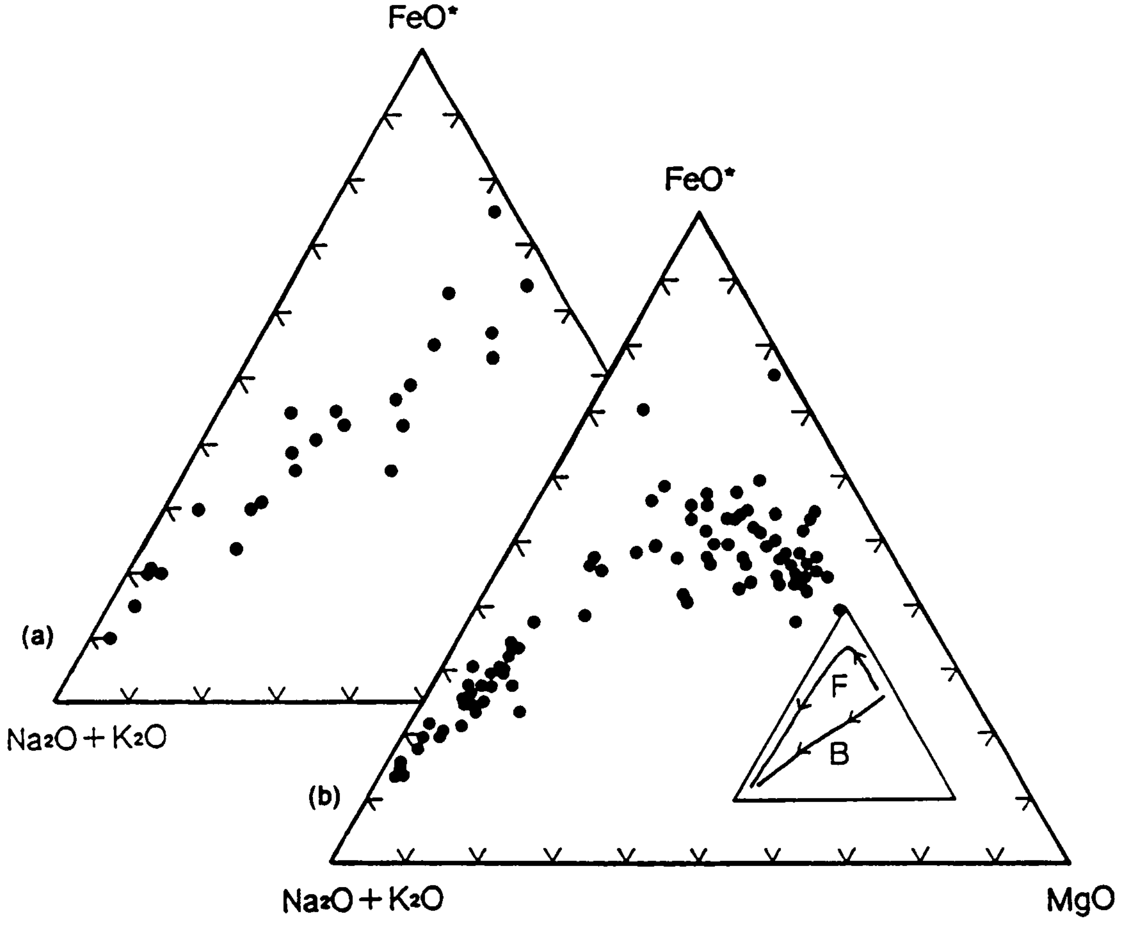

Figure 6: AFM diagram. Inset: B is the Bowen or calc-alkaline trend indicative of compressional tectonic settings; F is the Fenner or iron-enrichment trend characteristic of the rifting environment. (a) Charlotte belt data. (b) Carolina slate belt data.

Charlotte Belt. Figure 6a is an AFM diagram with the Charlotte belt data plotted on it. The data form a straight swathe from the FM line toward the A corner. The data, therefore, are consistent with the Bowen trend, and typical of the volcanic arc environment.

Carolina Slate Belt. Figure 6b shows the pattern made by Carolina slate belt rocks. The rocks show some initial enrichment in iron, but then the trend continues toward the alkali corner as do the Charlotte belt rocks. This is consistent with a calc-alkaline trend for the Charlotte belt rocks.

Alumina Saturation

Shand (1951) classified igneous rocks according to the molecular oxide proportion of Al to Ca, Na, and K. Rocks in which Al exceeds the sum of Ca, Na, and K are termed peraluminous. Rocks where Al is less than these three, but greater than the alkalis, are termed metaluminous. And rocks in which the sum of the alkalis is greater than Al are peralkaline. Volcanic arc volcanic rocks are characteristically peraluminous to metaluminous. Rift volcanic rocks vary, but are peralkaline.

Charlotte Belt. Alumina concentrations of the study area rocks are in the 12-19% range (Table 2). Thirteen of the 15 rocks are metaluminous, with the remaining two being peraluminous. Four of Kreisa's (1980) ten Charlotte belt rocks are metaluminous, with six peralkaline. Overall, the 25 Charlotte belt analyses are 68% metaluminous and 32% peraluminous.

Carolina Slate Belt. The 95 analyses compiled for the Carolina slate belt are 73% metaluminous, 26% peraluminous, and 1% peralkaline.

Basalt Chemistry

Several bulk chemical techniques can be applied to determine whether a rock is a basalt and, if so, whether it is from a compressional or extensional tectonic environment. Total silica of $<53\%$ is indicative of basalt (Williams and others, 1954). Normative plagioclase >50 mole % is also indicative of basalt (Barker, 1983). According to Chayes (1965), the titania content of circumoceanic or volcanic arc basalts averages about 1%, whereas that of oceanic basalts from mid-ocean ridges and intraplate volcanism averages about 3%. Although the rocks in the study area are at amphibolite grade, Ti is considered to be one of the more immobile elements (Pearce and Cann, 1973). Ti can thus be relatively increased as other components are removed by dissolution.

Pearce and Cann (1973) developed a technique by which basalts could be discriminated according to original tectonic setting. This involved the plotting of various elements thought to be relatively immobile through low grade metamorphic conditions. In particular, these elements include Ti, Zr, and Y. Results of minor element analysis for the basalts are shown in Table 4. The Ti/100-Zr-Yx3 plot, however, does not appear to give answers consistent with all other indicators of original tectonic setting. Bland and Blackburn (1980) chose not to use this plot in their report, but did use the Ti/100-Zr-Sr/2 triangle (Pearce and Cann, 1973). Sr, however, is known to be a more mobile element than Y.

Further, Pearce (1976) published a discrimination technique whereby major element patterns could be used as indicators of tectonic environment. This technique utilizes basalts with $12\% \leq Ca + Mg \leq 20\%$, and is described as yielding greater discriminatory power due to its use of the major elements. It involves plotting discriminant functions F_1 against F_2, and F_2 against F_3 These functions are calculated as follows:

$$F1 = 0.0088SiO_2 - 0.0774TiO_2 + 0.0102Al_2O_3$$
$$+ 0.0066FeO^* - 0.0017MgO - 0.0143CaO - 0.0155Na_2O - 0.0007K_2O,$$

$$F2 = -0.013SiO_2 - 0.0185TiO_2 - 0.0129Al_2O_3$$
$$-0.0134FeO^* - 0.03MgO - 0.0204CaO - 0.0481Na_2O + 0.0715K_2O,$$

$$F3 = -0.0221Si_2 - 0.0532TiO_2 - 0.0361Al_2O_3$$
$$-0.0016FeO^* - 0.031MgO - 0.0237CaO - 0.0614Na_2O - 0.0289K_2O,$$

where $FeO^* = FeO + (0.9 \times Fe_2O_3)$.

Although, as discussed above, there are problems associated with the blind usage of chemical diagrams, it is instructive, particularly for comparing the Charlotte belt and slate belt assemblages, to consider them here.

Charlotte Belt. Table 1 shows the results of chemical analyses of samples from two mafic units in the area, the Catawba Creek Amphibolite and the St. Matthews Church Amphibolite (Figure 2, Plate 1a). The low silica range (44-49%) indicates that the protolith was a basalt (Williams and others, 1954). CIPW norms are shown in Table 3. Normative plagioclase is usually greater than the 50 mole % anorthite, also indicative of basalts (Barker, 1983). All five samples are quartz normative (Table 3).

For the basalts, titania content is less than 1% in all cases (Table 2). Plotted on Ti/100-Zr-Yx3 and Ti/100-Zr-Sr/2 diagrams (Figure 7a), the basalts seem to indicate a low-K tholeiite protolith.

The major element method (Pearce, 1976), gives results consistent with the trace element plots. The top diagram in Figure 8a show plots of the discriminants F_1 and F_2. The average composition of the samples is within the calc-alkaline basalt/low-K tholeiite field. The bottom diagram in Figure 8a further divides the calc-alkaline/low-K tholeiite field into two separate fields. In this diagram, three of the four samples plot as low-K tholeiites. Although the samples have been metamorphosed to amphibolite grade, and some, such as RB6-423, show partial retrogression to greenschist assemblages, the consistency is surprising.

Carolina Slate Belt. The rocks of the Carolina slate belt also average well below 1% Ti, indicating that they are from a volcanic arc environment. Carolina slate belt analyses that included Y, Sr, and Zr for the plot in Figure 7b are from Black (1978) and Bland (1979).

The data in the Ti/100-Zr-Yx3 plot (Figure 7b, top) fall mainly along the boundary between within-plate and ocean-floor basalts. The ocean floor basalt field, however, also defines the area of overlap between the calc-alkaline basalt and low-K tholeiite field field. It is thus difficult to draw any meaningful conclusions from this particular diagram. The Ti/100-Zr-Sr/2 plot (Figure 7b, bottom) appears to be a more consistent diagram, with most of the samples plot-

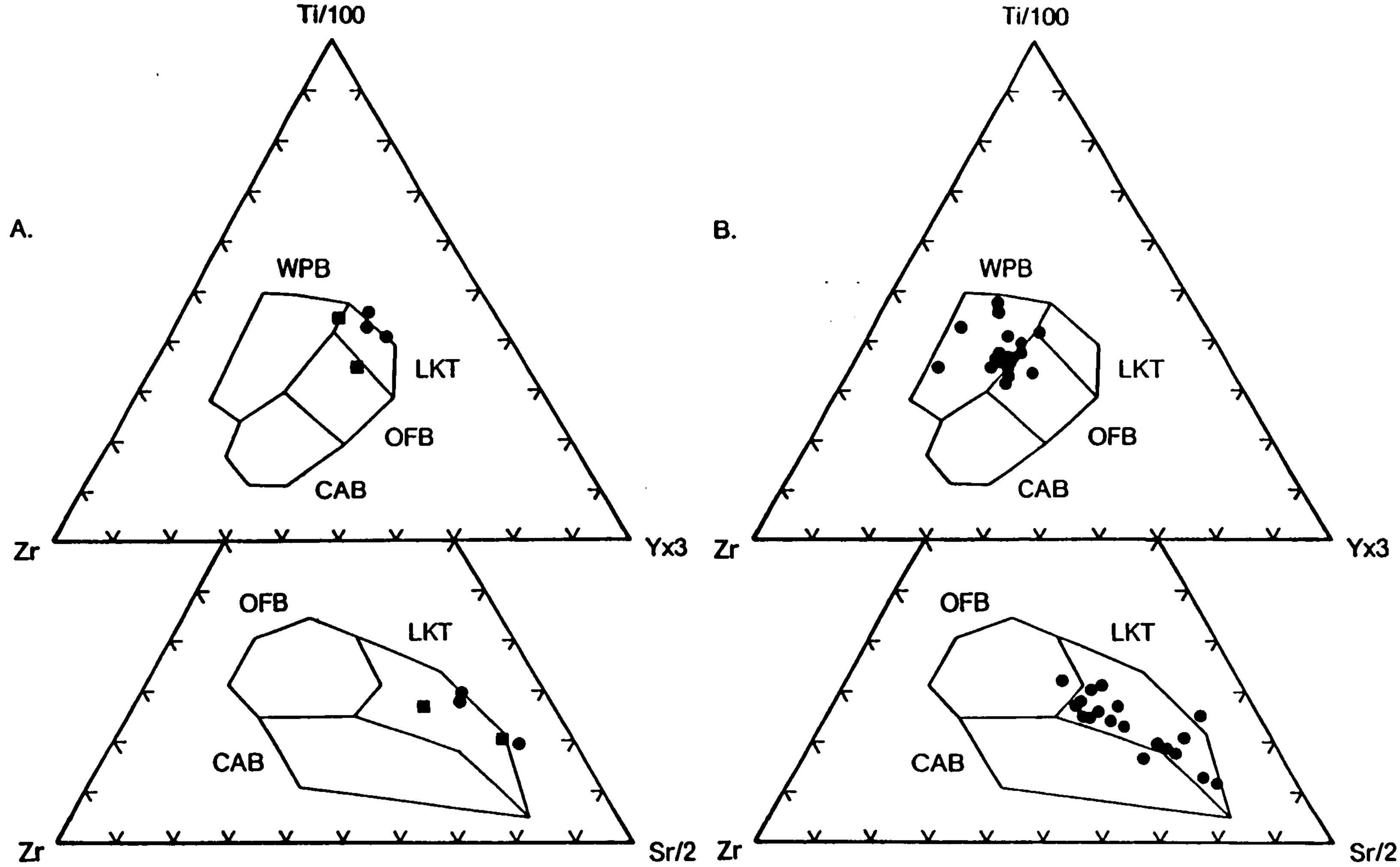

Figure 7: Ti/100-Zr-Yx3 (top) and Ti/100-Zr-Sr/2 (bottom) trace element discriminant diagrams. Fields are: WPB - within-plate basalt, LKT - low-K tholeiite, OFB - ocean-floor basalt and LKT/CAB overlap, CAB - calc-alkaline basalt. (a) Charlotte belt data. (b) Carolina slate belt data. (From Pearce and Cann, 1973).

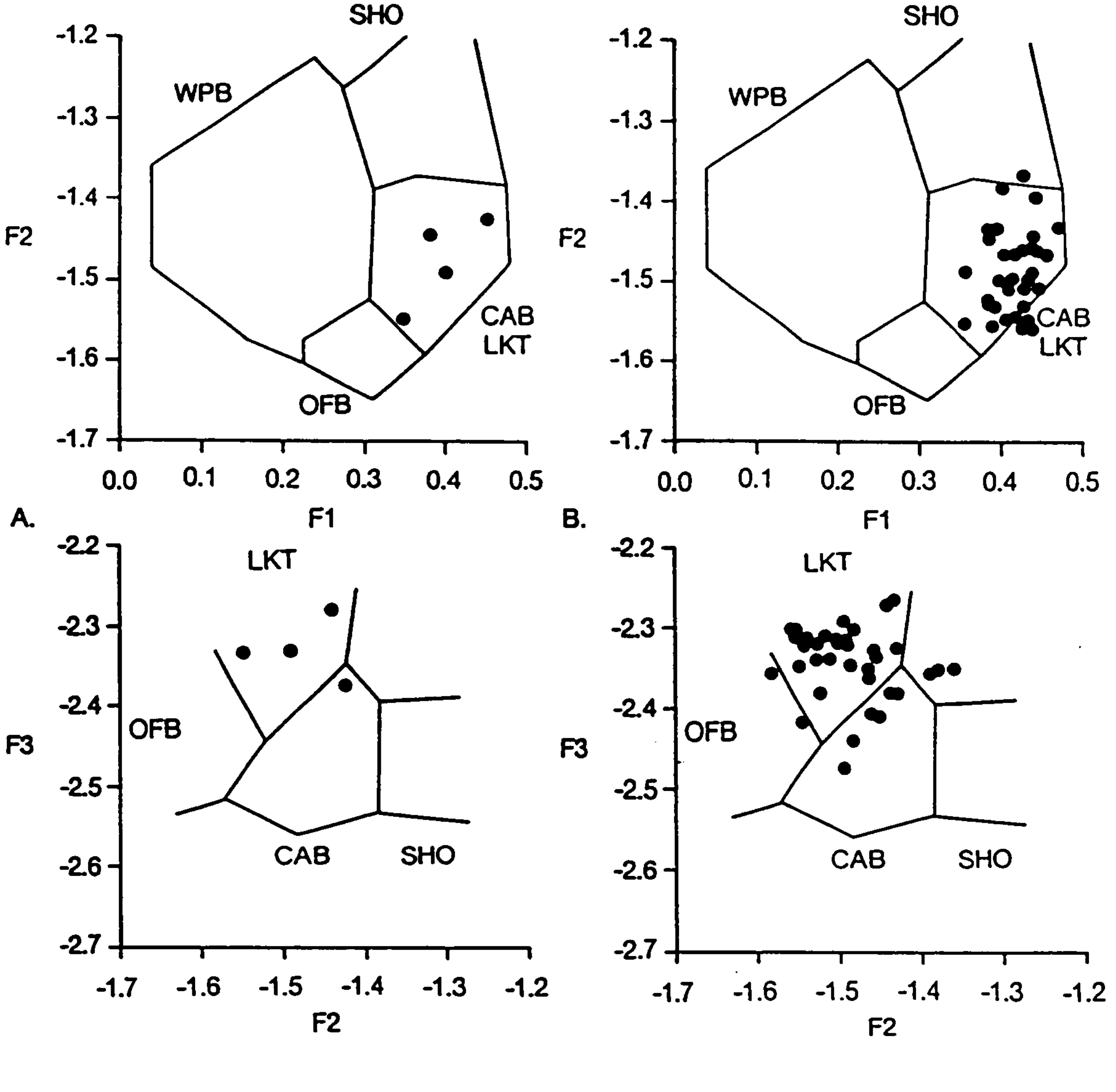

Figure 8: Plot of major element discriminant functions, F_1 and F_2 (top) and F_2 and F_3 (bottom). Fields are: WPB - within-plate basalt, SHO - shoshonitic basalt, LKT - low-K tholeiite, CAB - calc-alkaline basalt. LKT - low-K tholeiite, OFB - Ocean floor basalt. (a) Charlotte belt data. (b) Carolina slate belt data. From Pearce (1976).

ting within the low-K tholeiite field. Sr is a much more mobile element than Y, and it is apparent that the long string of Sr points in the diagram is the result of loss of Sr driving the points away from the Sr/2 corner.

The bulk of the points on the F_1-F_2 diagram in Figure 8b (top) plot neatly in the calc-alkaline basalt/low-K tholeiite field, and those outside are near it. Again, for the F_2-F_3 diagram in Figure 8b (bottom), the majority of the points plot as low-K tholeiites. A few plot as calc-alkaline basalts, whereas those falling outside are not far away.

θ-Value and Location of Volcanic Rocks with Respect to the Trench

The θ-value was used by Sigamura (1960, 1968) to characterize basalts and andesites with respect to their proximity to the trench. θ is equal to $SiO_2 - 47(Na_2O + K_2O)/Al_2O_3$. This works in part because K_2O generally increases away from the trench in the arc environment (Jakes and White, 1970). He found that values between 41 and 44 were representative of basalts nearest the trench, whereas values from 35 to 38 characterized volcanism on the continental side of the arc.

Charlotte Belt. For the Charlotte belt, θ-values of the Catawba Creek Amphibolite range from 40 to 47, and the St. Matthews Church Amphibolite is at about 40. These values suggest that the Charlotte belt rocks are derived from the near-vent area to somewhat toward the trench side.

Carolina Slate Belt. Forty-six basalts of the slate belt give an average θ value of 39.3. This is between the two ranges given as trench side and continent side and, as such, probably indicates that the slate belt volcanic rocks, like those of the Charlotte belt, accumulated in a near-vent setting. Green and others (1982) note that the slate belt rocks "appear to represent a very complex interfingering of similar lithofacies from multiple sources." Briggs and others (1978) interpreted the Roxboro Metagranite as a shallow magma chamber, intruded at a pressure of 0.35 kb, or roughly one kilometer depth. McConnell and Glover (1982) interpret the Flat River complex, a series of shallow plutons, as the probable source of the volcanic rocks that they intrude.

The plutons mentioned are probable sources of young slate belt volcanism, but their setting is probably analogous to that of the older slate belt. Multiple sources and the occurrence of shallow magma chambers argues that the slate belt volcanic rocks were probably accumulated right along the volcanic arc itself.

Crustal Thickness Beneath the Carolinia Arc

As a volcanic arc matures with time, its rocks become more calc-alkaline due to the progressive depletion of the mantle wedge above the descending slab (Miyashiro, 1974). There also exists a positive correlation between the proportion of calc-alkaline rocks in an area and the thickness of crust through which they ascended (Miyashiro, 1974).

Charlotte Belt. Although only 15 samples of Charlotte belt rocks have been analyzed (Table 2) from the study area, it is still possible to make a crude estimate of the proportion of calc-alkaline rocks in the area by relating the analyses back to the abundances of the various rocks they represent in the field. According to Figure 9, none of the basalts, 75% (4.5 out of 6) of the dacites, and 50% of the rhyolites are calc-alkaline.

In nearly every instance, it is possible to distinguish dacites from rhyolites in hand specimen alone. This is because the dacites are biotitic and have a distinct salt and pepper appearance, whereas the rhyolites are generally mica-poor and leucocratic (see above). Applying this to the mapped lithologies in the field area, 29% of the rhyodacites are rhyolites and 71% are dacites. The ratio of rhyodacites to basalts is about 3:1. This calculates to about 51% of the rocks of the area being calc-alkaline. Plotting this against crustal thickness on Figure 10, the range of crustal thickness falls from about 17-32 km. This indicates that the Charlotte belt rocks must have developed over thin to normal continental type crust.

Carolina Slate belt. Although there is no way to relate chemical analyses in the literature back to the actual proportion of rocks they represent in any given area, Black (1980) made a study similar to this one in Carolina slate belt rocks in the area to the southwest. He came up with a percent calc-alkalinity of 42% for 122 slate belt rocks. This sample set did not distinguish between old and young slate belt sequences, however. Considering only his data for

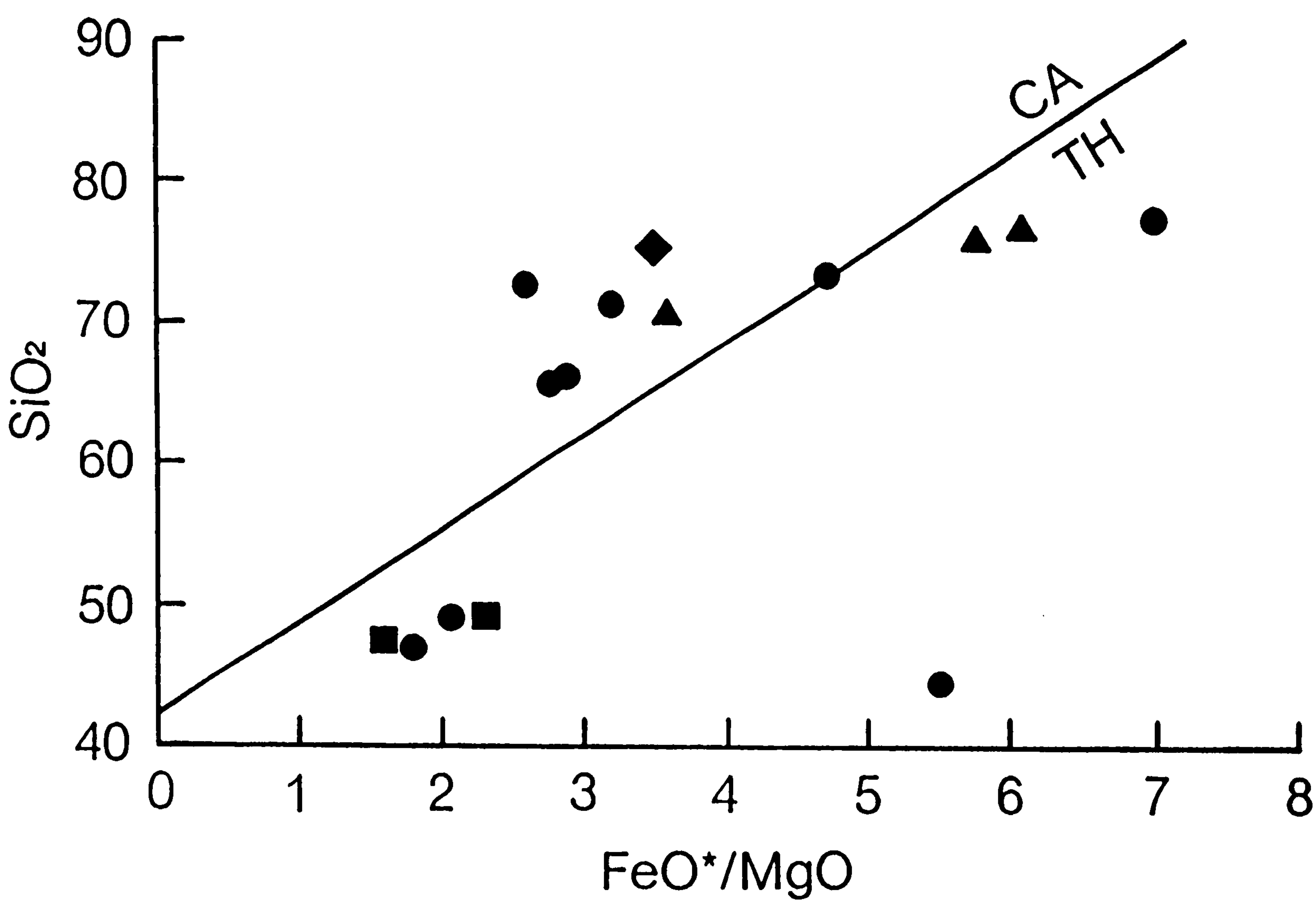

Figure 9: Low-K tholeiite/Calc-alkaline trend discrimination diagram. Diamond - Lower Hyco Formation. Circles - Upper Hyco Formation. Triangles - Catawba Creek Amphibolite. Squares - St. Matthews Church Amphibolite. After Miyashiro (1974).

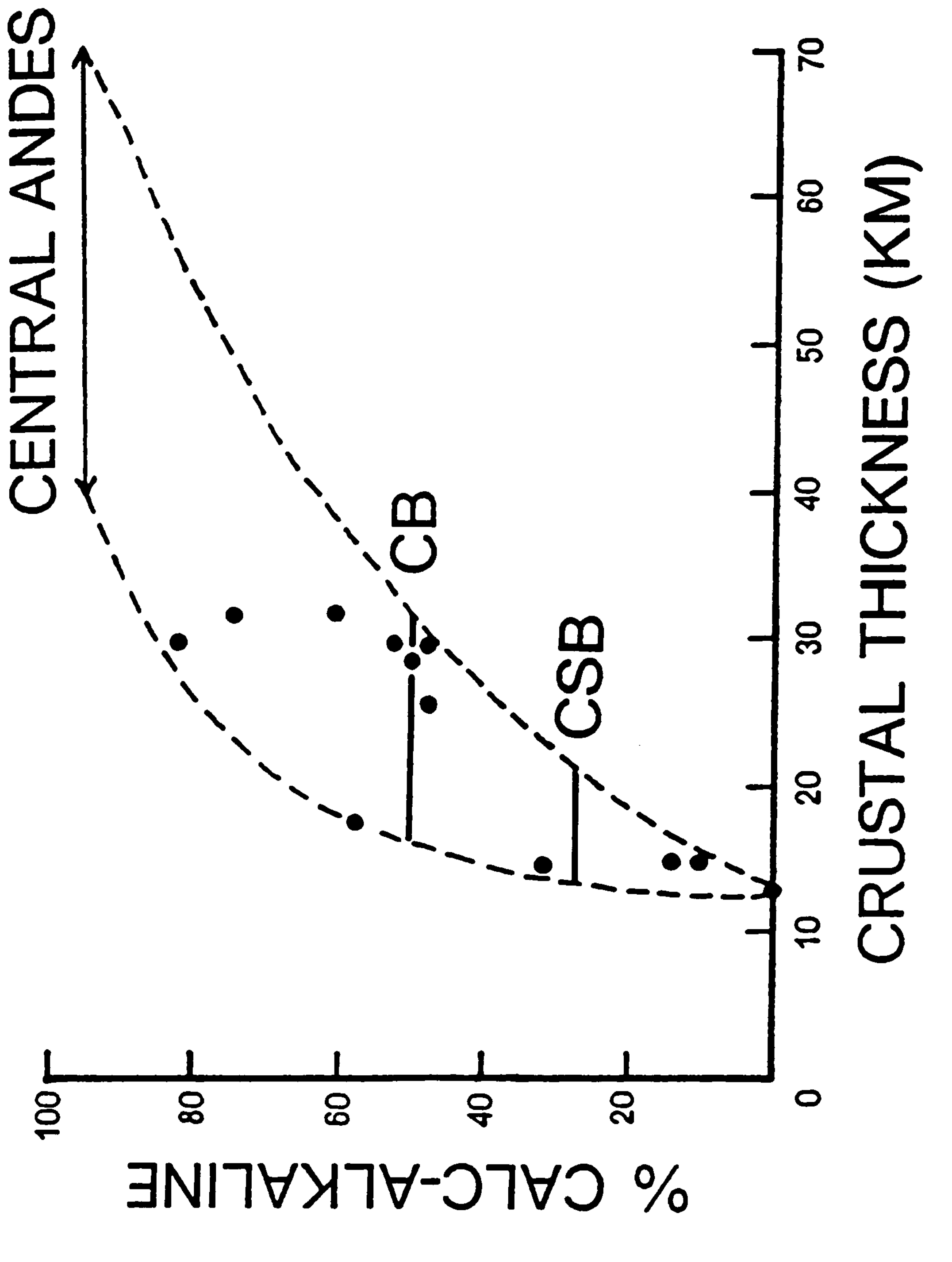

Figure 10: Calc-alkalinity versus crustal thickness diagram. Diagram and data points after Miyashiro (1974).

60 old slate belt rocks, a percent calc-alkalinity of 27% is obtained. This corresponds to about 13-21 km of crust (Figure 10). This overlaps with that obtained for the Charlotte belt above, and again suggests thin to normal continental type crust.

Type of Volcanic Arc Represented by Carolinia

Research over the last several years has led to the essentially unanimous conclusion that the Carolina slate belt is part of an ancient volcanic arc (Kish and Black, 1982). If the Charlotte belt is part of a stratigraphically continuous sequence with the Carolina slate belt, as proposed in Baird, Part I, then it is expected that the tectonic setting of the Charlotte belt be compatible with that of volcanic arc as well. Rogers (1982) lists characteristics by which to identify the various tectonic settings according to lithology and chemistry. The criteria for identification of ancient volcanic arcs in various stages of maturity and on different types and thicknesses of crust will be examined here, and are taken mainly from Rogers (1982).

Early, intraoceanic island arcs are characterized as bi-modal with respect to silica distribution, with andesites (about 55% to 65% SiO_2) being rare. Rogers (1982) states that it is unclear as to which end member dominates, and proceeds to note that in some arcs silicic and mafic rocks occur in equal abundance. In other cases, the rocks appear to be nearly entirely mafic. Bimodal suites with silicic end members predominating do not appear to occur in this setting. Ti and Zr show a linear relationship in mafic rocks. He goes on to say that even rocks with up to 75% silica are impoverished in large ion lithophile elements.

Mature island arcs are described as calcalkaline, based on low iron enrichment on an AFM diagram (Rogers, 1982). Furthermore, in this tectonic setting, SiO_2 shows a unimodal distribution, andesites are abundant, and rocks with $>68\%$ SiO_2 are rare on arcs developed on oceanic crust, but are somewhat more common on arcs developed over continental crust. Ti shows no linear relationship with Zr in mafic rocks. Large ion lithophile elements in this setting show a steady increase with increasing silica.

Continental margin subduction zones are characterized by calcalkaline trends and rocks with silica contents between 60-75%, with minor basalts (Rogers, 1982). Silica content increases with increasing thickness of crust (Miyashiro, 1974). Increase in large ion lithophile elements is greater with increasing silica than for mature intraoceanic arcs.

Charlotte Belt. The Charlotte belt rocks of the study area are bi-modal, and andesites are rare. The silicic end members dominate by a factor of 3:1 over the basalts. Silica is in the 44-78% range overall. The differentiation trend is calc-alkaline. The Pearson correlation coefficient for the relation of Ti and Zr in the mafic rocks is 0.66 for five samples. Table 2 shows an overall trend toward higher concentrations of large ion lithophile elements such as K, and Ba with increasing silica. Correlations here are 0.65 and 0.71 for silica versus K and Ba respectively. The Charlotte belt rocks were erupted over 17-32 km thick crust.

In favor of an early, intraoceanic arc, the ten samples from the study area show a bimodal character, andesites are rare, and there is a linear relationship of Ti and Zr in the mafic rocks. Against the early intraoceanic arc is the 3:1 ratio of rhyodacites to basalts, and the increase of large ion lithophile elements with increasing silica.

Supporting a mature arc origin is the calc-alkaline trend and the increase of large ion lithophile elements with increasing silica. Against a mature arc is the lack of andesites, common occurrences of rocks with >68% silica, and the linear relation of Ti and Zr in the mafic rocks.

Favoring a continental margin arc is the calc-alkaline trend, the bimodal character with silica in the 60-75% range and minor basalts, and the large ion lithophile element increase with increasing silica. No evidence is against a continental margin arc origin. The 17-32 km thick crustal thickness favors at least a thin continental type crust.

Based on the above, the Charlotte belt most likely developed over a thin to normal thickness continental crust. While some of the characteristics also fit an early intraoceanic arc, the preponderance of rhyodacites over basalts and increase of large ion lithophile elements seems to rule this out.

Carolina Slate Belt. Silica range of the Carolina slate belt rocks is a little greater than in the study area. The sample of 95 analyses used here is bimodal with respect to silica distribution. However, as previously mentioned, it is difficult to tell from published analyses whether this is representative or whether it is biased in favor of basalts chosen especially for trace element discriminant analysis. Regardless of whether there is a bias toward the mafic end, it is clear that intermediate rocks are not the most abundant, as silicic rocks dominate and cluster around 68% silica. Black (1980) found a bimodal distribution for the slate belt, but included both old and young sequences in his histogram (his Figure 5). Because the young slate belt represents a different episode of volcanism, it is difficult to evaluate a histogram consisting of samples from both sequences. The 95 slate belt analyses here show an increase in large ion lithophile elemental percentage with increasing silica. On the AFM diagram, they exhibit a calc-alkaline trend, with only minor early iron enrichment. Like the Charlotte belt, the slate belt also has a wide range of silica values, and is well represented in the 60-75% range. The older slate belt sequence appears to have developed over 13-21 km thick crust.

Favoring an early intraoceanic arc is the linear relationship between Ti and Zr. The rocks may also be bimodal. Against the early arc interpretation is the fact that andesites are not rare in the slate belt. Nor are they impoverished in large ion lithophile elements.

On the side of a mature arc, the rocks exhibit a calc-alkaline trend. They may possibly be unimodal. Andesites, whereas not abundant, are fairly common, and there is an increase in large ion lithophile elements with increasing silica content. Against a mature arc is the abundance of rocks with >68% silica, and the good correlation of Ti and Zr in the mafic rocks.

For a continental margin origin, the rocks again exhibit a calc-alkaline trend. The belt may be bimodal. The rocks commonly fall in the 60-75% silica range, and large ion lithophilic elements are enriched with increasing silica. No factors militate against a continental margin origin. Moreover, the crust appears to have been within the range of 13-21 km.

The choice seems to be between a mature arc and a continental margin arc. The fact that the rocks probably represent a bimodal sequence, along with the abundance of rocks >68% silica and the linear relationship of Ti and Zr in the basalts seems to rule out a mature arc origin. The evidence is thus in favor of a continental margin arc developed on thin continental crust. Rogers (1982) looked at some of the same portions of the slate belt, and concluded that the slate belt rocks in the Virgilina area represented either a mature island arc or a continental margin arc, whereas those of Orange County, North Carolina probably also represented a continental margin arc. Glover and Sinha (1973) came to the same conclusion based in part on the presence of slate belt conglomerates containing quartz arenite clasts.

DISCUSSION AND CONCLUSIONS

That the Carolina slate belt is a volcanic arc sequence is already well established (Black, 1980; Bland and Blackburn, 1980; Kish and Black, 1982). Although there has been a growing recognition in recent years that the Charlotte belt and Carolina slate belt constitute a single lithotectonic terrane (Secor and others, 1983; Harris and Glover, 1988; Glover, 1989; Baird, Part I), no chemical evidence heretofore has been presented for the Charlotte belt with a view toward its tectonic setting.

Both belts appear to be bi-modal. The predominance of the felsic end-member rocks over mafic is indicative of a collisional margin. Bi-modality in this instance is indicative of a mature arc developed over continental crust. Although the study area contained no andesites, andesites do appear to increase to the southwest in both belts (cf. Newton, 1983). On the whole, the belts may trend toward unimodal.

The calc-alkalic index on the Peacock diagram plots very high, around 60-64%, indicative of a subduction setting.

The trend exhibited by both belts on the AFM diagram is clearly one of a calc-alkaline trend with no iron enrichment, characteristic of a wet environment with high oxidation states. A convergent margin tectonic setting, with water supplied by the subducting plate is indicated.

Overall, about two-thirds of the Charlotte belt and Carolina slate belt rocks are metaluminous, whereas the remaining third are peraluminous. This result is consistent with a convergent tectonic setting. It is at least theoretically possible that large amounts of alkalis have been removed from the rocks, making rift-generated rocks appear as though they were from a convergent tectonic setting. However, one key point that argues against any origin other than a convergent margin is that neither the Charlotte belt nor the Carolina slate belt have been found to contain any other types of rocks that are predominant in rift and other situations, such as sedimentary conglomerates, sandstones, etc.

The FeO*/MgO vs. silica plot distinguishes the Charlotte belt basalts as tholeiites. Quartz in the CIPW norm also qualifies these basalts as tholeiites (Yoder and Tilley, 1962). Rocks from both belts plot in the low-K tholeiite fields on F_1-F_2, and F_2-F_3 diagrams. Both belts have rocks averaging less than 1% Ti, indicative of a convergent tectonic setting.

Basalts from both the Charlotte belt and Carolina slate belt plot in the low-K tholeiite field on the Ti/100-Zr-Sr/2 diagram, indicative of a convergent margin (Pearce and Cann, 1973).

On the tectonic setting question, there is little doubt that the Charlotte belt and the Carolina slate belt are both from identical tectonic settings, as should be the case if they are partially equivalent.

θ-values indicate a near-vent to trench side of arc setting, supported by interfingering and laterally discontinuous lithologies noted by Green and others (1982) and by the shallow magma chambers intrusive into their own pile, as found by McConnell and Glover (1982).

The calc-alkaline trend and the rough calculation of percent calc-alkalinity are indicative of a mature volcanic arc developed over thin to normal continental type crust. From available data, the crustal thickness overlap of both belts falls within the 17-21 km range.

Because of the problems associated with the losses and additions of elements during eruption and alteration on the sea floor, no single tectonic criterion discussed can be considered definitive. However, in spite of these potential problems, all criteria considered for both the Charlotte belt and the Carolina slate belt are completely consistent and point to the same conclusion, with the single exception of the Ti-Zr-Y plot for the slate belt. Supporting the Charlotte belt results is the fact that it was previously shown (Baird, Part 1) that equivalence exists between the Carolina slate belt which is already widely accepted as an ancient volcanic arc (Kish and Black, 1982). That the chemistry of both belts is so similar even thought they are at different metamorphic grade, and that stratigraphic equivalence is likely between the belts argues that the chemistry and the results drawn from it are reliable.

It is thus concluded that the Charlotte belt and Carolina slate belt both originated in a volcanic arc tectonic setting, and that both developed over thin to normal continental type crust.

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STRUCTURAL AND METAMORPHIC DEVELOPMENT OF THE ROOTS OF AN OROGEN
CHARLOTTE BELT, SOUTH CENTRAL VIRGINIA

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STRUCTURAL AND METAMORPHIC DEVELOPMENT OF THE ROOTS OF AN OROGEN CHARLOTTE BELT, SOUTH CENTRAL VIRGINIA

ABSTRACT

Much of the southern Appalachian Piedmont consists of a microcontinent, Carolinia, that collided with Laurentia during the Late Cambrian to Middle Ordovician Taconic Orogeny. In south central Virginia Carolinia consists of the Charlotte belt and Carolina slate belt, probably allochthonously overlying Cambro-Ordovician shelf sediments. The Charlotte belt here is the upper limb of a Taconic recumbent fold nappe (Milton nappe) some 34 km across in plan, and formed during the Taconic collision. The belt is bounded on both the northwest and the southeast by Late Paleozoic dextral shear zones. Later folding produced a series of large northeast-trending open folds across the nappe, resulting in the present structure of a large gently northeast-plunging anticlinorium. This paper deals with the overall structural and metamorphic development of the Charlotte belt rocks that comprise the roots of the Paleozoic Appalachian orogen. Special emphasis is placed on the nappe forming event, and on the later Paleozoic dextral shearing.

Around 600 Ma, Carolinia experienced the D_1 Virgilina deformation, which resulted in broad upwarping of the area. An early foliation, S_1, observed locally in the Charlotte belt, but not the Carolina slate belt, is interpreted to be the result of the Virgilina deformation.

D_2 Taconic collision of Carolinia with eastern Laurentia caused the northwestward thrusting of the infrastructural Charlotte belt sequence beneath a Carolina slate belt suprastructure forming a recumbent fold nappe. This event folded the S_1 foliation into near parallelism with S_2. The result was an area of sub-horizontal Charlotte belt volcanic rocks adjacent to Carolina slate belt volcanic rocks with moderate southeast dips. The Taconic metamorphic grade of the south central Virginia portion of both belts was amphibolite, upper amphibolite in the central Charlotte belt grading to lower amphibolite/epidote amphibolite in the slate belt. Thermobarometric calculations based on microprobe analyses of coexisting phases give P-T conditions up to about 600°C and 6 kb for this event. M_1 metamorphism ex-

tended through both D_1 and D_2 deformational events. Carolinia then consisted of a large recumbent fold nappe with a broad antiformal structure. S_2 is the regional foliation of both the Charlotte belt and Carolina slate belt.

Bordering the Charlotte belt on the southeast and northwest are the Clover and Brookneal shear zones, respectively, formed during the inferred Acadian/Alleghanian approach of Africa and Laurentia. Imposition of strain caused the development of a local S_3 foliation in and around the shear zones. Within the Clover shear zone, shearing took place along the S_2 foliation, transforming S_2 into shear bands (C), and causing S_3 (S) to rotate into C. The result is a typical S-C mylonite (Lister and Snoke, 1984). Displacement of the Clover zone is probably within the 25-37 km range. Conditions of M_2 metamorphism varied from M_1 conditions depending on location. M_2 effects are not recognized in the central part of the Charlotte belt, but are discernible only in the Clover and Brookneal shear zones. In the Clover zone, M_2 ranged from chlorite to biotite grade conditions and M_1 amphibolite assemblages were retrograded to greenschist. In the Brookneal shear zone the Late Paleozoic metamorphic grade also ranged to about 600°C, but pressures appear to have been somewhat higher at around 7 kb.

A later D_4 deformation caused large northeast-trending folds to be imposed upon the upper limb of the Charlotte belt recumbent fold nappe, producing its present-day anticlinorial structure.

Lastly, Mesozoic rifting caused the formation of several Triassic basins in the area, and the intrusion of diabase dikes.

INTRODUCTION

The division of the southern Appalachians into geologic belts evolved over the decades until 1955, when King placed them into the current format (Figure 1). This paper deals with development of a portion of the volcanic arc, Carolinia (name modified from Secor and others, 1983). Carolinia is coincident with the "Atlantic seaboard volcanic province" of Higgins (1972). In the southern Appalachians, Carolinia consists of the Charlotte belt and the Carolina slate

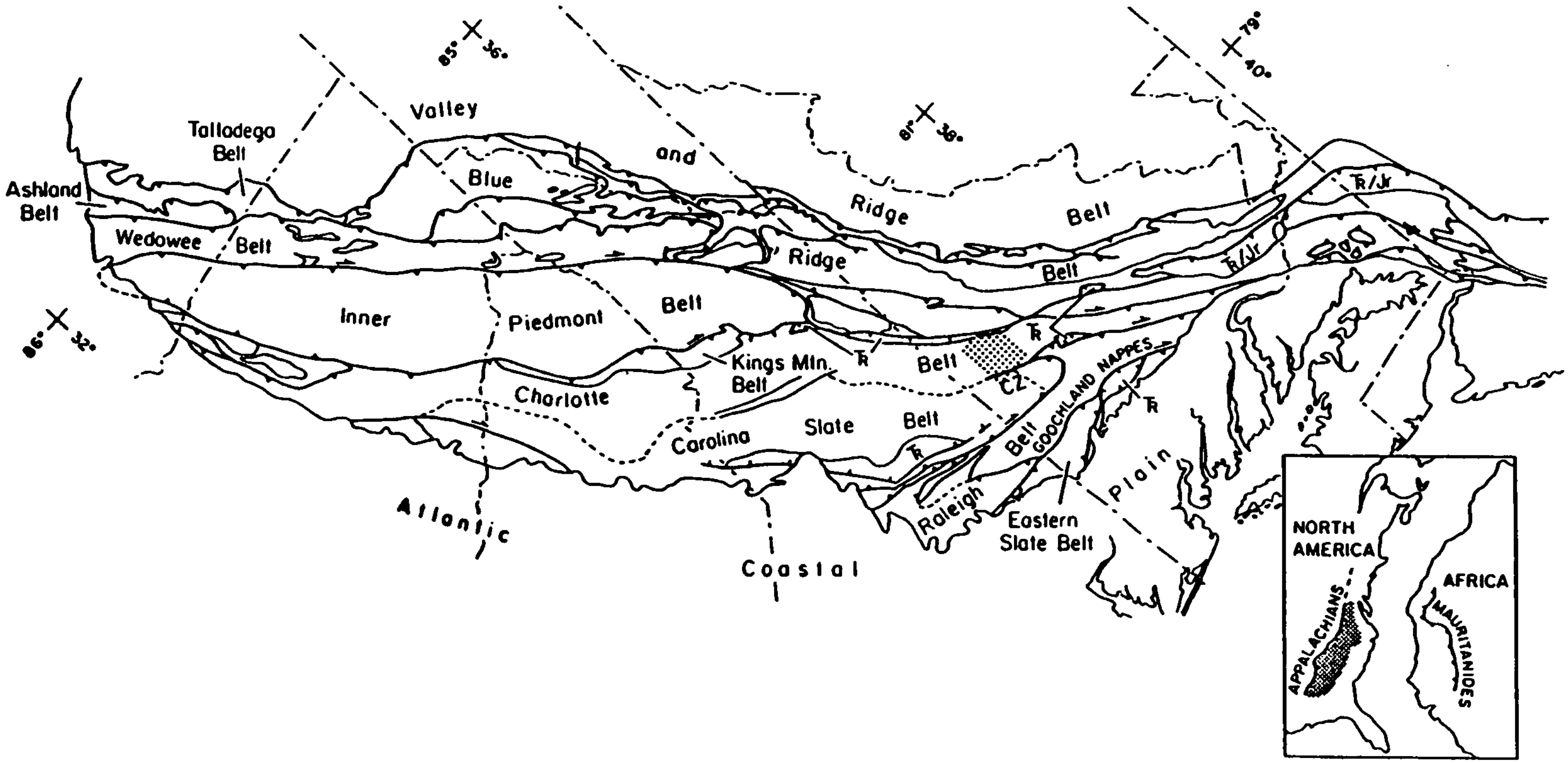

Figure 1: Tectonic map of the southern Appalachians showing location of major lithotectonic belts. Shaded area in inset gives location with respect to eastern North America. CZ is Clover shear zone. Tr and Jr are Triassic and Jurassic, respectively. Dotted enclosure is study area in Figure 2. Other names are self-explanatory. Map from Glover (1989).

belt, together with smaller belts, such as the Raleigh, Kings Mountain, eastern slate, Kiokee, and Belair belts.

The focus of the paper is on part of the Charlotte belt in south central Virginia (Figures 1 and 2). Detailed geologic mapping across the Charlotte belt and into the Carolina slate belt (Figures 1 and 2) here reveals that the Charlotte belt and the older Carolina slate belt represent a continuous volcanic arc sequence (Baird, in preparation). The structural setting is that of the infrastructural Charlotte belt thrust northwestward beneath the suprastructural Carolina slate belt as a recumbent fold nappe. This explains both the tectonic and stratigraphic equivalence between the two belts (Baird, in preparation).

The stratigraphy of the area is framed in terms of a central Charlotte belt stratigraphy, and an eastern Charlotte belt and Carolina slate belt stratigraphy, bounded by the intrusive Tanyard Branch Granitic Gneiss (Figure 2, Plate 1a). In the central Charlotte belt, the rocks of the nappe core were mapped by Tobisch and Glover (1971) and consist of pelites and intermediate volcanic rocks, conformably intruded by granitic rock. The rocks overlying this core are the focus of the paper. Immediately overlying and to the north-northeast of the core rocks in the central Charlotte belt are rhyodacitic volcanic rocks of the Lower Hyco Formation, the discontinuous Catawba Creek Amphibolite Member (basalt), the rhyodacitic Upper Hyco Formation, and the pelitic/epiclastic Aaron Formation. Overlying the Lower Hyco to the east in the eastern Charlotte belt and Carolina slate belt are the discontinuous St. Matthews Church Amphibolite Member (basalt), the rhyodacitic Hyco Formation, and the epiclastic Aaron Formation.

This paper details the structural and metamorphic development of this part of the Charlotte belt and Carolina slate belt.

PREVIOUS WORK

Glover and Sinha (1973) defined the 600 Ma Virgilina deformation in the Carolina slate belt near the Virginia-North Carolina border. Later work (Harris and Glover, 1985, 1988) has shown that the Virgilina deformation was accompanied by uplift and the formation of an ero-

EXPLANATION

STRATIGRAPHY

Triassic	Tr	*Arkose and conglomerate*
Ordovician-Silurian	OSa	*Arvonia Formation*
Ordovician	O(?)tb	*Tanyard Branch Granitic Gneiss*
Ordovician	Os	*Shelton Formation*
Cambrian	Cm	*Melrose Granite*
Cambrian	C(?)ro	***Red Oak Granite***
Late Precambrian	pCv	*Virgilina Formation*
Late Precambrian	pCa	*Aaron Formation*
Late Precambrian	pCuh	*Upper Hyco Formation*
Late Precambrian	pCav	*Altered volcanic rocks* A - Altered
Late Precambrian	pCbc	*Blackwater Creek Gneiss* H - Hornblende-bearing
Late Precambrian	pCec	*Ellis Creek Gneiss*
Late Precambrian	pCcc	*Catawba Creek Amphibolite*
Late Precambrian	pCsmc	*St. Matthews Church Amphibolite*
Late Precambrian	pClh	*Lower Hyco*
Late Precambrian	pCpel	*Pelitic schists*
Late Precambrian	pCiv	*Intermediate volcanic rocks*

SYMBOLS

- Overturned anticline
- Anticlinal axis
- Synclinal axis
- 1:24,000 quadrangle corner
- Shear zone boundary
- Brittle fault
- Lithologic boundary

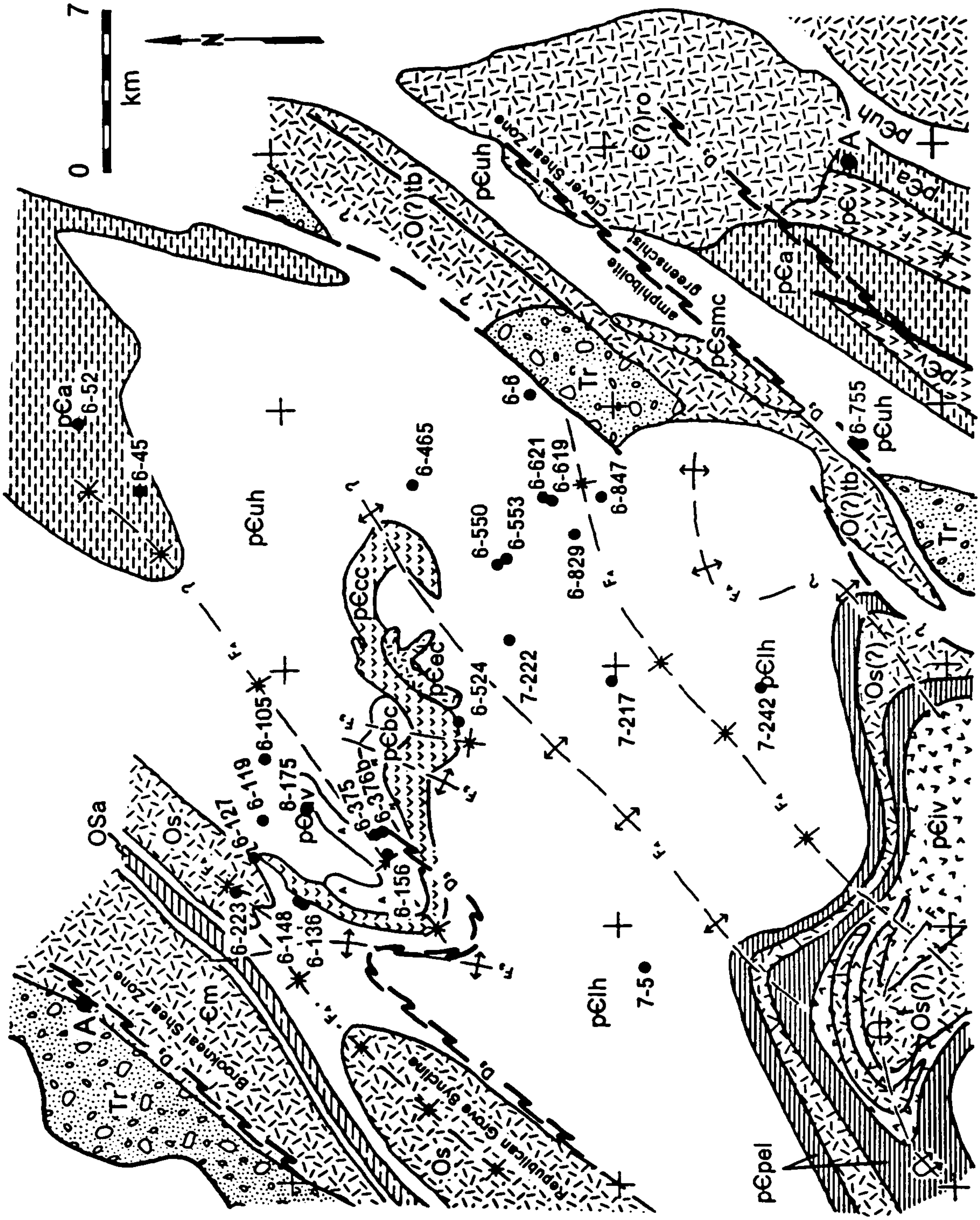

Figure 2: Geologic map of the south central Virginia Piedmont. All boundaries are approximate. Area of map is shown in Figure 1. Points A and A′ are end-points of cross-section in Figure 13. Sample locations corresponding to Table 2 are shown. Map after field mapping during this investigation, Laney (1917), VDMR (1963), Tobisch and Glover (1971), and Gates (1981). Explanation on facing page.

sion surface. The slate belt rocks below the unconformity are known as the older Carolina slate belt sequence. Volcanism subsequent to the development of the erosion surface deposited the younger Carolina slate belt sequence.

Brown (1969) worked in the Charlotte belt near Dillwyn, Virginia northeast of the study area. This part of the belt (his Hatcher Complex) consists of Chopawamsic Formation volcanic rocks (Conley, 1978) that are equivalent to the younger slate belt sequence (Bland and Blackburn, 1980). Unconformably overlying the Chopawamsic are tight infolds of Upper Ordovician to Lower Silurian Arvonia Formation slates (Tillman, 1970). Brown (1969) found evidence for two episodes of metamorphism in that the conglomeratic schist below the Arvonia Formation contained still older schist fragments. These older schist fragments were also found as xenoliths in the mildly foliated Diana Mills pluton. The earlier metamorphism was probably Taconic and the later one occurred between 324 and 287 Ma (Smith and others, 1964).

Marr (1981) found evidence for four episodes of deformation near Brown's area. First are F_1 folds that occur only within the Chopawamsic. F_2 tight folds accompanied the penetrative deformation of the area. Unconformably overlying the F_2 folded rocks is the Arvonia Formation. According to Glover and others (1983), the unconformity over which the Arvonia was deposited is Taconic in age, constraining F_2 to be Taconic. Following deposition of the Arvonia was a period of F_3 open and upright folding, that infolded the Arvonia Formation and formed the Whispering Creek anticline (Brown, 1969). Slates of the Arvonia have been dated at 300 Ma (K-Ar) by Harper and others (1973). Allowing for cooling, the F_3 event could be either late Acadian or early Alleghanian. Last were broad, open F_4 folds not accompanied by a foliation.

In the Danville area to the south-southwest of the study area, Henika also found four phases of folding: an F_1 set of isoclinal folds with northwest axes and sub-horizontal axial planes, an isoclinal F_2 set with northeast axes and sub-horizontal axial planes accompanying the formation of the regional foliation, an F_3 set of open folds with northeast axes and sub-vertical axial planes, and northwest-trending open F_4 folds with sub-vertical axial planes. His

F_3 folds are probably equivalent to Marr's F_4, as Henika (1977) interprets his F_4 set as related to a post-Triassic basin deformation.

Southeast of the study area in the Milton area, Tobisch and Glover (1971) recognized two episodes of folding. The first was a "Virgilina-Halifax" generation that, in the Charlotte belt, exhibits northeast trending axes, and sub-horizontal axial planes. Based on the abrupt transition of moderately- to steeply-dipping greenschist grade Carolina slate belt rocks into sub-horizontal amphibolite grade Charlotte belt rocks, they interpreted the Charlotte belt as a large nappe that was emplaced during the "Virgilina-Halifax" folding event. Metamorphism up to sillimanite zone accompanied and followed nappe emplacement. The later event was a "Milton-Hager's Mountain" generation that Tobisch and Glover divided into northwest- and northeast-trending sets. The northeast-trending set is represented by a large antiformal arch in the area, whereas the northwest-trending set is represented only by small scale structures. Both have sub-vertical axial planes. The northwest-trending set is described as not well developed, and represented in the Carolina slate belt by small chevron folds or kinks in the fine-grained rocks and rarely by small open folds in coarser-grained rocks. In the Charlotte belt, the northwest-trending set occurs as crenulations in the thinly laminated rocks and as open folds with wavelengths up to 10 m in other rock types. Tobisch and Glover interpreted the northwest and northeast fold sets as conjugate folds produced in the same folding episode. The two sets, however, were never observed together in the same outcrop. Based on the lack of recrystallization-type linear and planar structures, they concluded that recrystallization was minor during this folding event.

Gates (1987) worked in the Laurentian shelf rocks adjacent to and just northwest of the study area. He found a series of four deformations and two metamorphisms. The D_1 event produced F_1 folds, now found as intrafolial folds in F_2. D_2 produced flat-lying foliation and sub-horizontal structures. Gates interpreted these events as Taconic in age, accompanied by an M_1 middle- to upper-amphibolite grade metamorphism caused by the emplacement of a nappe over the area at that time. North-trending F_3 folds formed during a Late Paleozoic transpressional D_3 event, and were rotated toward a northeast trend by D_3 shearing along the dextral Bowens Creek Fault. The D_4 event caused the formation of northeast-trending large-scale F_4 tight asymmetrical folds, with southeast-dipping axial planes, accompanied by the formation of parasitic folds on the limbs of the larger F_4 structures. An M_2 metamorphic event encompassed the D_3 and D_4 deformations.

ORIGINAL LAYERING

Many workers in the Carolina slate belt have found original volcano-sedimentary features in the rocks there (e.g, Harris and Glover, 1985, 1988). Primarily because of D_3 shearing, original features and layering are rare in the portion of the slate belt studied, and phenocrysts in the felsic volcanic rocks are all that remains of original textures.

The layering in the Charlotte belt appears to be almost exclusively of dynamothermal origin. No recognizable sedimentary features, such as graded bedding, conglomerate layers, etc., were found. Locally, phenocrysts are preserved in some of the Charlotte belt volcanic rocks, as well as compositional layering reminiscent of relict bedding.

D_1 DEFORMATION

Toward the end of the older slate belt volcanism, about 600 Ma, Carolinia experienced a folding and uplift event known as the Virgilina deformation (Glover and Sinha, 1973; Harris and Glover, 1985, 1988) that allowed an erosion surface to bevel across the area. Volcanic rocks of the younger slate belt sequence (not present in this area) were deposited unconformably over this surface.

The Charlotte belt is characterized by a sub-horizontal regional foliation, S_2, with local evidence of an even earlier event. Overall, the map area is nearly devoid of F_1 folds, which makes the earlier event more difficult to demonstrate. However, at location RB6-209 (about 4 km northwest of Providence, Virginia, Conner Lake quadrangle), an isoclinal F_1 fold is seen within the limb of a tight F_2 fold (Figure 3) in a metagabbro.

Although F_1 folds are rare in the present area, Henika (1980) has noted the same D_1 event in the Charlotte belt in the Danville, Virginia area, and describes S_1 folds recumbent

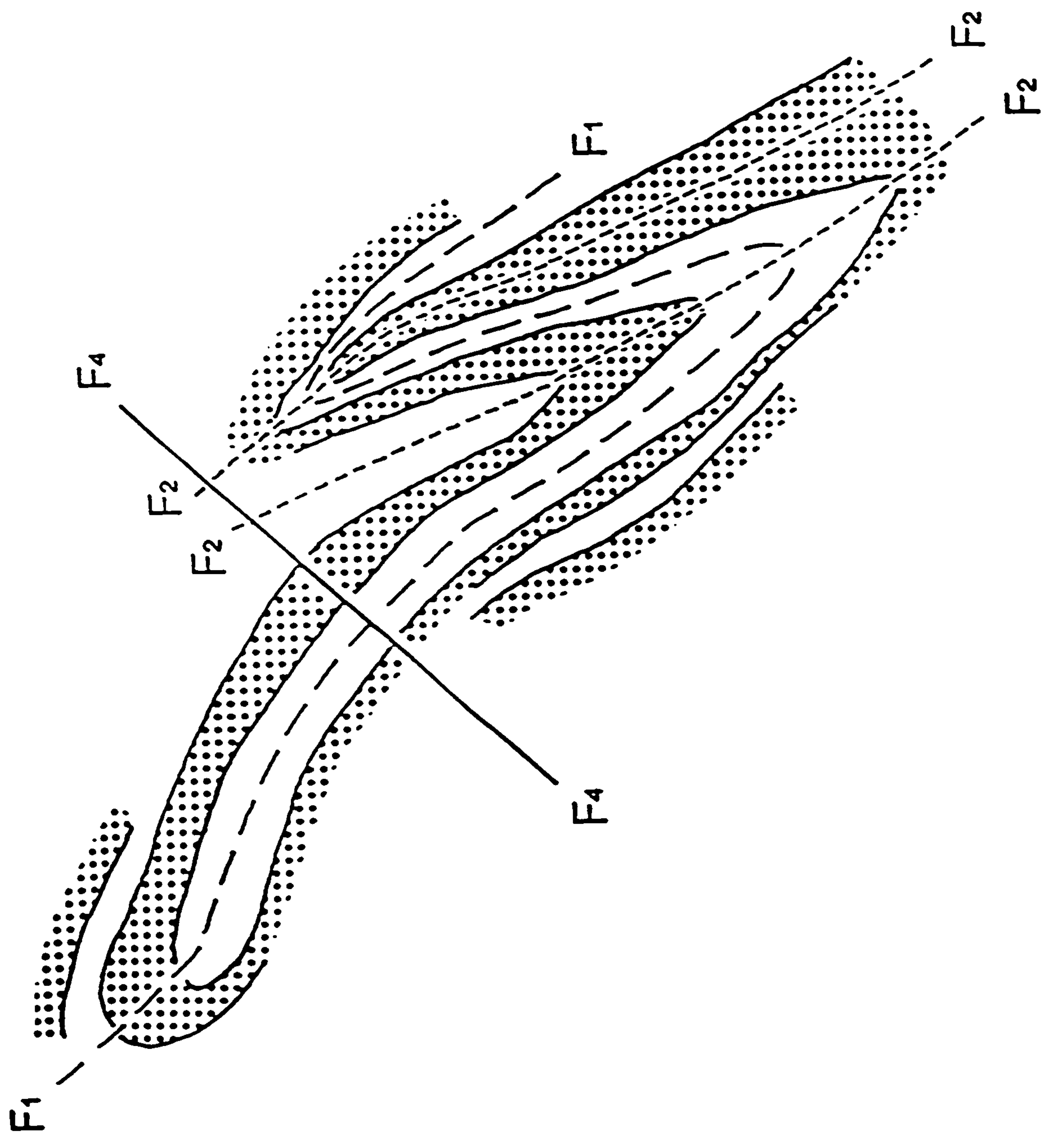

Figure 3: F_1 isoclinal fold refolded by F_2 tight fold. Later F_4 warping is also apparent. Length of fold shown is approximately one meter. Rock is metagabbro with mafic (dotted) and felsic (plain) banding.

with northwest-trending axes. Tobisch and Glover (1971) also observed occurrences of an earlier foliation in the Charlotte belt. This earlier folding and cleavage forming event has not been found in the Carolina slate belt rocks. S_1 is a sub-horizontal to gently dipping foliation, indicating that it has been folded into near parallelism with S_2. Because of later overprinting D_2 fabrics, lineations attributable to D_1 have not been identified with certainty. Table 1 gives a comparative listing of the deformational events as defined by workers in nearby areas in relation to this study.

On the microscopic scale, garnet from dacite at location RB6-847 (about 1.5 km south of Neals Corner, Virginia, Conner Lake quadrangle) shows evidence of two stages of growth (Figure 4). Contained in the core of the garnet are numerous inclusions oriented at an oblique angle to the regional S_2 foliation. There is also a subhedral overgrowth without inclusions over the rounded, anhedral core. The break between the core and rim is clearly visible. The oriented interior grains may thus be the earlier S_1 foliation incorporated by the growing D_1 garnet. Later, during D_2, the outer rim grew on the garnet.

D_2 DEFORMATION

The regional foliation, S_2, of the Charlotte belt is a penetrative, subhorizontal foliation (Figure 5). It occurs across the Charlotte belt and into the slate belt (Domain I) without significant change, other than the increase to moderate southeast dips in the slate belt. The foliation is usually defined by aligned micas, and locally by alternating mafic and felsic banding that tends to cleave along the more micaceous layers. Local occurrences of F_2 folds are tight to isoclinal, with northeast-trending axes and recumbent axial surfaces. Axial surfaces are sub-parallel with the regional foliation at any given locality. The regional mineral lineation, L_m (Figure 6), consists primarily of aligned micas, and is sub-parallel to F_2 fold axes. Locally, it is seen to be the intersection of the S_1 and S_2 cleavages. Henika (1980) described his F_2 folds in the Danville area in much the same manner, also stating that his S_2 foliation is the regional one. Although most F_2 folds are tight to isoclinal with vergence up to the north-

Table 1: Comparison of deformation sequences as noted by various workers in the area

Tobisch and Glover (1971)	*Henika (1977)*	*Marr (1981)*	*Gates (1987)*	*This Work*
	D_1: NW-trending isoclinal folds; horizontal axial planes	D_1: affects the Chopawamsic only	D_1: F_1 intrafolial folds in F_2	D_1: rare isoclinal folding and intrafolial folds
Virgilina-Halifax fold generation - NE-trending axes in Charlotte belt; axial planes sub-horizontal	D_2: NE-trending isoclinal folds; horizontal axial planes	D_2: tight folds accompanying the penetrative deformation of the area	D_2: Horizontal structures	D_2: NE-trending, isoclinal to tight folds; horizontal axial planes
Milton-Hager's Mountain fold generation - NW-trending axes; sub-vertical axial planes		D_3: folds more open and upright than D_2; infolding of the Arvonia Formation	D_3: N- to N15E-trending; en echelon; partially rotated toward northeast	D_3: N- and NW-trending open folds, N-trending set partially rotated to NNE; vertical axial planes
Milton-Hager's Mountain fold generation - NE-trending axes; sub-vertical axial planes	D_3: NE-trending open folds; vertical axial planes	D_4: broad, open folds	D_4: NE-trending tight asymmetrical folds and crenulation cleavage; axial planes dip to SE; parasitic folds on limbs	D_4: NE-trending open folds; vertical axial planes; parasitic folds on limbs

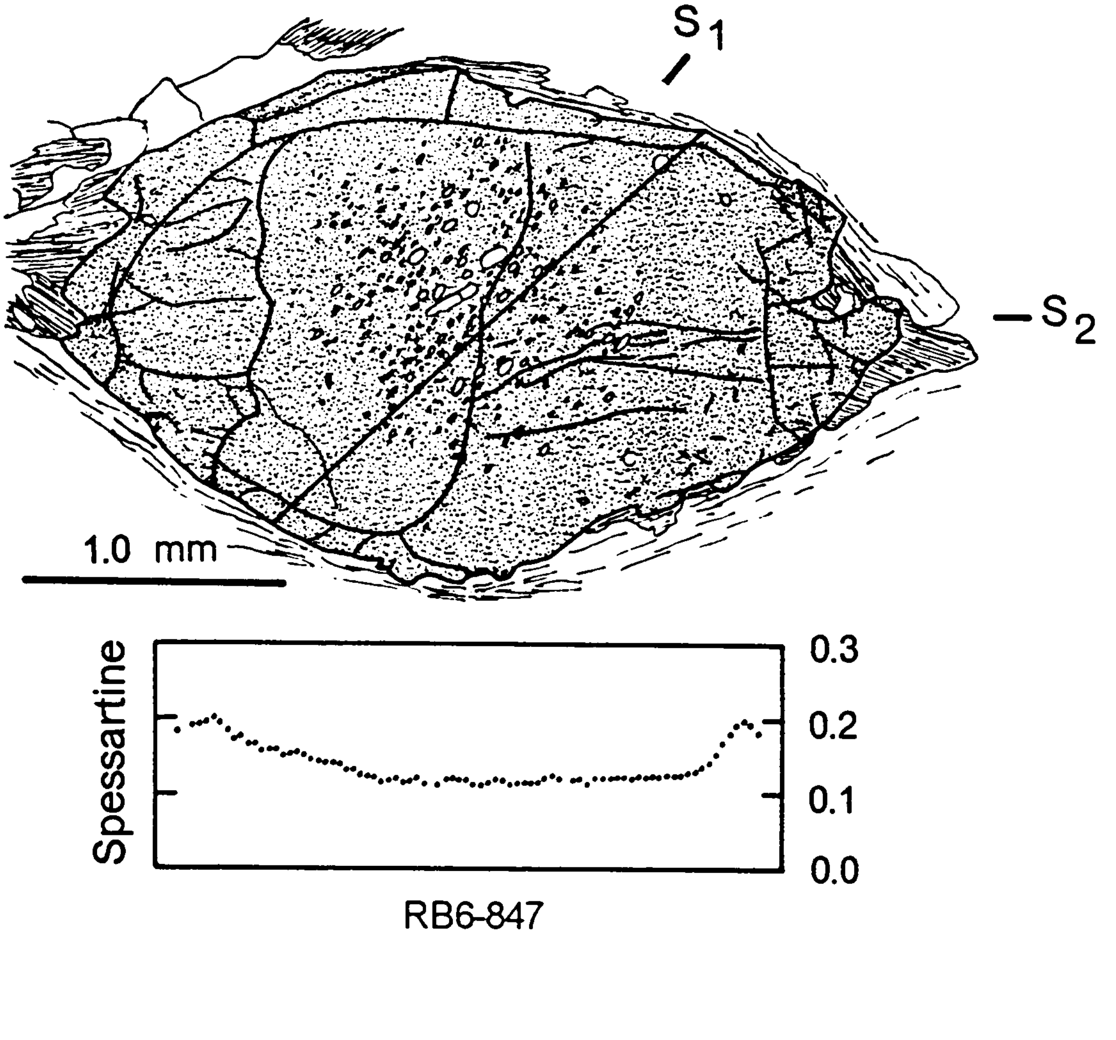

Figure 4: Garnet with oriented inclusions (S_1?) and anhedral shape with subhedral overgrowth. S_2 is horizontal plane normal to diagram. Mn profile is from upper right to lower left of garnet and appears to reflect a discontinuity related to the overgrowth. Mn units are in number of atoms out of three in the octahedral site.

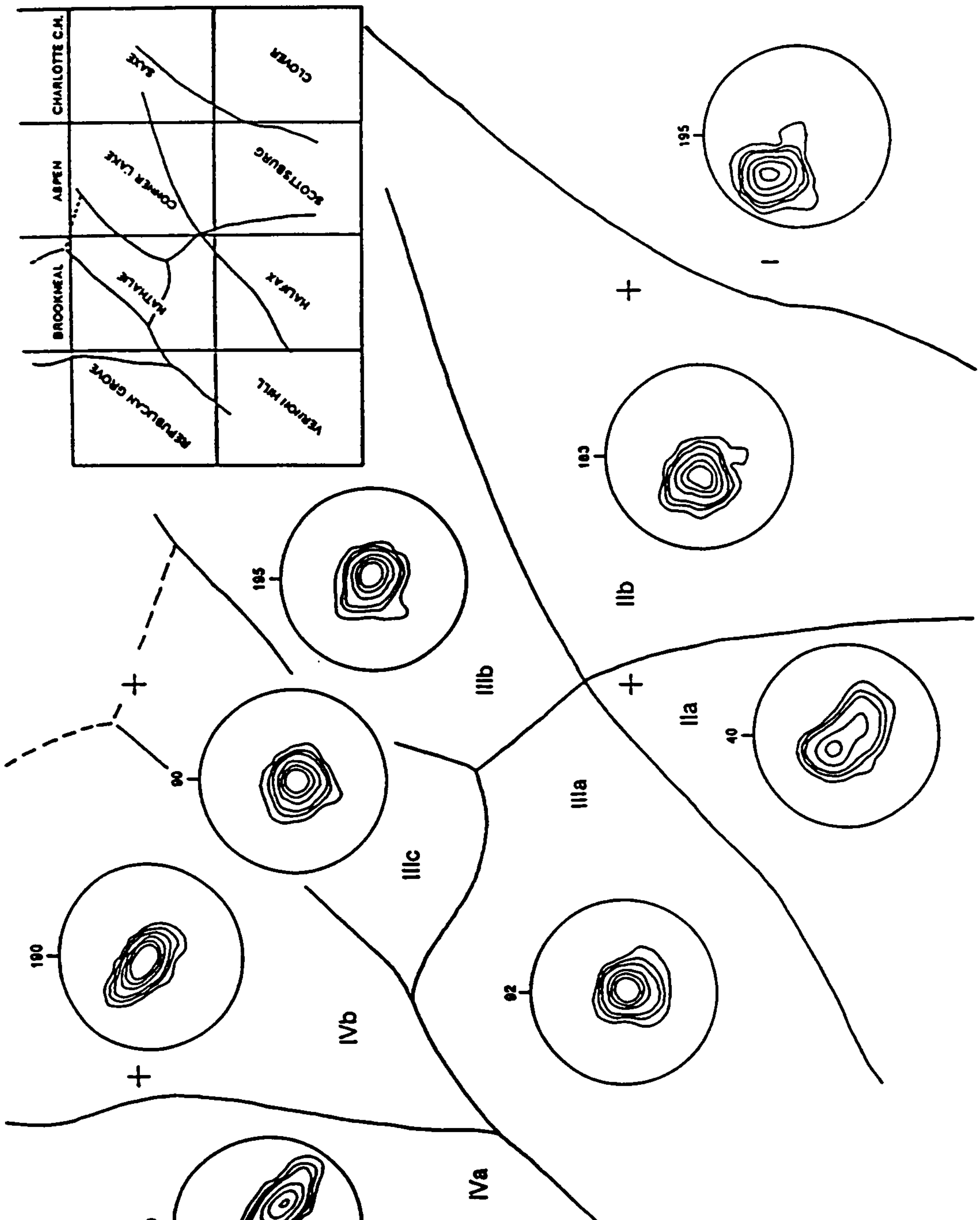

Figure 5: S_2 foliation domains. Sub-horizontal foliation over most of the Charlotte belt is indicative of a large fold nappe structure. Domain I is in the Carolina slate belt and part of the southeasternmost Charlotte belt. Domains II-IV are in the Charlotte belt. Contours are 1, 2, 3, 6, 9, and 12% per 1% area.

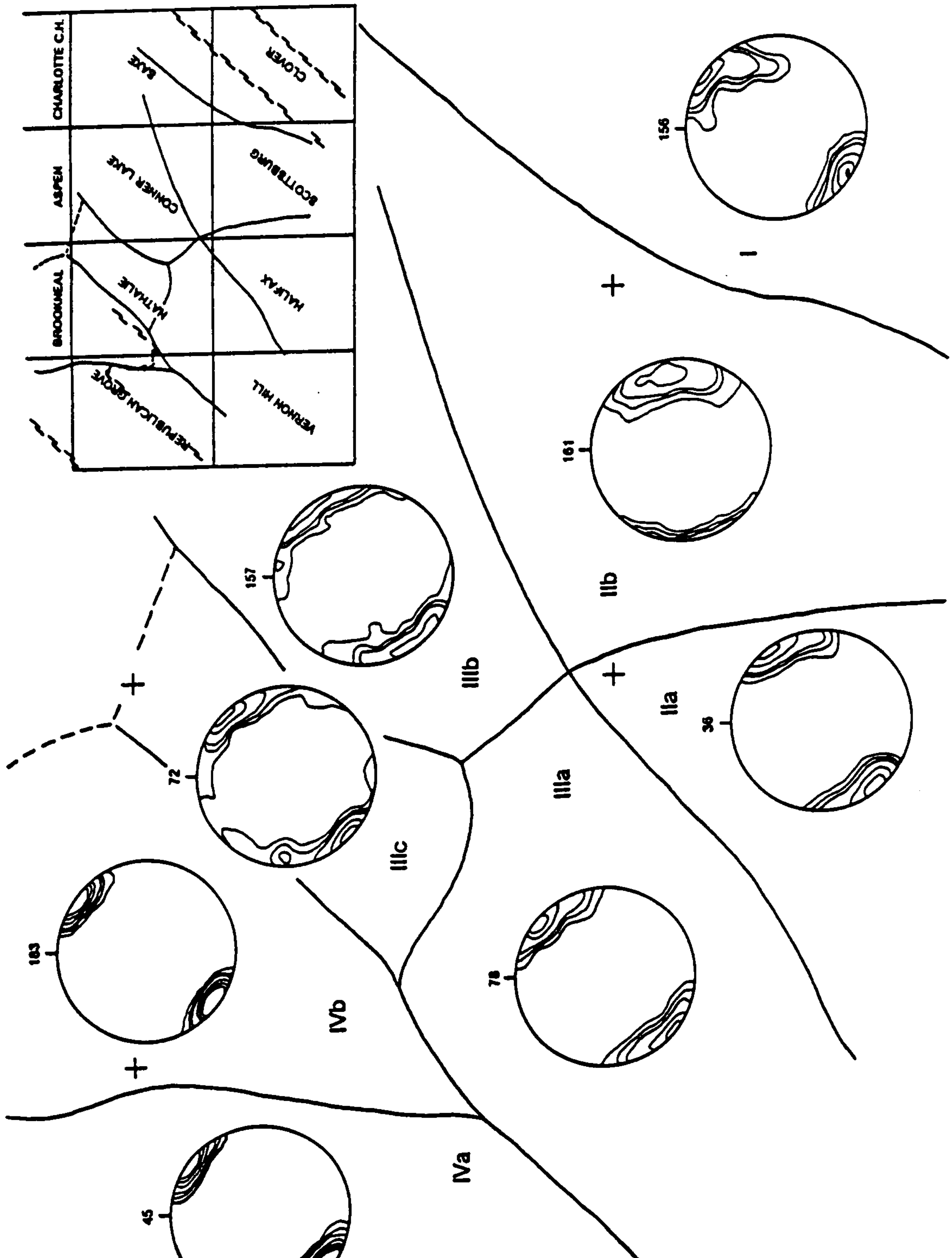

Figure 6: L_m mineral lineations defined by aligned mica. At 2-3% of the locations, these are clearly S_1 X S_2 intersection lineations. Contours are 1, 2, 3, 6, 9, and 12% per 1% area.

west, Figure 7 (along the railroad tracks, just south of Red Hill, Virginia) illustrates an asymmetric fold with vergence down to the southeast. The significance of this is discussed below.

The 425 Ma (Kish and others, 1979) Shelton Formation, a granite, is intruded into the hinges of F_2 folds (Henika, 1980). Allowing time for cooling below the blocking temperature for Sr diffusion, the actual intrusion may have been as early as about 450 Ma. This is within the 480-435 Ma age range for the Taconic orogeny (Glover and others, 1983). Both D_1 and D_2 are thus constrained to be Taconic or earlier.

D_3 DEFORMATION

D_3 deformation originally initiated by local development of an S_3 overprint, in the form of aligned micas and feldspar augen, which is usually oblique (as much as 45°) to S_2. S_3 is seen only near and within the Clover (Baird, 1988) and Brookneal (Gates and others, 1986) shear zones. Within the shear zones, S_3 is the schistosity, S, and is preserved in various stages of asymtotically rotated into the shear bands, C (Lister and Snoke, 1984). A plot of shear bands in rocks having a previous foliation is shown in Figure 8; those in granitic rocks are nearly identical. In the Clover zone, and commonly in the Brookneal, shear-bands formed sub-parallel with the earlier S_2 foliation (Baird, 1988). The mineral extension lineation associated with shearing plots with a strong northeast-southwest trend for both previously anisotropic (Figure 9) and previously isotropic rocks. D_3 is best demonstrated by the occurrence of these two shear zones, which bound the Charlotte belt on the northwest and southeast. Between the two shear zones, the area is devoid of evidence of shearing except locally (Figure 8, Domains IIb and IIIc).

Within the zone, the shear bands are locally observed to be folded into kinks having amplitudes and wavelengths up to a few cm. On an equal-area net of F_3 fold axes (Figure 10), the kink axes (labelled "K" in Domain I) form a girdle defining a northwest-trending fold axis. The figure also shows two distinct trends for F_3 fold axes (Domains IIIb and IIIc), one that trends nearly north to north-northeast, and another trending more northwesterly. Most of the north- and northwest-trending folds are broad warps or open folds with wavelengths on the

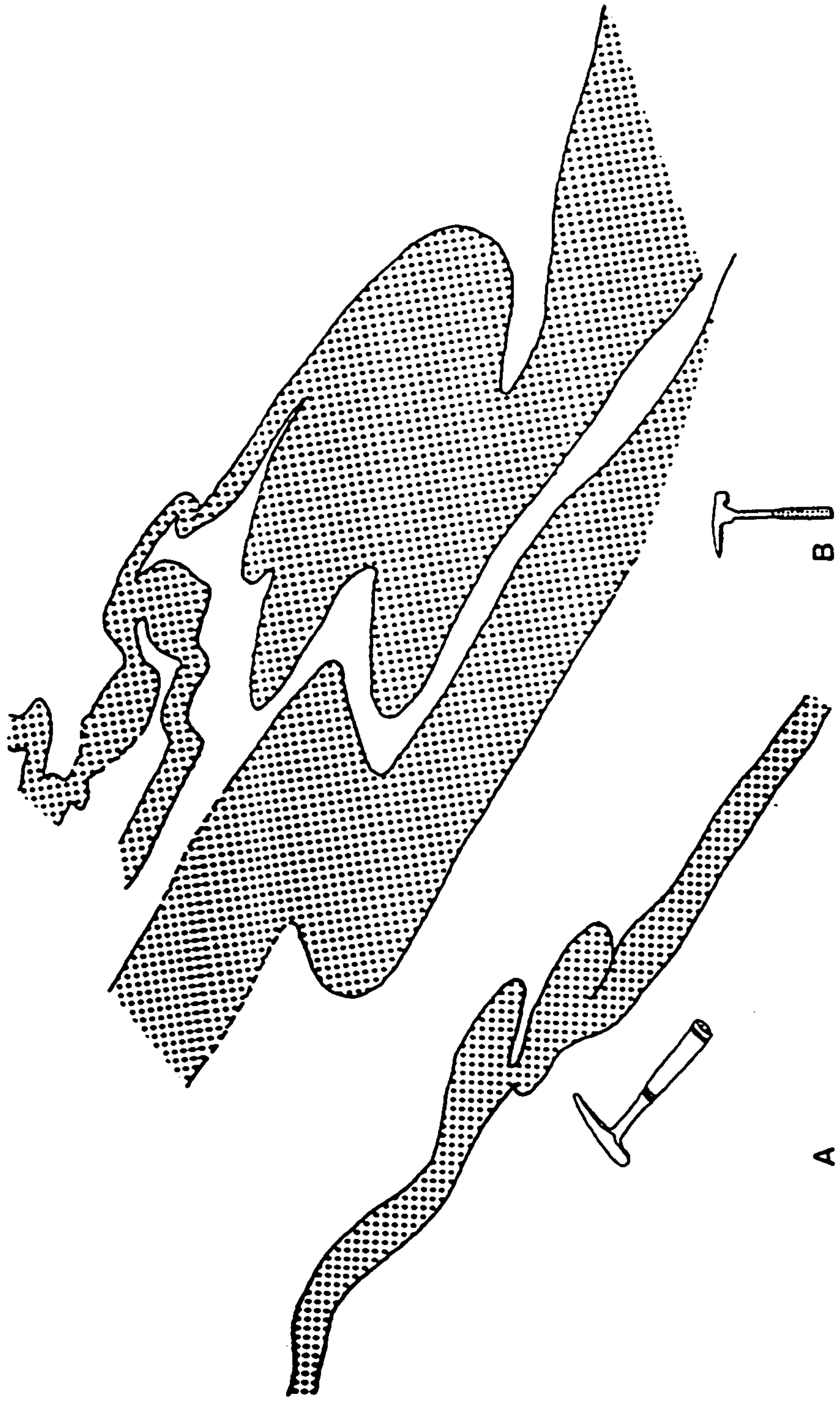

Figure 7: F_2 folds with vergence downward toward the southeast. Folds in (b) exhibit possible F_1/F_2 interference. Rock is Upper Hyco Formation dacite (dotted) interlayered with more biotitic layers (plain). Hammers in both (a) and (b) are approximately 30 cm in length.

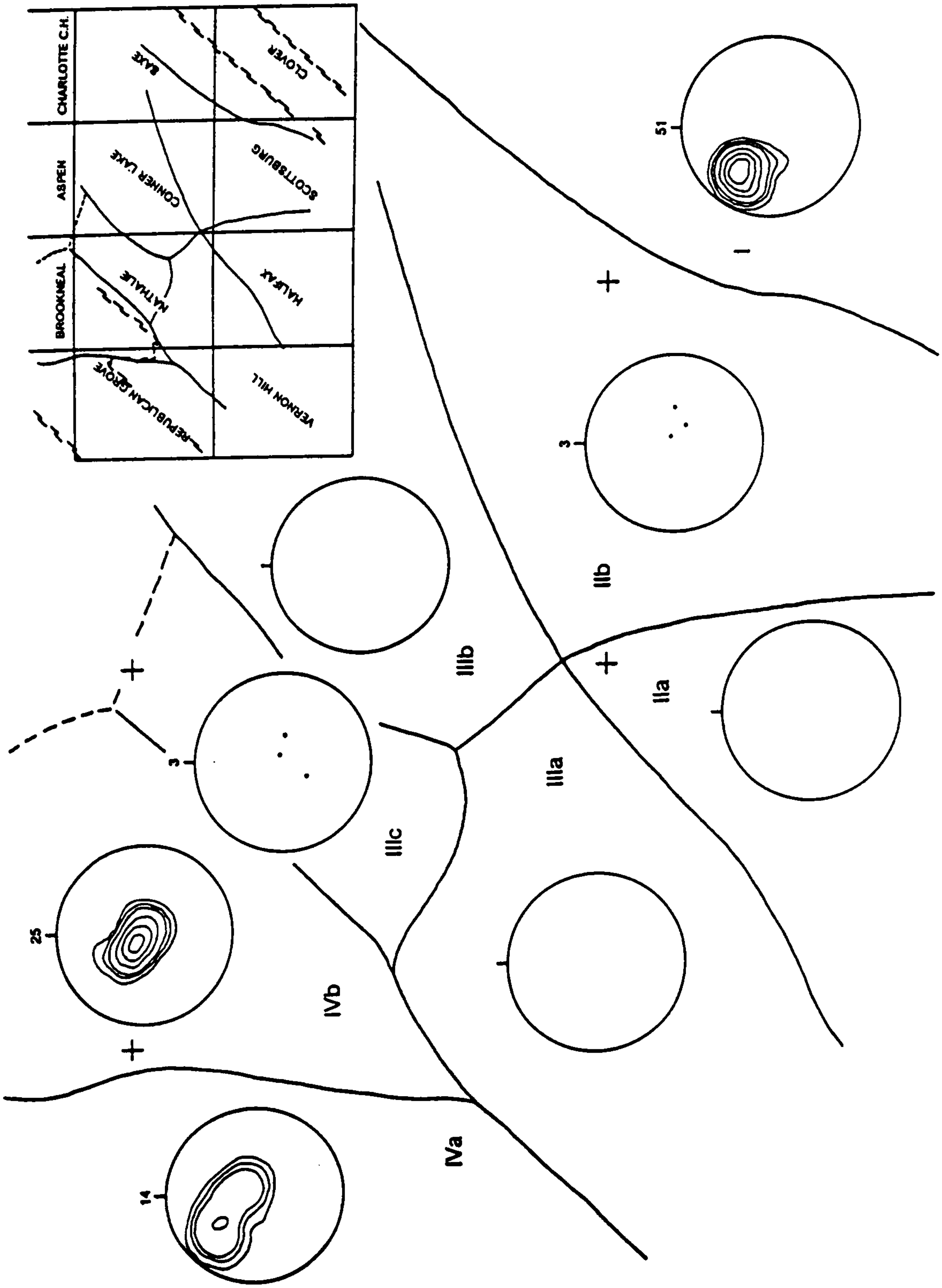

Figure 8: Shear band (S_b) domains from previously foliated rocks. Contours are 1, 2, 3, 6, 9, and 12% per 1% area. Plots with small amount of data points are not contoured.

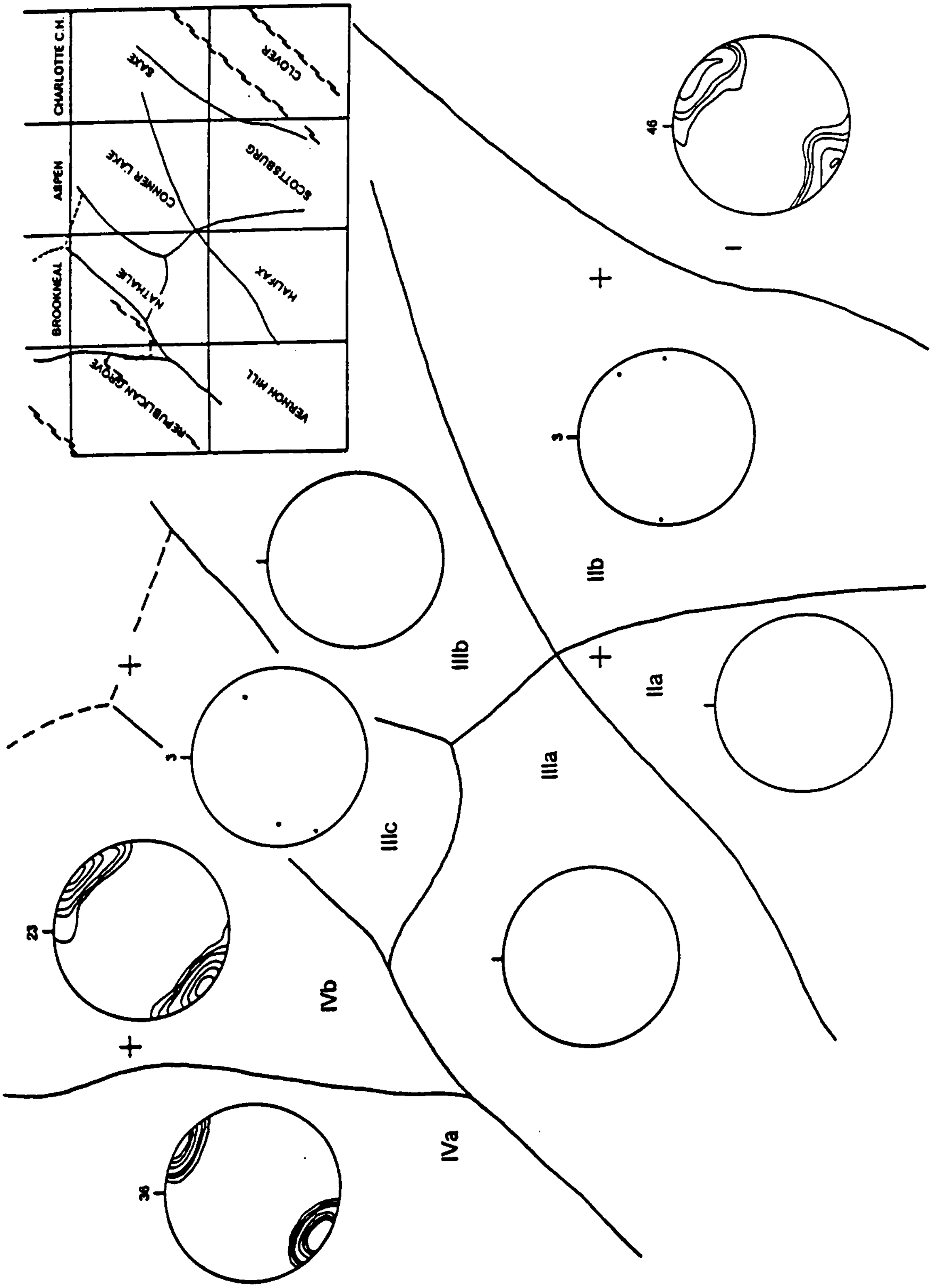

Figure 9: Mineral elongation lineations (L_3) related to shearing in previously foliated rocks. Contours are 1, 2, 3, 6, 9, and 12% per 1% area. Plots with small amount of data points are not contoured.

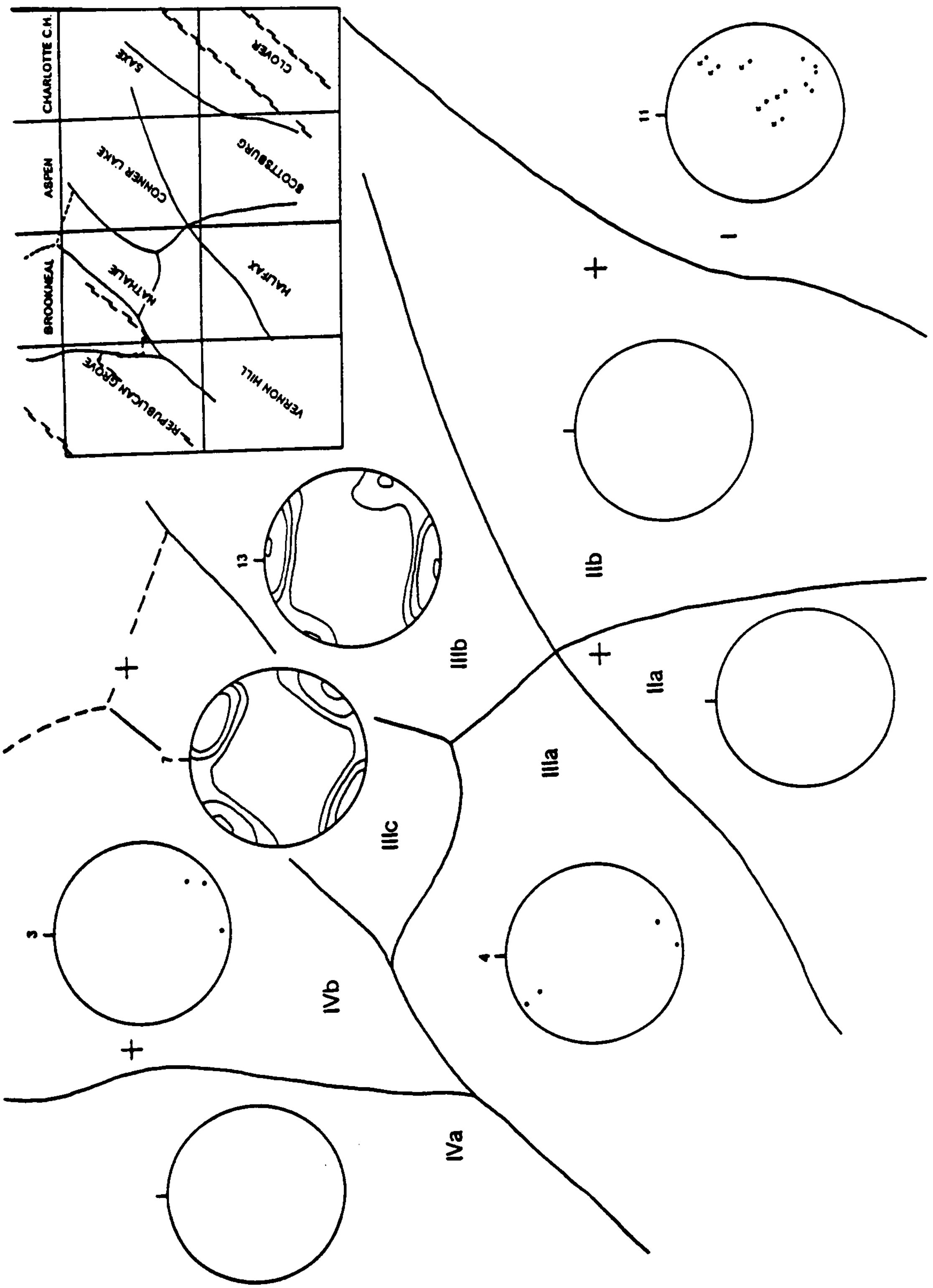

Figure 10: F_3 fold axes. Domain III shows two distinct trends for S_3 folds (see text). Domain I exhibits F_3 kink axes (labelled K) rotated about the northwest trend. These data indicate different phases during D_3 deformation. Contours are 1, 2, 3, 6, 9, and 12% per 1% area. Plots with small amount of data points are not contoured.

order of a few to tens of meters. Axial surfaces at this scale are difficult to determine, but appear to be sub-vertical.

The youngest rock in the area affected by shearing is the Upper Ordovician to Lower Silurian (Tillman, 1970) Arvonia Formation, which unconformably overlies the Carolinia volcanic sequence. Triassic basin rocks are undeformed and unconformably overlie the Brookneal shear zone. Shearing in the Brookneal zone is thus constrained to be Acadian to Alleghanian in age. Glover and others (1983) give a 380-340 Ma range for the Acadian event and 330-230 for the Alleghanian. Gates and others (1986) report that the 512 Ma (U/Pb) Melrose granite gives an age of 300 Ma (Rb-Sr) in portions of it affected by shearing. They interpreted this age as a cooling age post-dating most of the shearing because of the 300°C closure temperature for ^{87}Sr diffusion in biotite. Thus the Brookneal zone is probably of Alleghanian age. By analogy, the Clover zone is probably about the same age. The Clover shear zone cuts the undated Red Oak granite. Dating of this granite is therefore desirable in order to determine the minimum age of shearing in the Clover zone.

D_3 deformation is apparently of late Acadian to late Alleghanian age, based on the pervasive shearing of the eastern Piedmont at that time. Gates (1988) reports that the age range of Appalachian dextral faults is from 345 to 250 Ma (late Acadian through late Alleghanian), concording with the statement by Glover and others (1983) that in the southern Appalachians the Acadian and Alleghanian "could be two phases of one long protracted event." Farrar and others (1981) note that 285-315 Ma plutons in the Raleigh belt are affected by a later folding and shearing event. Shearing of the Clover shear zone is probably equivalent to that along the Gold Hill shear zone in North Carolina. Based on cross-cutting relations of the Southmont and Catawba pluton, Butler and Fullagar (1977) have constrained the shearing there to have occurred between 368±2 Ma and 329 ±14 Ma. Glover and others (1983) report a 324±3 Ma (hornblende, $^{40}Ar/^{39}Ar$) date in the Charlotte belt just east of Farmville, Virginia. Using a 500°C blocking temperature for argon diffusion in hornblende, they postulate that the thermal maximum could have been Acadian. This, of course, depends on how much higher temperature than 500°C the assemblage attained. Thus, some type of geothermometry would be desirable in that area in the future. Based on the above range of dates, the Clover zone may have developed anytime within the range from late Acadian to late Alleghanian.

D_4 DEFORMATION

D_4 is best demonstrated by the presence of quadrangle scale northeast-trending F_4 folds (Figure 2, Plate 1a). The large Republican Grove syncline is an excellent example of this event. The syncline fills the Republican Grove quadrangle map, and is apparent on the topographic map by the pattern of streams that outline its perimeter. Figure 11 shows the northeast trend of F_4 axes, whereas Figure 5 shows the more pronounced folding of the regional S_2 foliation about those axes. This is especially prevalent in domains IVa, IVb, and IIa. The amplitude of the folding is too gentle to clearly show in some of the S_2 domains, but is revealed by examination of the structural data compiled for the area. The formation of prominent regional-scale synclines in the study area is probably analogous to the transpressional dome formation in the Laurentian shelf rocks described to the northwest (Gates, 1987).

No foliation accompanies D_4 except for a weakly developed S_4 schistosity in the hinges of some F_4 parasitic folds on the limbs of some of the large F_4 structures in the area. The parasitic folds are close to tight folds with amplitudes and wavelengths of a few decimeters. S_4 surfaces form a girdle about the larger F_4 structures, defining the northeast-trending F_4 axis. The large Nathalie syncline (Figure 2, Plate 1a) is also a D_4 structure. The open F_4 folds are similar to the open F_3 folds with wavelengths of a few to several tens of meters and subvertical axial planes, with the exception that the F_4 folds have northeast-trending axes. D_4 is demonstrated to be post-D_3 because the sheared rocks related to the southeast boundary of the D_3 Brookneal shear zone have been folded about F_4 axes (Figure 8, Domain IVa, etc.). As noted by Henika (1980), these quadrangle-scale folds often expose the 425 Ma (Kish and others, 1979) Shelton Formation in their cores.

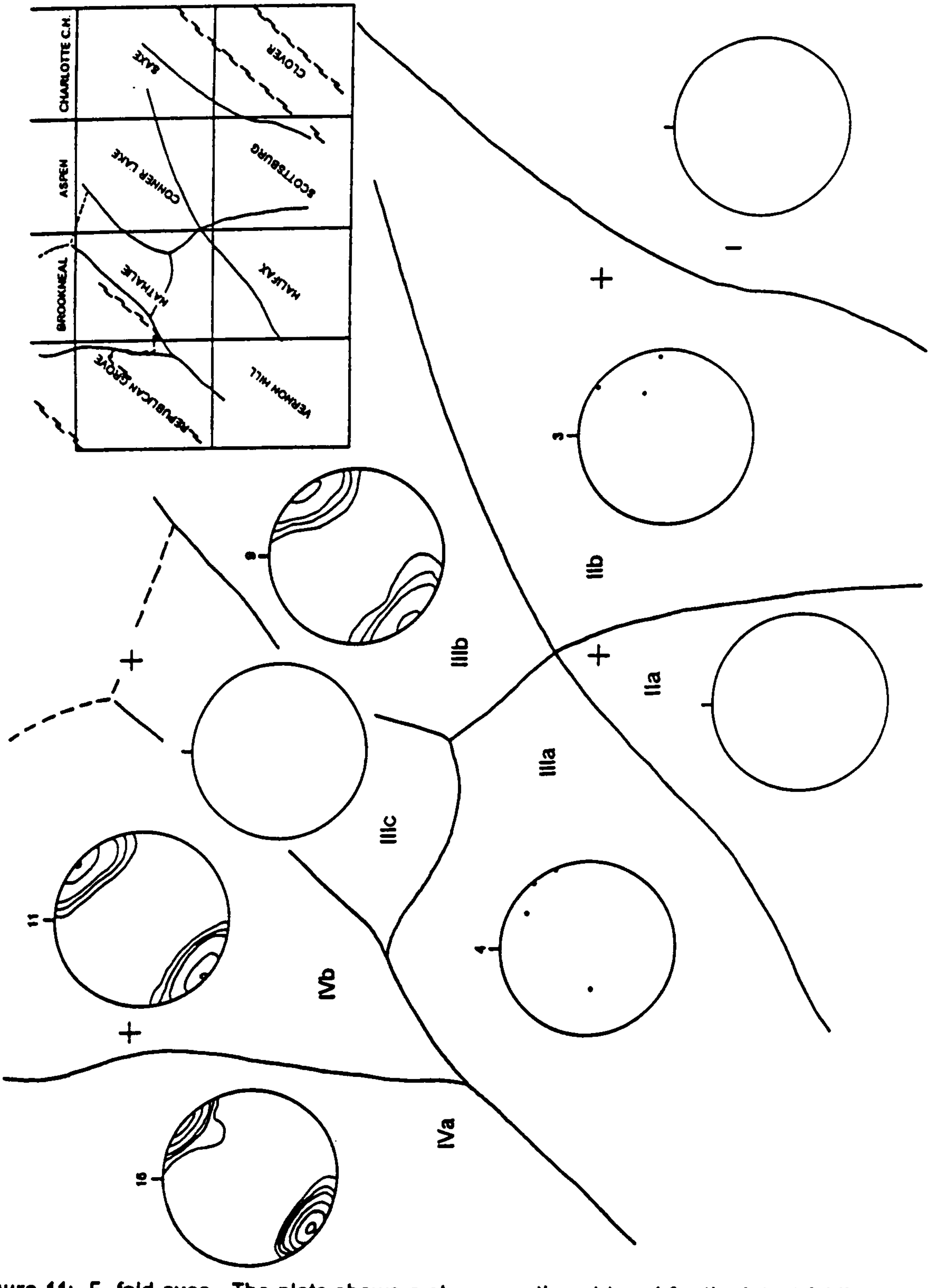

Figure 11: F_4 fold axes. The plots shows a strong northeast trend for the latest folding event. Contours are 1, 2, 3, 6, 9, and 12% per 1% area. Plots with small amount of data points are not contoured.

TRIASSIC RIFTING EVENT

The last major event to affect the area was the formation of several Triassic sedimentary basins related to the opening of the Atlantic Ocean. These basins lie on a northeast trend (Figure 2, Plate 1a). The large Danville basin lies northwest of the Brookneal shear zone. Three smaller basins lie just northwest of the Clover shear zone. Extending northeast from the latter basin is a straight section of stream extending for some 13 or 14 km. Evidence of brittle deformation (cataclasite) is seen along the railroad track here. Thus, a fault extending from the basin is inferred, and is named the Randolph-Drakes Branch fault after the small communities established along it.

In the southwest portion of the map area is a stretch of Bannister River that is extremely straight and northwest-trending for a distance of over six km. This feature is possibly also related to the faulting. Bobyarchick and Glover (1979) observed the occurrence of northwest-trending faults in the Richmond Basin, that may be related to that along the Bannister River here.

GEOTHERMOBAROMETRY

The monotonous quartzofeldspathic nature of the Charlotte belt rocks is such that the assemblages differ very little despite metamorphic grade. Only four samples were found to contain sillimanite. Index minerals such as staurolite or chloritoid are not present. The common presence of garnet in the rhyodacites and hornblende in the basalts indicate that amphibolite conditions prevail over a large area of the Charlotte belt, whereas the absence of those minerals, and the presence of epidote and chlorite, is indicative of greenschist conditions in the Carolina slate belt. Because of this situation, little in the way of metamorphic gradients, etc., can be discerned except in the most general way. The common presence of garnet in these simple quartzofeldspathic assemblages, however, allows a variety of thermobarometric techniques to be used to glean information not available from examination of the mineral assemblages.

Sample Selection and Analytical Techniques

The samples selected were biotitic dacites, but also included metagraywacke and rhyolite. They were all relatively fresh, and portions showing obvious signs of weathering, such as friability or limonitic staining, were avoided during preparation.

Minerals in polished sections of the samples were analyzed by means of an automated, nine-spectrometer ARL-EMX electron microprobe. Standardization procedures and analytical schemes used are given in Solberg and Speer (1982). Calculation of the data into oxide percents was accomplished according to the Bence and Albee (1968) method. Oxide percentages were then recalculated into mineral formulae via the computer program SUPERRECAL (Rucklidge, 1971).

Differentiation Between M_1 and M_2 Garnets

Petrofabric examination indicated that two populations of garnets were present. M_1 garnets are included within the S_2 fabric, and locally they have been somewhat rotated by the shearing event. As they are syn-S_2 and pre-D_3, they are considered to be Taconic in age. They range up to a couple of millimeters in diameter, subhedral to anhedral, inclusion-rich, and fractured. Fractures are normal to the foliation. Oriented inclusions and possible garnet overgrowths have been observed in only one sample (see Figure 4). Typically, the garnets are characterized by high almandine, moderate pyrope, and low spessartine and grossular contents.

M_2 garnets have either slightly displaced or, more commonly, have grown across earlier minerals or fabrics. They commonly overprint mica fish formed during the shearing event. Because of this, they are constrained to be late syn-kinematic or post-kinematic Alleghanian garnets. The typical M_2 garnet is "small," on the order of a few tenths of millimeters, euhedral to subhedral, inclusion-free, and crack-free. Chemically, they are somewhat lower in almandine than the M_1 garnets. Pyrope is usually very low, whereas spessartine + grossular rivals almandine content.

Temperatures used in the interpretation of the M_1 and M_2 events were calculated according to the equilibrium

$$\text{pyrope} + \text{annite} = \text{almandine} + \text{phlogopite} \quad (1)$$

(Thompson, 1976; Ferry and Spear, 1978), modified to take Mn and Ca into account (Hodges and Crowley, 1985). The results are believed to be accurate to within $\pm 50°C$ (Tracy and others, 1976). Over the temperature range here, the parameters of Thompson (1976) gave consistently higher temperatures.

Tracy and others (1976) note that retrogression can be common on rims of garnets. Loss of Mg from the garnet during retrogression would cause a corresponding increase of Mg in another coexisting ferromagnesian phase, such as biotite, giving an anomalously low temperature for the pair. However, this problem is partially ameliorated when the ratio of garnet to biotite is small, and the biotite becomes an infinite reservoir (Tracy and others, 1976). In the samples used for geothermobarometry, garnet and biotite were the only ferromagnesian phases, retrograde rims on the garnets tended to be narrow, and the garnet to biotite ratio was usually small. Where there was no retrograde rim, the rim composition of the garnet was used; where there was a retrograde rim, a point was chosen just inside the rim according to Tracy and others (1976). The resulting temperature in such a case is a minimum.

Pressures were determined using garnet-muscovite-plagioclase-biotite geobarometry (Ghent and Stout, 1981), garnet-rutile-almandine-ilmenite geobarometry (GRAIL, Hodges and Crowley, 1985), and quartz-garnet-almandine-plagioclase geobarometry (QGAP, Ghent, 1976; Newton and Haselton, 1981). Garnet-muscovite-plagioclase-biotite geothermometry is based on the equilibrium relation

$$\text{pyrope} + \text{grossular} + \text{muscovite} = \text{plagioclase} + \text{phlogopite}, \quad (2)$$

its iron counterpart,

almandine + grossular + muscovite = plagioclase + annite, (3)

as well as,

almandine + phlogopite = pyrope + annite (4)

(Ghent and Stout, 1981). These three reactions are based on Ca partitioning between garnet and coexisting plagioclase and are pressure sensitive (Hodges and Spear, 1982).

QGAP is based on the reaction

3 anorthite = grossularite + 2 aluminosilicate + quartz. (5)

Newton and Haselton (1981) state that laboratory runs must be made at over 900°C in order for the reaction to proceed in reasonable times, and the results are extrapolated to lower temperatures. They note that the four most complete studies give an error of ± 1.1 kb for the reaction. QGAP temperatures for M_1 assemblages are higher in comparison with those of the other methods (Table 2). Because of monotonous composition, most samples did not allow the use of multiple geobarometers.

Hodges and Crowley (1985) recommended that the above reactions for both temperature and pressure be not used for garnets with >25 mole% spessartine. R. J. Tracy (personal communication, 1989), however, states that high Mn content has little effect but that Ca content greater than 15-20 mole% can throw off the results. None of the M_1 and six of the M_2 garnets had Ca higher than 15 mole% (Table 2). Temperatures and pressures of all the garnets appear reasonable, with the M_2 garnets giving somewhat higher pressures than M_1. Hodges and Crowley also commend the Ferry and Spear (1978) calibration for biotite-garnet geothermometry and the Newton and Haselton (1981) QGAP parameters as consistently yielding geologically reasonable results.

Table 2
Microprobe Data and Results for Geothermobarometry

SAMPLE	Event	Garnet XFe	XMg	XMn	XCa	Biotite F/FM	Xann	Xphl
RB6- 6	M_1							
RB6- 45	M_1	.661	.079	.132	.128	.545	.451	.379
RB6- 52	M_1	.636	.095	.154	.115	.509	.405	.400
RB6-105	M_2(?)	.439	.040	.356	.165	.632	.517	.311
RB6-119	M_2(?)	.374	.045	.386	.195	.549	.431	.365
RB6-127	M_2(?)	.426	.021	.318	.236	.743	.599	.212
RB6-136	M_2(?)	.460	.025	.311	.204	.720	.538	.213
RB6-148	M_2(?)	.432	.035	.351	.182	.668	.539	.274
RB6-156	M_2(?)	.453	.157	.377	.014	.315	.251	.564
RB6-175	M_1	.624	.103	.245	.029	.399	.385	.572
RB6-223	M_2(?)	.528	.058	.200	.214	.583	.485	.352
RB6-375	M_2	.519	.123	.336	.022	.384	.316	.506
RB6-376b	M_2	.552	.146	.230	.072	.349	.307	.580
RB6-465	M_1							
RB6-524	M_1	.586	.094	.268	.053	.477	.403	.420
RB6-550	M_1							
RB6-553	M_1	.759	.135	.051	.055	.503	.398	.394
RB6-619	M_1	.785	.116	.057	.041	.552	.436	.356
RB6-621	M_1							
RB6-755	M_2(?)							
RB6-829	M_1	.752	.081	.118	.050	.593	.471	.317
RB6-847	M_1	.749	.144	.061	.045	.464	.372	.433
RB7- 5	M_1	.416	.037	.469	.078	.609	.491	.328
RB7-217	M_1	.784	.116	.046	.055	.530	.411	.366
RB7-222	M_1	.634	.079	.229	.059	.554	.444	.362
RB7-242	M_1	.625	.159	.145	.071	.411	.330	.479

F/FM - Fe/(Fe+Mg) in biotite
Xann - mole fraction of annite component of biotite
Xphl - mole fraction of phlogopite component of biotite

Table 2 (cont.)
Microprobe Data and Results for Geothermobarometry

SAMPLE	Event	Muscovite Xmu	XAlIV	Feldspar Xan	Ilmenite? Xilm	Rutile?	Al_2SiO_5
RB6- 6	M_1			.19			
RB6- 45	M_1			.36	Yes		
RB6- 52	M_1			.36			
RB6-105	M_2(?)			.19			
RB6-119	M_2(?)	.978	.732				
RB6-127	M_2(?)	.980	.761	.19			
RB6-136	M_2(?)	.972	.783	.22			
RB6-148	M_2(?)	.974	.748	.22			
RB6-156	M_2(?)	.787	.885	.03			
RB6-175	M_1	.800	.873	.13			
RB6-223	M_2(?)	.905	.798	.24	Yes		
RB6-375	M_2			.13			
RB6-376b	M_2(?)			.24	Yes		
RB6-465	M_1			.27			
RB6-524	M_1	.837	.842	.13			
RB6-550	M_1			.39			
RB6-553	M_1			.32	.97	Yes	Sill
RB6-619	M_1	.906	.902	.24			Sill
RB6-621	M_1			.34			
RB6-755	M_2(?)			.34			
RB6-829	M_1						
RB6-847	M_1	.895	.903		.97	Yes	Sill
RB7- 5	M_1	.966	.727	.16			
RB7-217	M_1	.905	.909	.27			Yes
RB7-222	M_1			.42			
RB7-242	M_1			.31		Yes	

Xmu - mole fraction of muscovite component in muscovite
XAlIV - mole fraction of aluminum in the octahedral site in muscovite
Xan - mole fraction of anorthite component of plagioclase
Xilm - mole fraction of ilmenite component in ilmenite

Table 2 (cont.)
Microprobe Data and Results for Geothermobarometry

		Temperature (°C)		Pressure (kb)				
				G&S		GRAIL		QGAP
SAMPLE	Event	ABT	F&S	Mg	Fe	Bohlen	H&C	N&H
RB6- 6	M_1							
RB6- 45	M_1	580	560					
RB6- 52	M_1	595	580					
RB6-105	M_2(?)	600	590					
RB6-119	M_2(?)	590	570					
RB6-127	M_2(?)	600	585	6.6	7.3			
RB6-136	M_2(?)	580	560	6.3	6.8			
RB6-148	M_2(?)	615	605	6.2	6.7			
RB6-156	M_2(?)	585	570	6.8	7.0			
RB6-175	M_1	495	460	3.7	3.7			
RB6-223	M_2(?)	620	610	7.2	7.9			
RB6-375	M_2	565	540					
RB6-376b	M_2	565	540					
RB6-465	M_1							
RB6-524	M_1	565	530	5.7	5.9			
RB6-550	M_1							
RB6-553	M_1	615	605			6.7	6.4	5.4
RB6-619	M_1	615	605	4.6	4.7			5.4
RB6-621	M_1							
RB6-755	M_2(?)							
RB6-829	M_1	575	555					
RB6-847	M_1	590	575			6.3	6.0	
RB7- 5	M_1	550	525	4.2	4.5			
RB7-217	M_1	595	580	5.0	5.2			5.5
RB7-222	M_1	575	555					
RB7-242	M_1	620	610					

ABT - Garnet-biotite temperatures per the parameters of Thompson (1976)
F&S - Garnet-biotite temperatures per the parameters of Ferry and Spear (1978)
G&S - Pressures per the parameters of Ghent and Stout Mg and Fe; calculated using the F&S temperatures
GRAIL - Pressures for garnet-rutile-aluminosilicate-ilmenite geobarometer per the parameters of Bohlen, and Hodges and Crowley (1985); calculated using the F&S temperatures
QGAP - Pressures for the quartz-garnet-aluminosilicate-plagioclase geobarometer per the parameters of Newton and Haselton (1981); calculated using the F&S temperatures

M_1 Metamorphism

M_1 encompasses both D_1 and D_2 deformations. If D_1 is Virgilinian, then the rocks affected remained deeply buried until the Taconic orogeny, at which time they were thrust northwestward during D_2 nappe formation. By the end of Taconic time, the greenschist/amphibolite isograd lay somewhere within the present limits of the Clover shear zone.

Charlotte Belt. Within the pre-thrusting stack of volcanic rocks on Carolinia, the deeper portion would have been expected to have experienced higher T/P conditions than the upper portion of the stack. The post-thrusting structure of the area allows the metamorphic grade differential between the two to be easily observed. The deeper Charlotte belt was metamorphosed to sillimanite grade based on four occurrences of sillimanite. In the main, however, the volcanic rocks are relatively alumina-poor. Garnet is, however, more common.

The mineral assemblages in the M_1 Charlotte belt rocks are as follows: qtz + pl + ksp + ms ± bt ± ep ± gt for rhyolites, pl + qtz + bt ± ms ± ep ± hb ± gt ± als for dacites, hb + pl + qtz + ep ± bt for basalts, and pl + qtz + bt + ms ± gt for pelites. Garnet-biotite geothermometry indicates a P-T of up to around 6.0 kb and 600°C. (Table 2). Using a pressure gradient of 0.3 kb per 1 km of overburden (Turner, 1981), this corresponds to a depth of about 20 km for the assemblage. Using an average surface temperature of 20°C, the temperature increase is 580°C over 20 km, giving a geothermal gradient of 29°C/km. This falls within the low-pressure range for regional metamorphism (Miyashiro, 1973), and is typical of a volcanic arc tectonic regime where heat is constantly added via plutonism.

Carolina Slate Belt. The Carolina slate belt in this area is of low metamorphic grade, but shows evidence that during M_1 it experienced amphibolite-grade metamorphic conditions. For example, hornblende cores in epidote grains occur within a mile or so of the boundary with the Charlotte belt. At least one garnet partly altered to chlorite was found. Because of the D_2 shearing and M_2 metamorphic overprint in the slate belt, little remains with any certainty of M_1 assemblages there.

M_2 Metamorphism

M_2 mineral assemblages can be seen predominantly in two portions of the study area. These are the areas affected by shearing in the Clover and Brookneal shear zones. Etheridge and others (1983) note that there is evidence from a number of shear zones that fluid flux during retrogression may be very large. It is such high fluid flux that possibly facilitated retrogression and re-equilibration of M_1 assemblages to M_2 metamorphic grade within the shear zones. The best examples of M_2 are thus the Clover and Brookneal shear zones, the rocks of which have been reequilibrated to M_2 conditions during shearing.

Charlotte Belt. The bulk of the Charlotte belt is amphibolite grade and primarily exhibits M_1 metamorphic assemblages. In the Brookneal shear zone and adjacent areas affected by it, however, stabilization of M_2 assemblages has occurred.

The mineralogical proportions of the quartzofeldspathic Charlotte belt assemblages are little affected by the M_2 overprint and, as such, do not differ substantially from M_1 assemblages in these rocks. The mineral assemblages in the M_2 Charlotte belt rocks are as follows: qtz + pl + ksp + ms $\pm$ bt $\pm$ ep $\pm$ gt for rhyolites, pl + qtz + bt $\pm$ ms $\pm$ ep $\pm$ hb $\pm$ gt $\pm$ als for dacites, hb + ep + pl + qtz $\pm$ sph for basalts, and pl + qtz + bt + ms $\pm$ gt for pelites. P-T conditions up to about 600°C and 7 kb (Table 2) correspond to a geothermal gradient of about 25°C/km.

M_2 garnets are more difficult to prove. In only a few cases is it unquestionable that the garnet growth post-dated the shearing event. Fabric relations in these cases show that garnet grew across sheared micas and earlier fabrics having been only slightly or not at all affected by the shearing event. M_2 temperatures without queries, however, give temperatures similar, within range of error, to queried M_1 temperatures. M_2 temperatures are late syn-kinematic to early post-kinematic temperature, and do not represent the actual temperature during shearing, although they are probably nearly the same.

Carolina Slate Belt. The Clover zone of the Carolina slate belt is presently of greenschist metamorphic grade, contains no M_2 garnet, and is consists predominantly of low-grade volcanic rocks with some development of chlorite in the felsic volcanic rocks. The mineral assemblages in the M_2 Carolina slate belt rocks are as follows: pl + qtz + ms + chl + ep ± bt for dacites, ep + chl + qtz ± pl for basalts, and pl + qtz + ms + chl + ep ± bt for pelites. Based on petrographic work, the M_2 biotite isograd falls slightly northwest of the center of the zone.

DISCUSSION

Sequence of Deformations

The sequence of deformations in the study area was determined as follows: There is a regional penetrative foliation in the Charlotte belt with local occurrences of an earlier s-surface. The older s-surface is interpreted as having formed during D_1 and the regional foliation in D_2. A dextral shearing event affected the regional D_2 fabrics and is, as such, D_3. Both D_2 and D_3 fabrics have been deformed by a later folding event, D_4. Henika (1980) found evidence for three of these deformations in the Danville, Virginia area west of that of Tobisch and Glover (1971) in the Milton, Virginia area. Henika's deformations correspond well with those found in this area. His D_1, D_2, and D_3 events correspond well with the D_1, D_2, and D_4 events found here. He did not recognize the D_3 shearing event in his area, whereas his D_4 is Mesozoic. He does note that his D_3/D_4 events produced the most prominent structures with respect to the erosional unroofing of major rock units, such as the Shelton. This is the case for the D_4 event described here, this is the case as well. Table 1 gives a comparison of the various deformational events defined by workers in this and surrounding areas.

D_1 Deformation

Glover and others (1983) estimated a thickness of 13 km for the Carolina slate belt by Cambrian to Ordovician time, sufficient, given the effects of thermal blanketing and continuous magma injection, for low to middle greenschist conditions at a few kilometers depth. This being the case, the underlying Charlotte belt volcanic rocks were probably undergoing amphibolite grade metamorphism. As early as Late Precambrian, the Charlotte belt and the older slate belt sequence had attained their present thicknesses. Under amphibolite, or near amphibolite, grade conditions the Charlotte belt sequence would have been a prime candidate for the imposition of a tectonically induced foliation at the onset of a deformational event. It is thus likely that the local S_1 foliation formed during the Virgilina deformation, while the cooler and less ductile older slate belt rocks experienced folding and faulting. If this is the case, then the absence of the S_1 foliation in the slate belt is explained.

D_2 Fold Nappe Formation

The Charlotte belt here is an area of sub-horizontal stratigraphy some 34 km across (Figure 5). Hobbs and others (1976, p. 416-418) note that two processes will produce a sub-horizontal foliation across a large area. The first involves regions which served as the soles of thrust sheets. The nearer to the thrust plane, the more strained the rocks are, and the better a gently-dipping foliation has developed sub-parallel with the thrust plane. Although this mechanism is applicable in certain areas, the present situation does not lend itself to such an interpretation. The rocks of the central Charlotte belt show no significant shear strain, although the belt is bounded by moderately-dipping shear zones. The foliation is uniform and penetrative and does not change significantly throughout the section.

The second mechanism consists of the impartation a moderate to steep foliation ($>30°$ dip) during a collisional event followed by nappe emplacement. As the nappe develops, the foliation is eventually rotated to near horizontality. Brown (1968) utilized this explanation when interpreting the large (24 km or so) area of flat-lying schistosity of the Otago schist terrane of New Zealand. This mechanism is also called upon here as the only viable solution for the sub-horizontal foliation of the Charlotte belt, and serves to support the Virginia Charlotte belt structure as that of a recumbent fold nappe as proposed by Tobisch and Glover (1971). The nappe is a large structure some 34 km across, which compares with that of other large nappes in the Alps and elsewhere. According to Cooper (1981), such fold nappes form by gravitational instability, rising and spreading laterally via ductile upwelling of the hot, buoyant infrastructure of an orogen. As the Shelton Formation appears to be a syntectonic granite, this appears to have been the case here as well.

Ramsay and others (1983), in a paper on the Helvetic nappes, discussed how increasing strain during nappe thrusting can cause the overturning of an asymmetric fold and cause reversal of its vergence (Figure 12). Figure 7 shows examples of this in mafic volcanic rocks near Brookneal, Virginia. The asymmetric folds appear to verge down to the southeast; they are interpreted to be the result of up to the northwest movement. This mesoscopic structure is one more bit of evidence in support of the nappe interpretation for the Charlotte belt. An alternative to the reversed vergence fold proposition is that the folds are Z or S folds on the limbs of one of the large F_4 antiforms or synforms. This, however, would still result in northwest-verging folds on any southeast-dipping limbs. Moreover, F_4 parasitic folds are easily recognized on the limbs of the Republican Grove syncline, for instance, but the folding style is different than that of the reversed vergence folds. And, whereas there is apparently enough amplitude on the Republican Grove structure to form parasitic folds, no parasitic folds have been identified that are related to any of the low amplitude F_4 regional folds, such as those in the vicinity of the reversed vergence folds here.

By comparison with Figure 12, the folds in Figure 7 show a shear strain of about $\gamma = 7$. Ramsay and others (1983) give values of about $\gamma = 8$-10 for the overturned limb of a nappe, and of $\gamma \leq 3$ for the upright limb. In the interpretation here, however, this fold occurs on the upright limb of the Milton nappe. The higher strain may be due to the fact that the nappe is a much larger one (some 34 km across on Figure 2, Plate 1a) than that studied by Ramsay and others (1983) and high strains occur in both limbs, or it may be a localized zone of high strain.

During D_2, deep, infrastructural Charlotte belt rocks were thrust northwestward beneath the overlying Carolina slate belt suprastructure. folding the Charlotte belt into an F_2 fold nappe ("Virgilina-Halifax" fold generation of Tobisch and Glover, 1971). This event folded the earlier S_1 foliation into near parallelism with S_2 (Figure 13, Plate 1b). Consistent with the thinning of units during nappe thrusting, the Catawba Creek-Upper Hyco sequence of the central Charlotte belt is 1.3 km thick, as compared to the 2.4 km thickness of the St. Matthews-Hyco sequence of the eastern Charlotte belt and Carolina slate belt. By D_2 time, the Carolina slate belt material was deep enough to have been imprinted with the same S_2

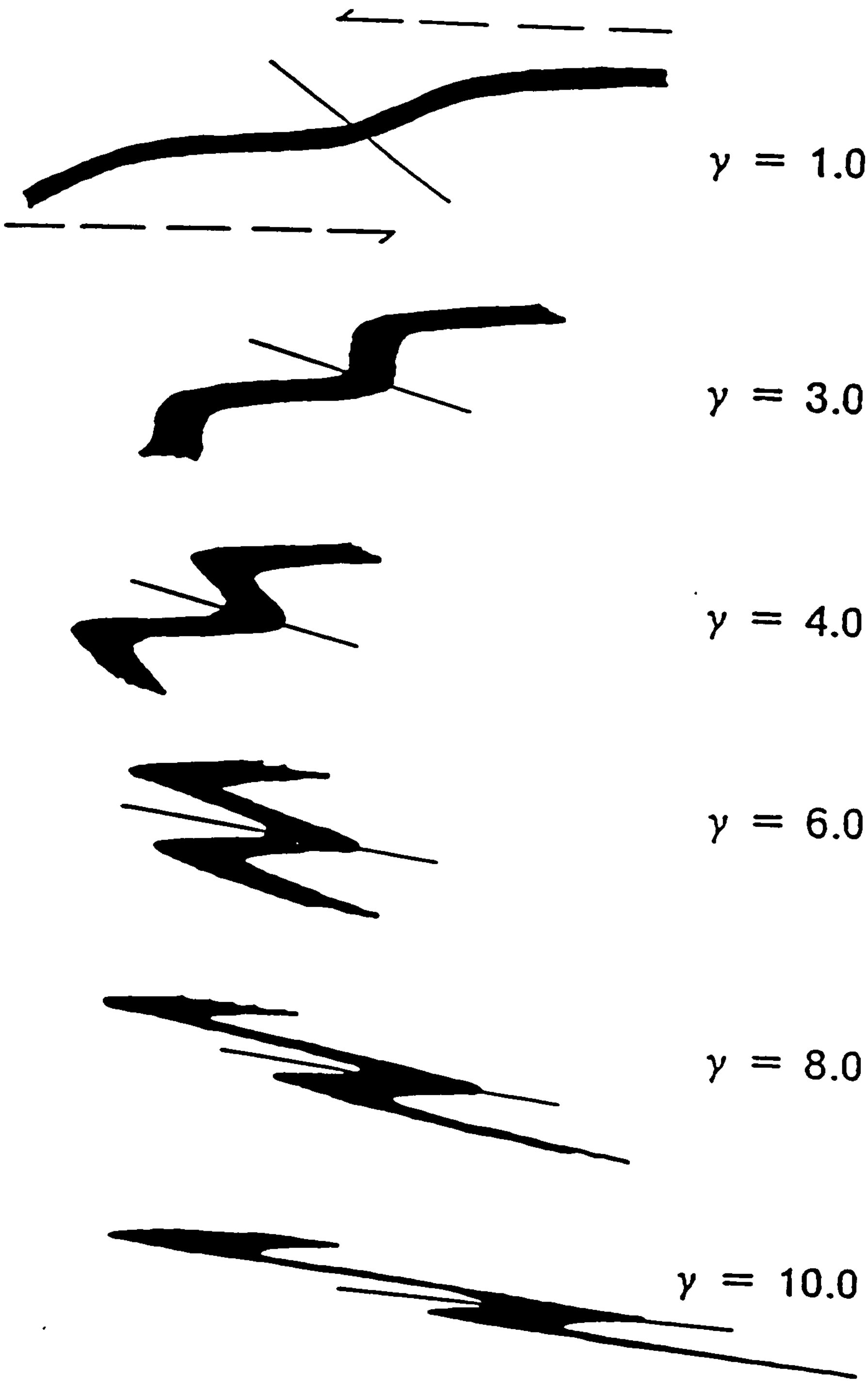

Figure 12: Formation of reversed vergence folding. From Ramsay and others (1983). The folds in Figure 7 appear to have a shear strain of about $\gamma = 7$.

Cross-Section A - A'

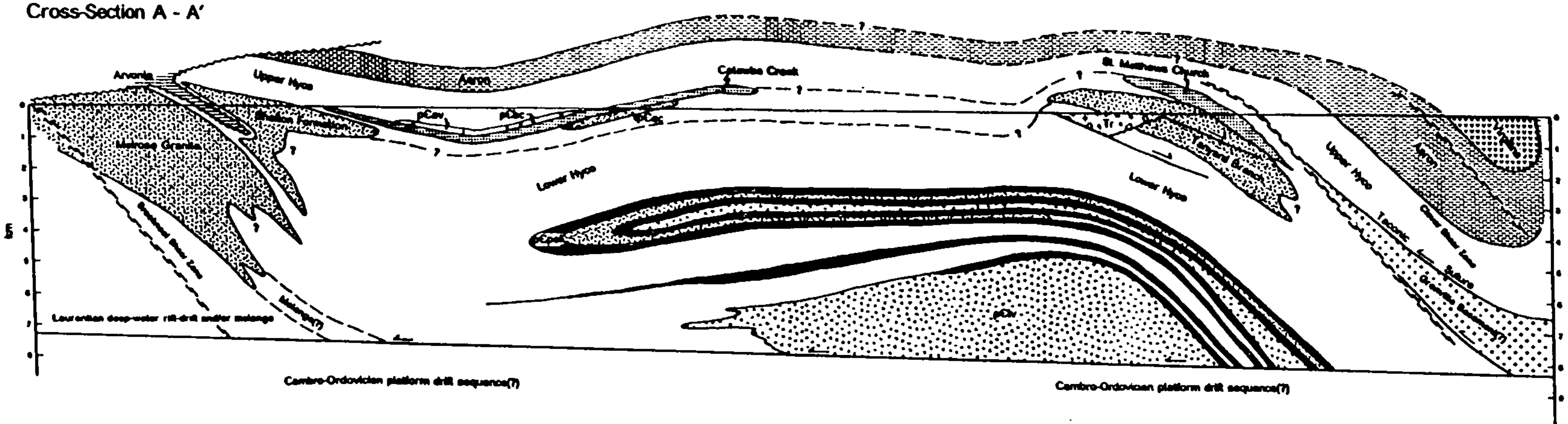

Figure 13: Cross-section across the area showing the detail of the fold nappe structure of the Charlotte belt. Horizontal line at 0 km is the approximate land surface. See Figure 2 for location of the cross-section.

foliation. Thus, S_2 is the regional foliation of this portion of Carolinia. Henika (1980) also noted that the regional foliation in his area was an S_2 cleavage.

The area to the northwest mapped by Gates (1987) near Altavista, Virginia, is complementary to the present area. The situation there of upright stratigraphy and an inverted metamorphic gradient suggests that a large nappe was emplaced over the region. The Milton nappe either is that nappe or is related to it. The sequence of four structural events as defined by Gates for that region are in good accord with that found here.

Although the Charlotte belt in south central Virginia consists of a recumbent fold nappe, this situation apparently does not hold farther to the southwest in the Charlotte belt. Griffin (1978), working near the South Carolina/Georgia border, indicates that the structure there consists of a concordant Charlotte belt stratigraphy underlying the Carolina slate belt, both of which have been deformed into a series of accordion-like moderately- to steeply-dipping folds. In York County, South Carolina, Butler (1966) found that the average strike and dip of Charlotte belt rocks was N54E, 72SE. This contrasts with the sub-horizontal average foliation attitude of the Charlotte belt in south central Virginia, and argues that the Charlotte belt does not consist of a nappe in this area of South Carolina. The nappe boundary probably lies somewhere in the northeastern part of the North Carolina Charlotte belt. Ramsay and others (1983) noted that strain is greatest at the nappe boundary, so this strain gradient should be evident there if annealing and recrystallization has not obscured it.

M_1 Metamorphism

M_1 metamorphism ranged up to about 600°C at 6 kb. Considering the ±50°C error, the temperature was fairly uniform across the area now exposed in the Charlotte belt, apparently dropping off somewhat to the northwest and southeast. Temperatures probably graded down to greenschist conditions in the Carolina slate belt at the time.

D_3 Deformation

D_3 consisted of several phases, some of which probably operated throughout the event. The first was the imposition of the S_3 foliation and initiation of shearing within the Clover and Brookneal zones. Folding about a north-trending axis probably occurred throughout the event (Figure 10, Domain IIIb). This trend appears to rotate toward a north-northeast trend to the northwest in Domain IIIc. The second was minor kinking within the Clover zone. Because this kinking affects the earlier sheared rocks, it must post-date the shearing. The third was folding of the kinks about a northwest-trending axis (Figure 10, Domain I). Some F_3 fold axes also have a northerly-trending mode.

Shearing Event. Gates and others (1986) determined that the Brookneal shear zone in the originally isotropic Melrose granite was oriented at N40E, 50SE. Within the Arvonia Formation, just two or three km to the southeast, the shear bands dip about 30° to the southeast (Figure 2, Plate 1a). In the sheared Aaron Formation a few more km to the east, the shear bands lie sub-horizontal, and shearing occurred along the plane of the subhorizontal S_2 foliation.

The only scenario that appears to explain this situation is that most of the zone movement took place along the part of the Brookneal shear zone within the Melrose granite, but part of the strain was partitioned as slip that occurred along the sub-horizontal S_2 foliation in the Charlotte belt (Figure 14). Slip was particularly favored in the more micaceous, schistose lithologies.

F_3 Fold Trends. In light of the foregoing, the cause of bimodality in F_3 fold trends (Figure 10, Domains IIIb and IIIc) adjacent to the Brookneal shear zone may be discussed. The northerly trend (Domain IIIc) is interpreted to have resulted as the east-west stress regime that caused the shearing was imposed upon the area. To the northwest, in Domain IIIb, the northerly-trending folds of Domain IIIa have been rotated to a north-northeast trend toward parallelism with the Brookneal shear zone. The east-west stress field is inadequate, however, to account for the northwesterly set of F_3 axes. The Brookneal shear zone is a northeast-trending dextral zone where the southeastern block has moved southwest relative to the

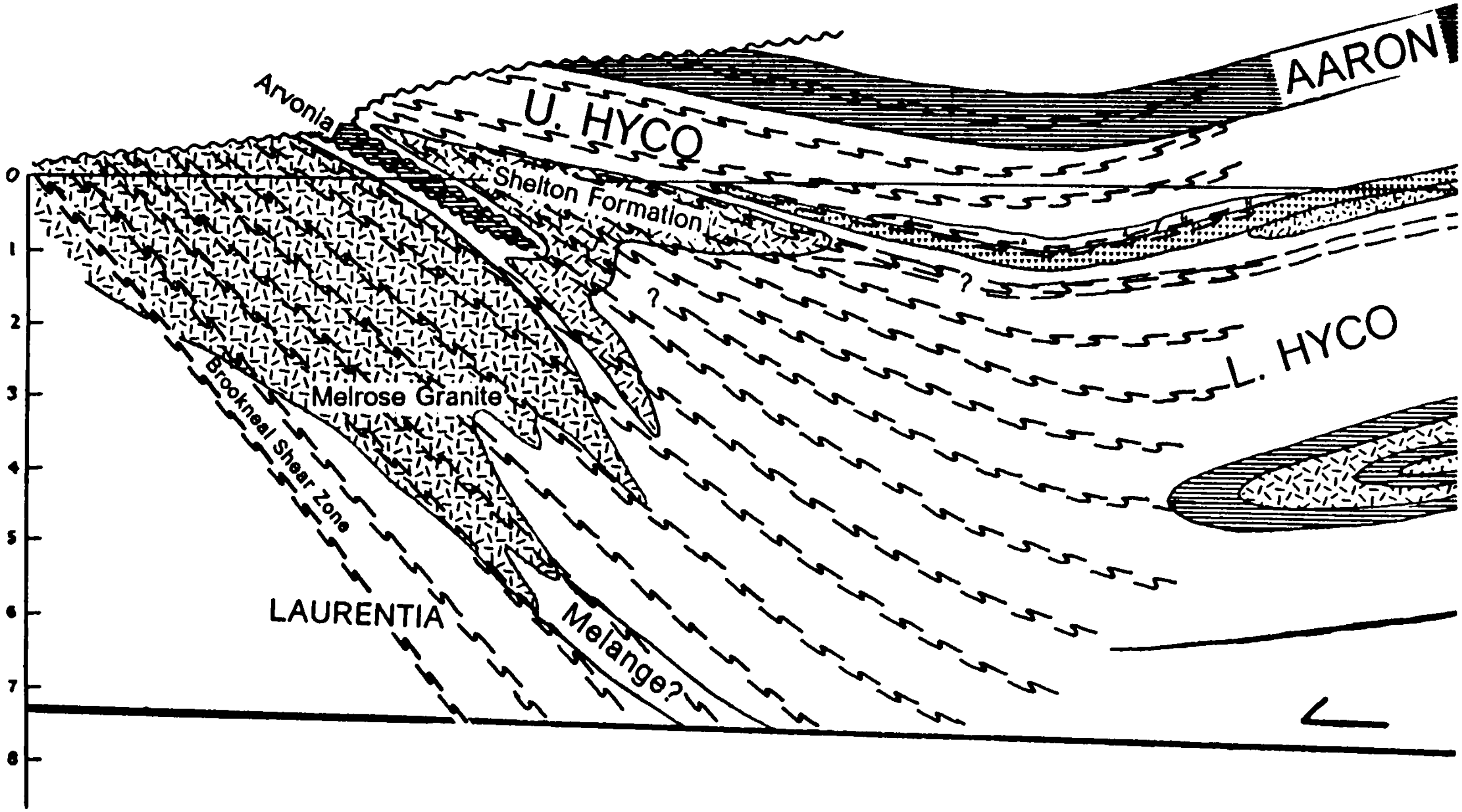

Figure 14: Enlargement of northwest portion of the cross-section in Figure 13 illustrating the interpretation of distributed shear strain adjacent to the Brookneal shear zone. S-shaped symbols parallel the shear planes at any given location.

northwestern block. The northwest-trending set of F_3 axes is interpreted to have formed normal to this component of movement along the zone. In Domain I of Figure 10, the cluster of five data points in the southeast part of the plot represent the axis of folding about which the kinks (labelled K) were folded.

M_2 Metamorphism

The D_3 shearing events took place during M_2 allowing determination of the Alleghanian metamorphic conditions in the area by examination of the Clover and Brookneal shear zones. The M_1 Taconic greenschist/amphibolite isograd lay southeast of the present Charlotte/Carolina slate belt boundary. During the D_3 event, the Clover zone developed across this old isograd, and overprinted both amphibolite and greenschist grade rocks. Shearing took place under greenschist conditions, thus, amphibolite grade M_1 rocks in the zone were retrograded to greenschist, causing the northwest Clover shear zone boundary to coincide with the greenschist/amphibolite boundary (Baird, in preparation). This boundary is not a true isograd because it is a retrograde and not a prograde boundary.

Etheridge and others (1983) have noted that there is evidence from a number of shear zones that fluid flux during retrogression was very large. Rocks within the Clover shear zone could have been retrograded due to such an increased fluid flux. Part of this fluid could have been derived from dewatering of hydrous minerals during the shearing event. Bobyarchick and Glover (1979) noted retrogression of earlier amphibolite material under greenschist grade shearing in the Hylas shear zone. Similarly, Butler and Fullagar (1977) observed that greenschist metamorphism was associated with the shearing along the Gold Hill fault zone in North Carolina.

No evidence of an Alleghanian metamorphic event has been found between the two zones. This could be because the area was still dry from Taconic prograde metamorphism and D_3 shearing did not occur there. Apparently, no outside fluid was added to the area between the zones as may have been the case in the shear zones.

In the Brookneal zone, however, amphibolite M_2 conditions somewhat higher than M_1 prevailed. It is not possible from the available data to say whether M_1 conditions had undergone little decay by M_2 time, or whether the rocks cooled substantially after the Taconic and were reheated during the M_2 event.

D_4 Folding

The character of the present-day Virginia Charlotte belt was complete by the end of Alleghanian D_4 deformation. At that time, a series of large, northeast-trending folds was superposed upon the upright limb of the recumbent fold nappe. This resulted in its final slightly northeast-plunging anticlinorial structure.

Henika (1977) noted that his F_3 structures were the dominant northeast-trending structures. These are equivalent to F_4 here (Table 1). Tobisch and Glover (1971) found two post-nappe fold sets with northwest- and northeast-trending axes, respectively. They interpreted these as a single set of conjugate folds, although no conjugate folds were actually observed. They are probably equivalent to the F_3 and F_4 folds, respectively, found in the present study. Similarly, Kreisa (1980) found in the Charlotte belt an earlier north-trending set of folds, later folded into a major northeast-trending anticline. This also accords well with F_3 and F_4 fold events as found here and by Gates (1987) in the Altavista, Virginia area to the northwest.

CONCLUSIONS

Originally, Carolinia was most likely a microcontinent upon which accumulated a thick pile of volcanic rocks. The Charlotte belt part of the stack was probably already deep and hot with the onset of M_1 metamorphism by the time of the D_1 Virgilina deformation about 600 Ma. Deformation probably produced an S_1 foliation in the deeper (Charlotte belt) material whereas the cooler slate belt rocks did not pick up this foliation.

Collision of Carolinia with Laurentia produced the D_2 Taconic deformation. The lower part of this package, the Charlotte belt, continued to experience M_1 amphibolite grade metamorphism. The upper levels graded into lower amphibolite and greenschist, roughly corresponding to the present Carolina slate belt rocks.

D_2 consisted of the northwestward thrusting of the hot infrastructural Milton nappe beneath a Carolina slate belt suprastructure. Some 15 km of cover probably overlay the slate belt at the time. During nappe formation, the earlier S_1 foliation was folded into F_2 isoclinal folds, producing an S_2 axial plane foliation sub-parallel with S_1. Nappe thrusting resulted in a moderately southwest-dipping S_2 in the Carolina slate belt that bends over a short distance into the sub-horizontal S_2 of the Charlotte belt. The boundary for nappe thrusting was approximately along the thermal divide between amphibolite and greenschist grade metamorphism. This resulted in the Carolina slate belt stratigraphy at much lower grade, but abruptly grading into the amphibolite conditions of the Charlotte belt.

During initial Late Paleozoic D_3 deformation, an S_3 foliation overprinted the preexisting S_2. The S_3 foliation is not regionally pervasive, however, but occurs principally in and near the the Clover and Brookneal shear zones. D_3 is thus demonstrated by the S_3 foliation and by the Brookneal and Clover Shear zones. Alleghanian M_2 metamorphism was somewhat higher in the Brookneal shear zone as in the same area during the Taconic, whereas conditions in the Clover shear zone were somewhat cooler at greenschist grade. D_3 shearing in the Clover zone took place under greenschist conditions, and caused retrogression of amphibolite grade rocks within the zone (Baird, in preparation).

D_4 caused the Charlotte belt to be folded into a number of antiformal and synformal F_4 regional structures with northeast-trending axes, most notably, the large Republican Grove syncline. By that time, the present structure of Carolinia was complete, a gently northeast-plunging anticlinorium, consisting primarily of a large F_2 antiformal nappe upon which were superimposed a series of regional-scale northeast-trending F_4 antiforms and synforms.

Brittle deformation took place during the rifting event associated with the opening of the present-day Atlantic. At that time, several Triassic basins formed in the area, and related Triassic diabase dikes were intruded throughout the area at the time.

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APPENDIX A:

THE THIRD QUASI-ANNUAL

VDMR - VPI&SU

FIELD CONFERENCE

MAY 30-31, 1989

1989 FIELD TRIP GUIDEBOOK
TECTONIC AND GEOLOGIC DEVELOPMENT
OF THE CHARLOTTE BELT
SOUTH CENTRAL VIRGINIA PIEDMONT

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TECTONIC AND GEOLOGIC DEVELOPMENT OF THE CHARLOTTE BELT

SOUTH-CENTRAL VIRGINIA PIEDMONT

BRIEF TECTONIC HISTORY

The western and central Piedmont of south-central Virginia consists of the Charlotte belt and Carolina slate belts on a basement of unknown age. These belts comprise a volcanic arc, Carolinia, which was erupting volcanic material as early as 740 Ma (Glover et al, 1971; Glover, 1989). By about the time of the Late Precambrian rifting of Laurentia (ca. 690 Ma), older formations of the Charlotte belt had begun deposition. Conformably above them accumulated volcanic rocks of the older Carolina slate belt sequence.

At about 600 Ma., Carolinia experienced the D_1 Virgilina deformation, which resulted in tight folding and the uplifting of the area and the formation of an erosion surface (Glover and Sinha, 1973; Harris and Glover, 1985, 1988, and references therein). Local occurrences of an earlier foliation, S_1, throughout the Charlotte belt may be the result of the Virgilina deformation. Alternatively, it may represent an early phase of the Taconic Orogeny. Subsequently, Carolinia began drifting toward the eastern margin of the Laurentian craton. Subsidence allowed for the accumulation of the younger Carolina slate belt volcanic sequence. Up to this time, Carolinia consisted of basement with a relatively undeformed stack of volcanic rocks upon it. Bentonites within the Ordovician carbonates of the Laurentian shelf record the approach of Carolinia.

Taconic D_2 deformation was responsible for the northwestward thrusting of a deep, hot infrastructural Charlotte belt nappe beneath a suprastructural Carolina slate belt sequence. The event folded S_1 into parallelism with S_2. The result was an area of greenschist to lower amphibolite grade Carolina slate belt volcanic rocks with a moderate southeast dip juxtaposed against an area of sub-horizontal middle to upper amphibolite grade Charlotte belt volcanic rocks. Amphibolite grade rocks extended into the area of the present Carolina slate belt based on the occurrence of relict garnet and hornblende there. The gross structure of Carolinia was that of a large recumbent fold nappe. Accompanying the nappe forming event was the intrusion of the 425 Ma. Shelton granite (Kish and others, 1979) into the core of the large F_2 structures (Henika, 1980). The structure of the Charlotte belt and that of the Carolina slate belt grade into one another, and the regional foliation in the belts is S_2.

Throughout the Middle and Late Paleozoic, Africa was approaching North America. This approach resulted in the formation of the eastern Piedmont fault system. At that time, the Brookneal shear zone (Gates et al, 1986) in the northwest portion of the present mapping area, and the Clover shear zone (Baird, 1988), in the southeast portion, formed. Initial imposition of stress caused the development of a local S_3 foliation in and around the Clover and Brookneal shear zones. The shearing overprint allowed retrogression of Taconic amphibolite grade rocks to greenschist facies to take place in the Clover shear zone, which affects the Carolina slate belt rocks. The Charlotte belt/Carolina slate belt boundary is thus the boundary between prograde M_1 amphibolite grade rocks in the Charlotte belt, and retrograde M_2 rocks in the Carolina slate belt.

Within the Clover shear zone, shearing took place along the S_2 foliation, transforming S_2 into shear bands, C, and causing S_3 (S) to rotate into C. The result is a typical S-C mylonite.

Adjacent to the Brookneal shear zone, shear strain was also distributed in the form of slip along the preexisting sub-horizontal S_2 foliation, with the effect that these areas appear to be part of a thrust, rather than a shear, zone.

Final docking and suturing of North America and Africa caused the imposition of a D_4 compressive stress field across eastern North America. At this time, a series of regional scale northeast-trending folds was imposed upon the Charlotte belt portion of Carolinia, producing its present-day anticlinorial structure. Valley and Ridge structures probably formed at about this same time.

Finally, Mesozoic rifting caused the formation of several Triassic basins in the area, and related diabase dikes are common throughout the region.

CHARLOTTE BELT/CAROLINA SLATE BELT STRATIGRAPHY

The basic package of Carolinia stratigraphy consists of dominantly volcanic arc felsic volcanic rocks, with subordinate mafic volcanic rocks and pelites. Lesser amounts of mafic to felsic intrusives are also found. Within a given map unit, small amounts of other rock types usually occur.

The oldest rocks of the area (Figure 1, Plate 1a) are to the southwest in part of the area mapped by Tobisch and Glover (1971), and constitute the core of the nappe structure (Figure 2, Plate 1b). Overlying those are the rocks of the present mapping area. The sequence may be conveniently divided into two portions, bounded by the intrusive Tanyard Branch Granitic Gneiss (Figure 1, Plate 1a). Although the Carolina slate belt Hyco can be mapped directly across the boundary into the Charlotte belt, due to the intervening Tanyard Branch, this portion of the Hyco of the Eastern Charlotte belt and Carolina slate belt cannot be physically connected, at least in the map area, with the rest of the volcanic rocks, also proposed to be Hyco, in the Central Charlotte belt. Based on similarity in both lithology and stratigraphic sequence, however, the rocks of the central Charlotte belt are correlated with those of the eastern Charlotte belt and Carolina slate belt.

Central Charlotte Belt

From oldest to youngest, these units are (1) Lower Hyco Formation - biotite quartz plagioclase gneiss (dacite), with biotite schist, the latter representing distal, finer-grained products of eruption or local epiclastic material, (2) Catawba Creek Amphibolite Member - mafic volcanic rocks, (3) Blackwater Creek Gneiss Member - hornblende dacite volcanic rocks/Ellis Creek Gneiss Member - hornblende tonalite intrusive, (4) Upper Hyco Formation - similar to Lower Hyco, but more biotitic overall, (5) Aaron Formation - muscovite biotite schist unit, (6) Shelton Formation - coarse orthogneiss. (7) Arvonia Formation - graphitic muscovite schist, (8) unmetamorphosed Triassic sedimentary rocks and diabase dikes (Figure 1, Plate 1a).

EXPLANATION

STRATIGRAPHY

Age	Map unit	Description
Triassic	Tr	*Arkose and conglomerate*
Ordovician-Silurian	OSa	*Arvonia Formation*
Ordovician	O(?)tb	*Tanyard Branch Granitic Gneiss*
Ordovician	Os	*Shelton Formation*
Cambrian	Cm	*Melrose Granite*
Cambrian	C(?)ro	*Red Oak Granite*
Late Precambrian	pCv	*Virgilina Formation*
Late Precambrian	pCa	*Aaron Formation*
Late Precambrian	pCuh	*Upper Hyco Formation*
Late Precambrian	pCav	*Altered volcanic rocks* A - Altered
Late Precambrian	pCbc	*Blackwater Creek Gneiss* H - Hornblende-bearing
Late Precambrian	pCec	*Ellis Creek Gneiss*
Late Precambrian	pCcc	*Catawba Creek Amphibolite*
Late Precambrian	pCsmc	*St. Matthews Church Amphibolite*
Late Precambrian	pClh	*Lower Hyco*
Late Precambrian	pCpel	*Pelitic schists*
Late Precambrian	pClv	*Intermediate volcanic rocks*

SYMBOLS

Overturned anticline

Anticlinal axis

Synclinal axis

1:24,000 quadrangle corner

Shear zone boundary

Brittle fault

Lithologic boundary

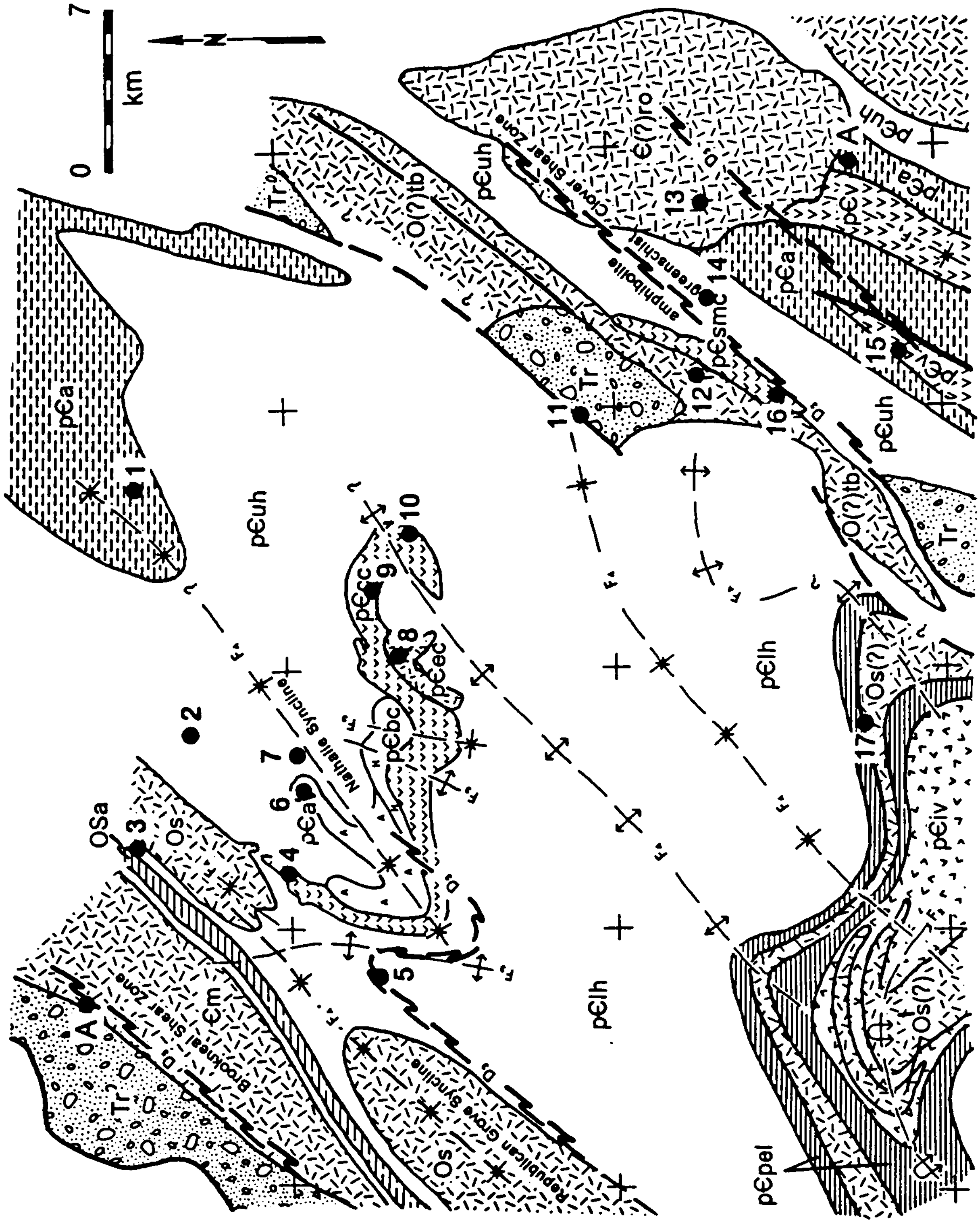

Figure 1: Geologic map of the south central Virginia Piedmont showing field stop locations. All boundaries are approximate. Points A and A′ are end-points of cross-section in Figure 2. Map after field mapping during this investigation, Laney (1917), VDMR (1963), and Tobisch and Glover (1971), and Gates (1981). Explanation on facing page.

Cross-Section A - A'

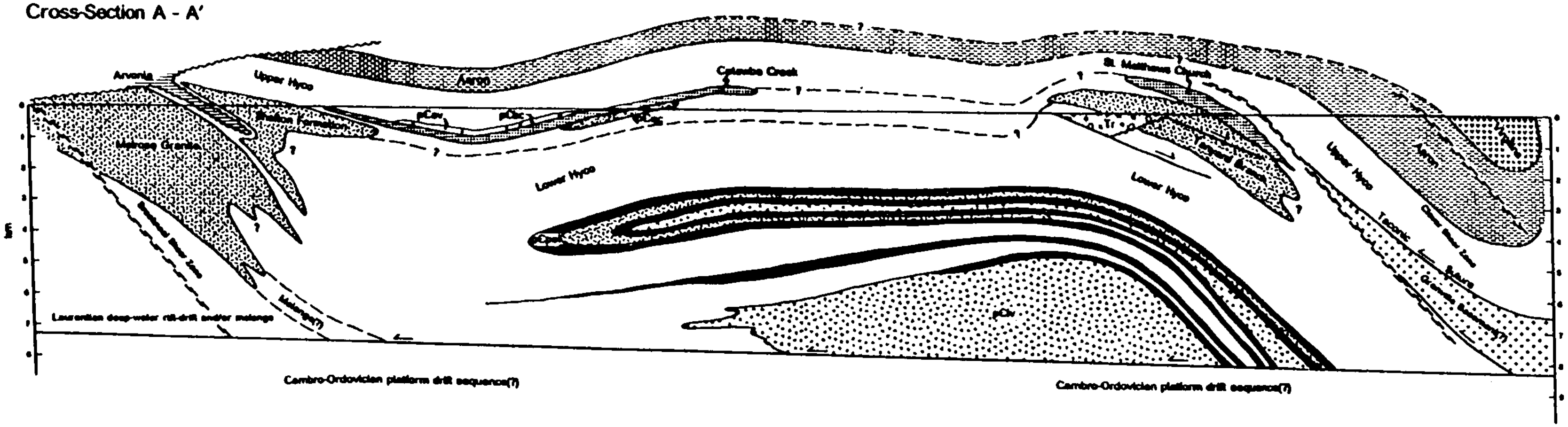

Figure 2: Cross-section across the Milton Nappe. The southeastern boundary of the Brookneal shear zone is not shown so that thin formations in the area may be more readily apparent. See Figure 1 for location of line.

The altered volcanic rocks and the Blackwater Creek Gneiss occur at the same stratigraphic level, and so are approximately coeval. The Ellis Creek Gneiss is probably the intrusive equivalent of the Blackwater Creek Gneiss. Fine-grained mafic xenoliths occur within the Ellis Creek Gneiss and, considering its cross-cutting relationship with the Catawba Creek Amphibolite, are probably fragments of Catawba Creek Amphibolite. An overall increase in biotite content from the Lower through the Upper Hyco may represent migration of arc volcanism away from the depositional area.

Eastern Charlotte Belt and Carolina Slate Belt

From oldest to youngest, the sequence here is (1) St. Matthews Church Amphibolite Member of Hyco - mafic volcanic rocks. (2) Hyco Formation - felsic volcanic rocks, (3) Aaron Formation - felsic volcanic fines and epiclastic pelitic material, (4) Virgilina Formation - greenstone/mafic volcanic rocks, (5) Red Oak Granite, (6) Tanyard Branch Granitic Gneiss (Figure 1, Plate 1a).

Proposed Charlotte Belt/Carolina Slate Belt Correlation

The Lower Hyco of the central Charlotte belt underlies the rest of both the central Charlotte belt and the eastern Charlotte belt/Carolina slate belt sequences. Overlying the Charlotte belt Lower Hyco, the fundamental rock sequence in the central Charlotte belt is (1) the Catawba Creek Amphibolite, (2) the Charlotte belt Upper Hyco, and (3) the Charlotte belt Aaron Formation. Starting with the Lower Hyco again and moving into the eastern Charlotte belt/Carolina slate belt, the sequence is (1) the St. Matthews Church Amphibole, (2) the Carolina slate belt Upper Hyco Formation, and (3) the Carolina slate belt Aaron Formation. The Catawba Creek-Charlotte belt Upper Hyco-Charlotte belt Aaron package of the Central Charlotte belt is thus interpreted as correlating with the St. Matthews Church Amphibolite-Carolina slate belt Upper Hyco-Carolina slate belt Aaron package of the eastern Charlotte belt/Carolina slate belt (Figure 3). Examination of Figure 2 (Plate 1b) shows how consistent this interpretation is with the regional nappe structure as well.

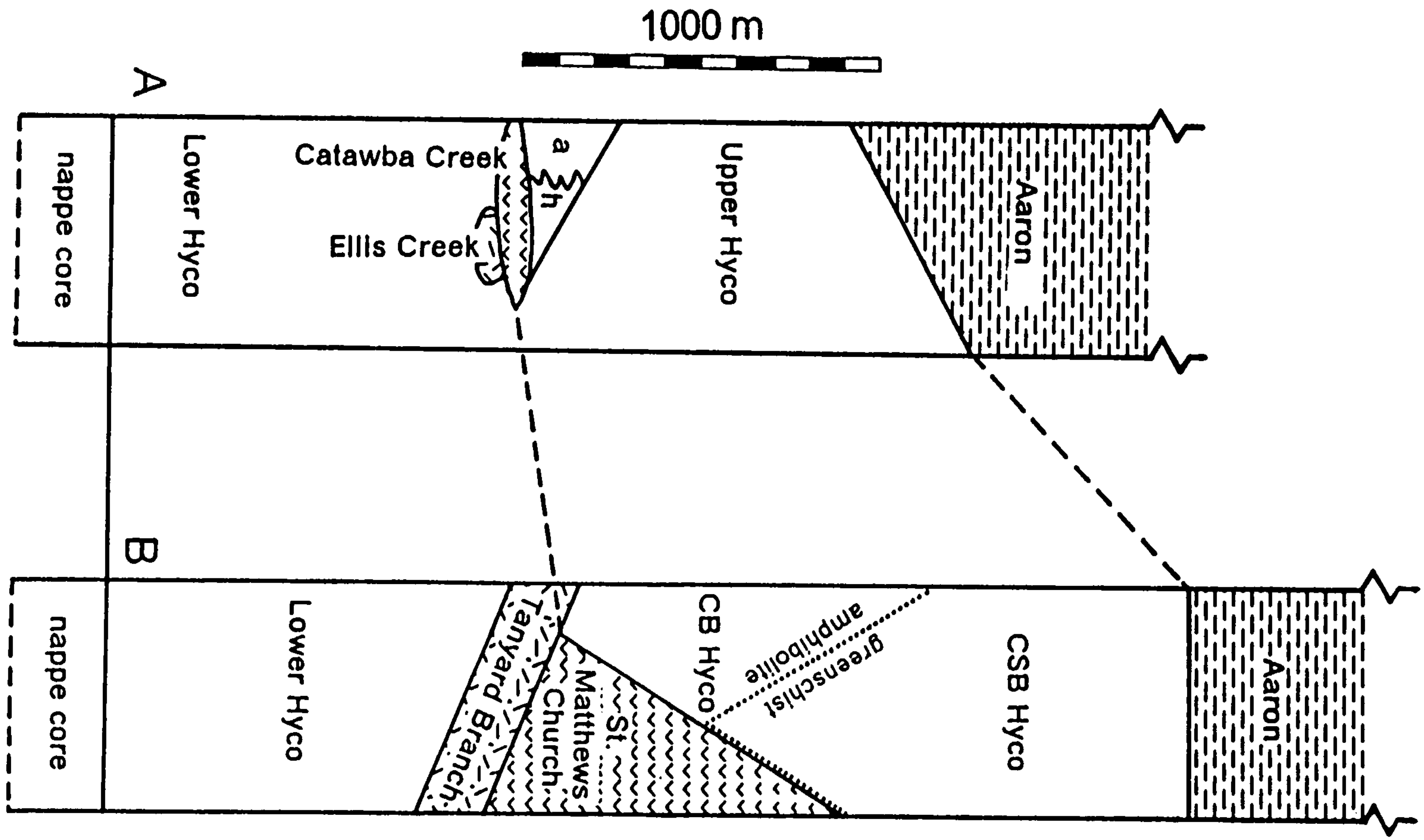

Figure 3: Stratigraphic columns and correlations between (a) the central Charlotte belt and (b) the eastern Charlotte belt and Carolina slate belt. Compare with cross-section in Figure 2.

FIELD TRIP STOPS AND DESCRIPTIONS

The purposes of the field trip are (1) to demonstrate the D_1-D_4 sequence of deformations in the area, and (2) to demonstrate the stratigraphic equivalence between the Charlotte belt and Carolina slate belt sequences. Because outcrops displaying the various features of importance are not in chronologic order with respect to either the stratigraphic or the deformational sequence, and because each stop may exhibit more than one piece of the total picture, it will be necessary for each field trip participant to take note of the features at each stop, and relate them to the objectives as stated and in the conclusions below.

Please refer to Figure 4 for locations of the following stops. The maps at the end of this guide give detailed location information for each stop.

From Highway 40 between Brookneal and Phenix, VA (Aspen Quadrangle), turn south on Highway 617. Stay right on Highway 617 at the "Y" in the road. Stop at the overpass over the Norfolk and Western railroad tracks. Walk down any of the railroad access roads until the railroad tracks can be reached. Large exposures of Aaron Formation biotite schist and gneiss are present.

Stop 1 (RB6-45) - Thrusting related to Brookneal shearing in the Aaron Formation

The Aaron Formation here is typical of this unit. Exposures along this railroad track extend at least to the northeast corner of the Charlotte Court House quadrangle, the next quadrangle over. Mapping of the unit is of a reconnaissance nature only, but it appears on this basis to be fairly extensive.

Close inspection of the schist will reveal the presence of asymmetric feldspar augen indicating that this unit has been sheared. Shearing has occurred along the plane

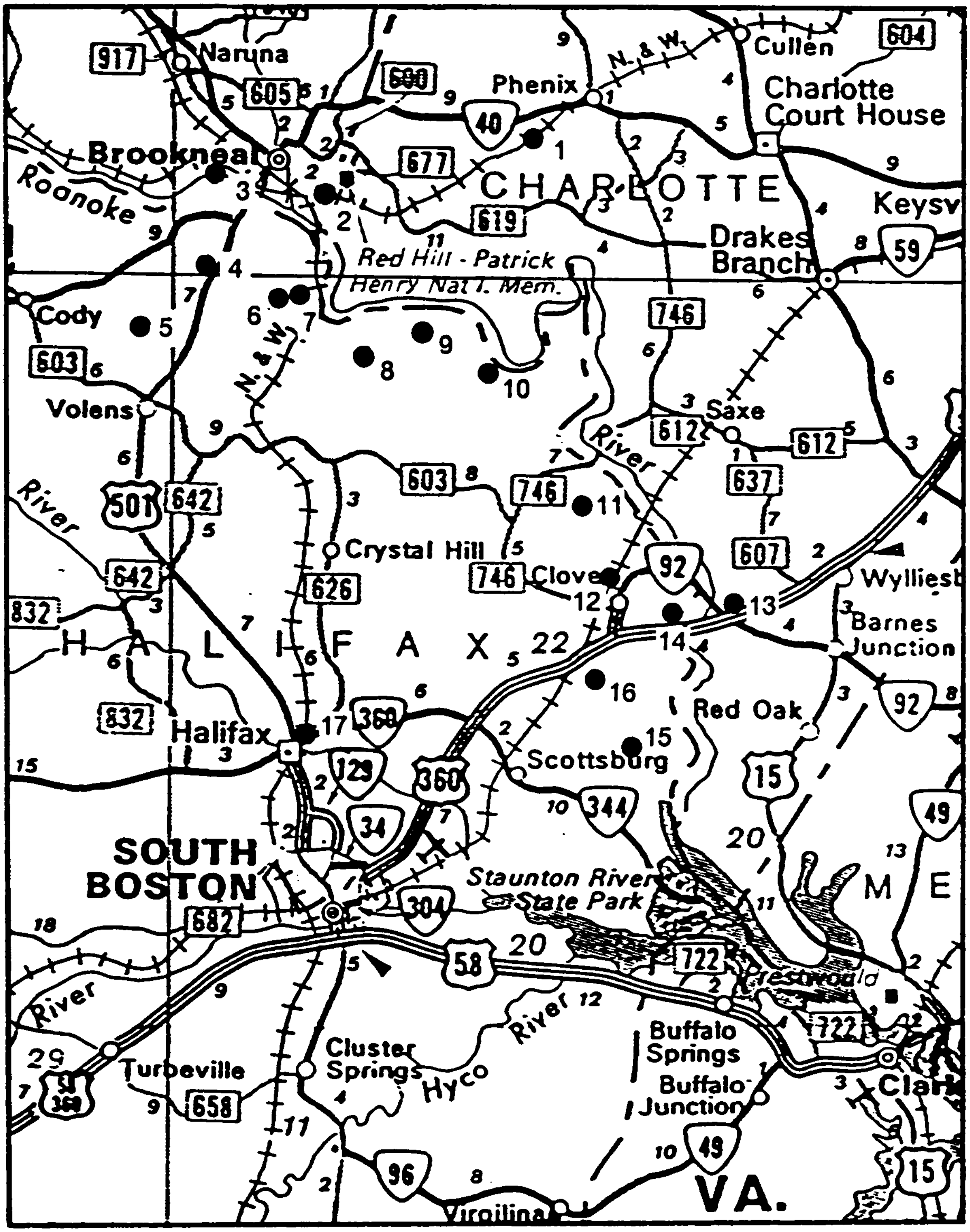

Figure 4: Locations of the field stops on a Virginia highway map.

of the earlier S_2 foliation. Mesoscopic shear sense indicators are also present, such as sigmoidally-shaped aplite stringers. The shear bands here are nearly horizontal, and shearing occurred along the planar anisotropy provided by the earlier S_2 foliation. The shear sense indicators consistently indicate top toward the southwest. According to Gates et al (1986), the Brookneal shear zone in the Melrose Granite to the northwest is oriented at about N40E, 50SE, as contrasted with sub-horizontal here. Regional structure rules out any major flattening of the shear zone, so the interpretation is that part of the strain was partitioned along foliation shearing in the sub-horizontal S_2 layering adjacent to the main Brookneal shear zone (see Figure 5).

Figure 6 shows that the entire 34 km wide Charlotte belt is characterized by a sub-horizontal to gentle S_2 foliation. Hobbs et al (1976) note that there are only two mechanisms whereby such a situation may be produced: (1) A region forms part of the base of a thrust, in which case mylonitic foliation forms parallel to the thrust surface. The intensity of foliation development decreases structurally downward, away from the thrust plane. (2) The region consists of a large recumbent fold nappe, the foliation of which used to be moderate to steep, but has now been rotated to sub-horizontality during thrusting of the nappe. As to mechanism one, the S_2 foliation was already subhorizontal prior to the shearing event, and the intensity of foliation development remains fairly constant over the area. Moreover, there is no evidence of shear strain in the 25 km wide central portion of the Charlotte belt between the two shear zones. Thus, the area is interpreted as a recumbent fold nappe.

Go back to Highway 40 and turn left (west) toward Brookneal. Turn left (south) onto Highway 600 (Brookneal Quadrangle). Turn left (east) onto Highway 619. Bear right on Highway 677. Stop at the home of Patrick Henry. Get permission from the visitor's center to walk down to the Norfolk and Western railroad tracks south of the home. Go northwest along tracks to large railroad cuts through Upper Hyco Formation dacites.

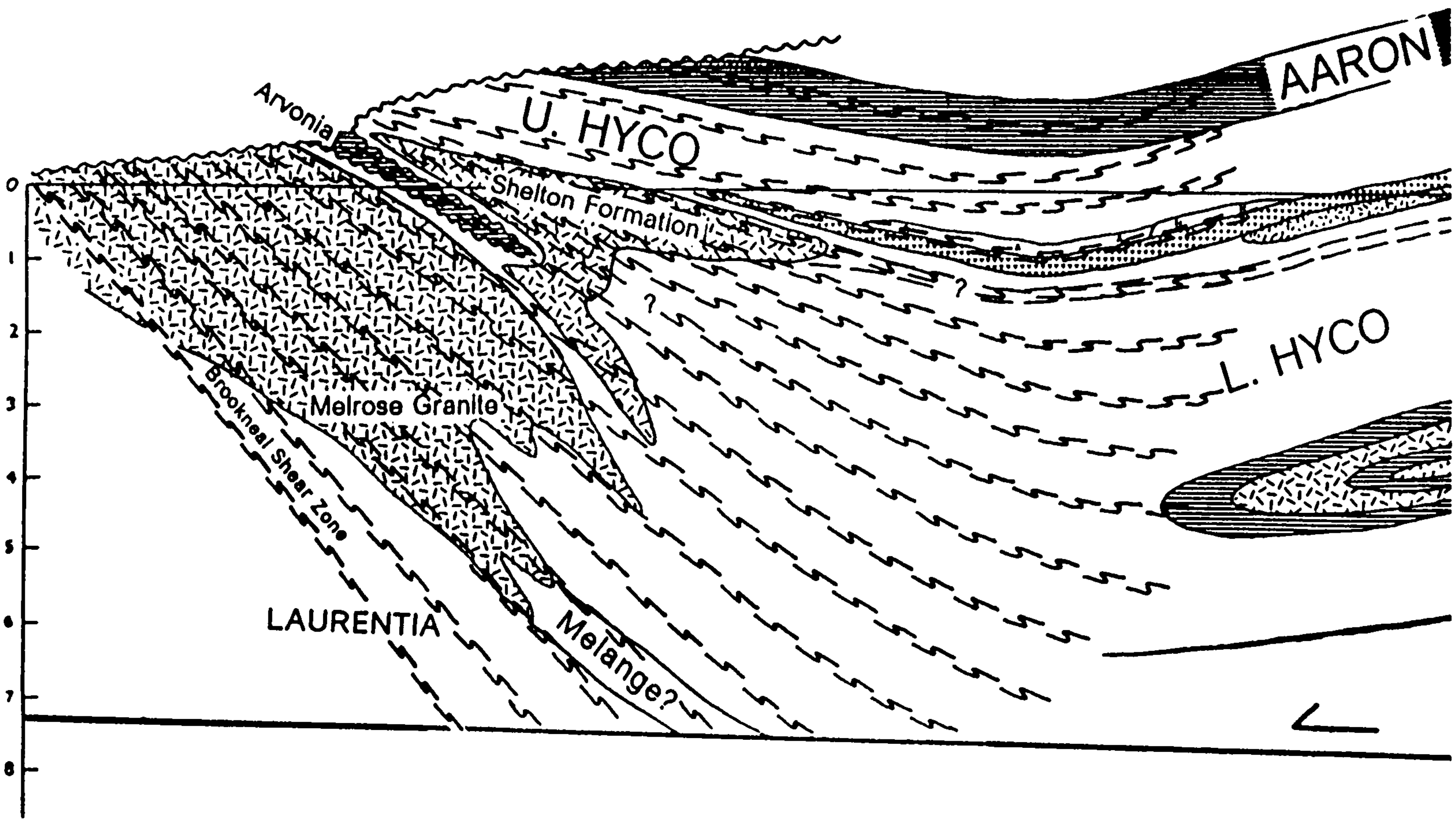

Figure 5: Enlargement of northwest portion of the cross-section in Figure 2 illustrating the interpretation of distributed shear strain adjacent to the Brookneal shear zone. S-shaped symbols parallel the shear plains at any given location.

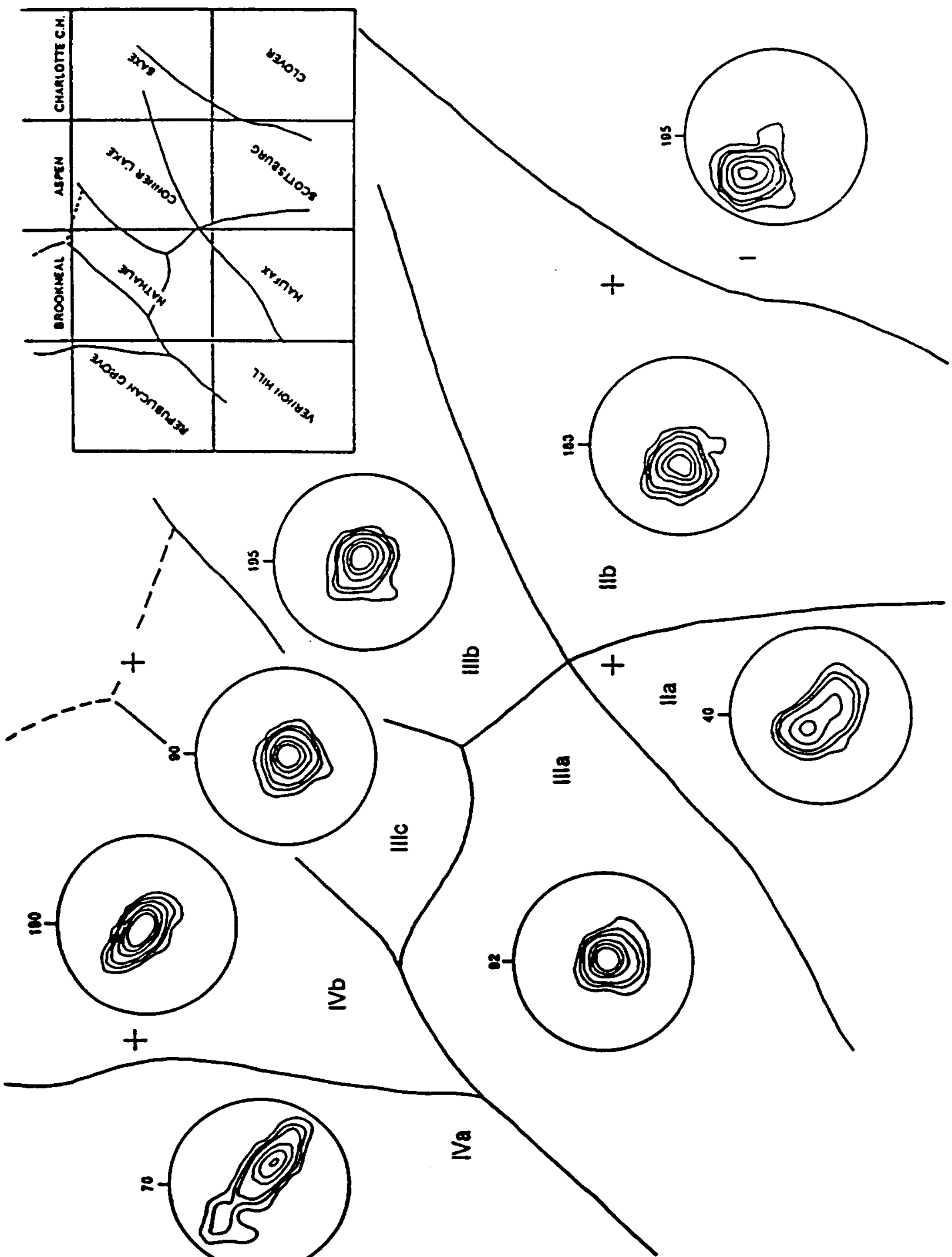

Figure 6: S_2 foliation domains. Sub-horizontal foliation over most of the Charlotte belt is indicative of a large fold nappe structure. Domain I is in the Carolina slate belt and part of the southeasternmost Charlotte belt. Domains II-IV are in the Charlotte belt. Contours are 1, 2, 3, 6, 9, and 12% per 1% area.

Stop 2 (RB6-13) - Reversed Vergence Folds

When a nappe is thrust out from its root zone, shearing along its base or within the nappe itself can completely overturn any folds therein and produce a fold with reversed vergence (see Figure 7).

Based on apparent vergence, the folds here (see Figure 8) appear to have been formed by movement down to the southeast. This is inconsistent with all other structure and tectonics of the area. The actual thrusting direction was up to the northwest, just the opposite of that indicated. The interpretation is that these are reversed vergence folds, and are supporting evidence that the Charlotte belt is part of a large recumbent fold nappe (Figure 2, Plate 1b). The shear strain of this fold is about $\gamma = 7$ by comparison with Figure 7.

From Brookneal, VA, go west on Highway 501 about 0.6 miles from the intersection with Highway 601, and turn south (left) on Highway 928 and cross the Norfolk and Western railroad tracks. Keep straight after crossing the tracks and keep going downhill. The road becomes a dirt road. Continue to stay right as the road branches. There is a large area to park next to the tracks. Excellent exposures of fresh sheared/lineated Shelton Granite are present in railroad cuts to the left (southeast). Up river to the right (southwest) are exposures of sheared graphitic Arvonia schist (Brookneal Quadrangle).

Stop 3 (RB6-11) - Brookneal Shear Zone

This stop along the railroad tracks west of Brookneal are of fresh Shelton Formation, and Arvonia Formation (about 0.3 miles upriver at the bend). The Shelton is a typical S-C mylonite, and is an excellent example of an L-S tectonite. Note the southeast dips of the mylonitic foliation. This is part of the extension of the southeast-dipping northwest limb

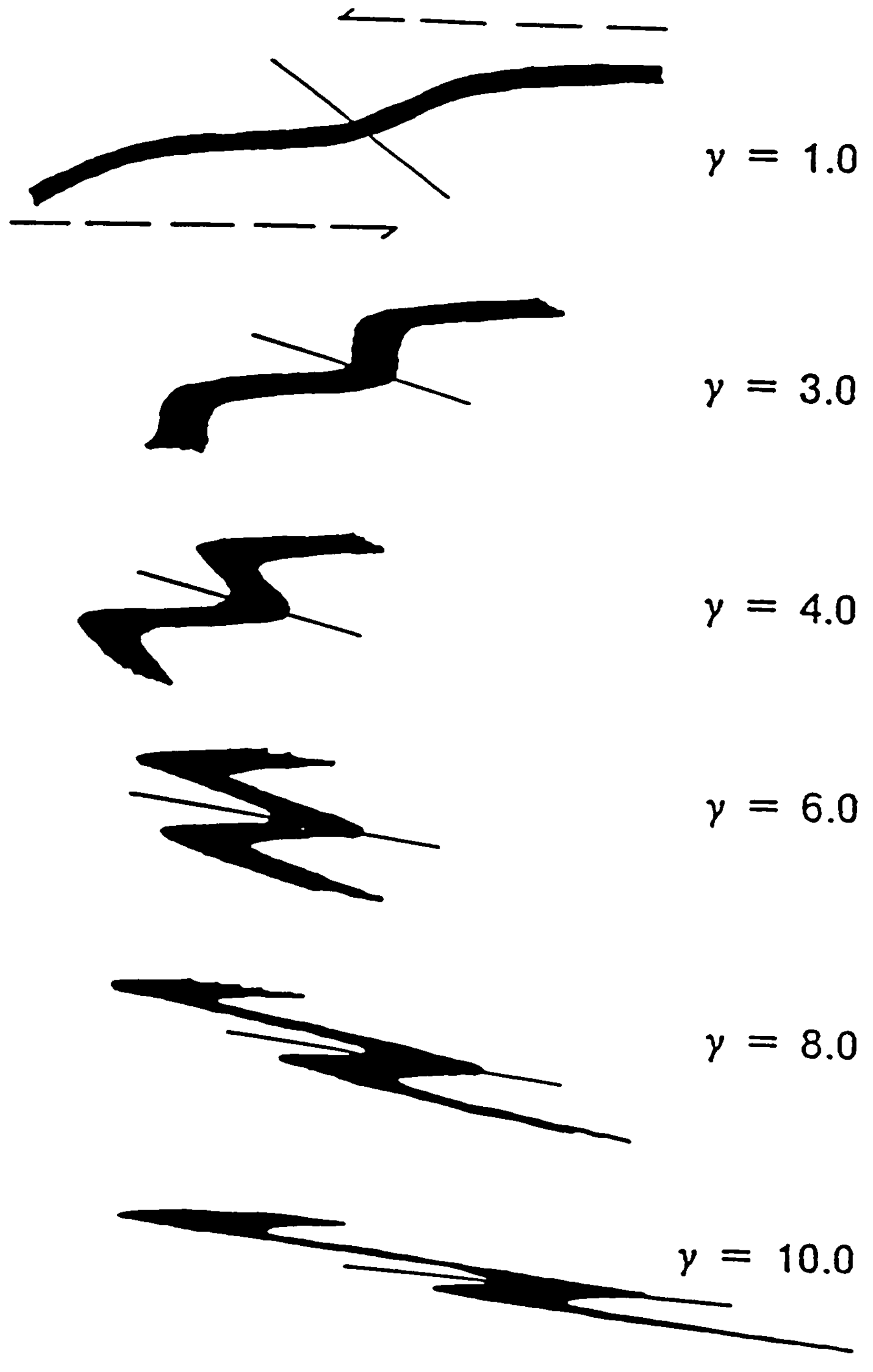

Figure 7: Formation of reversed vergence folding. From Ramsay and others (1983). The folds in Figure 7 appear to have a shear strain of about $\gamma = 7$.

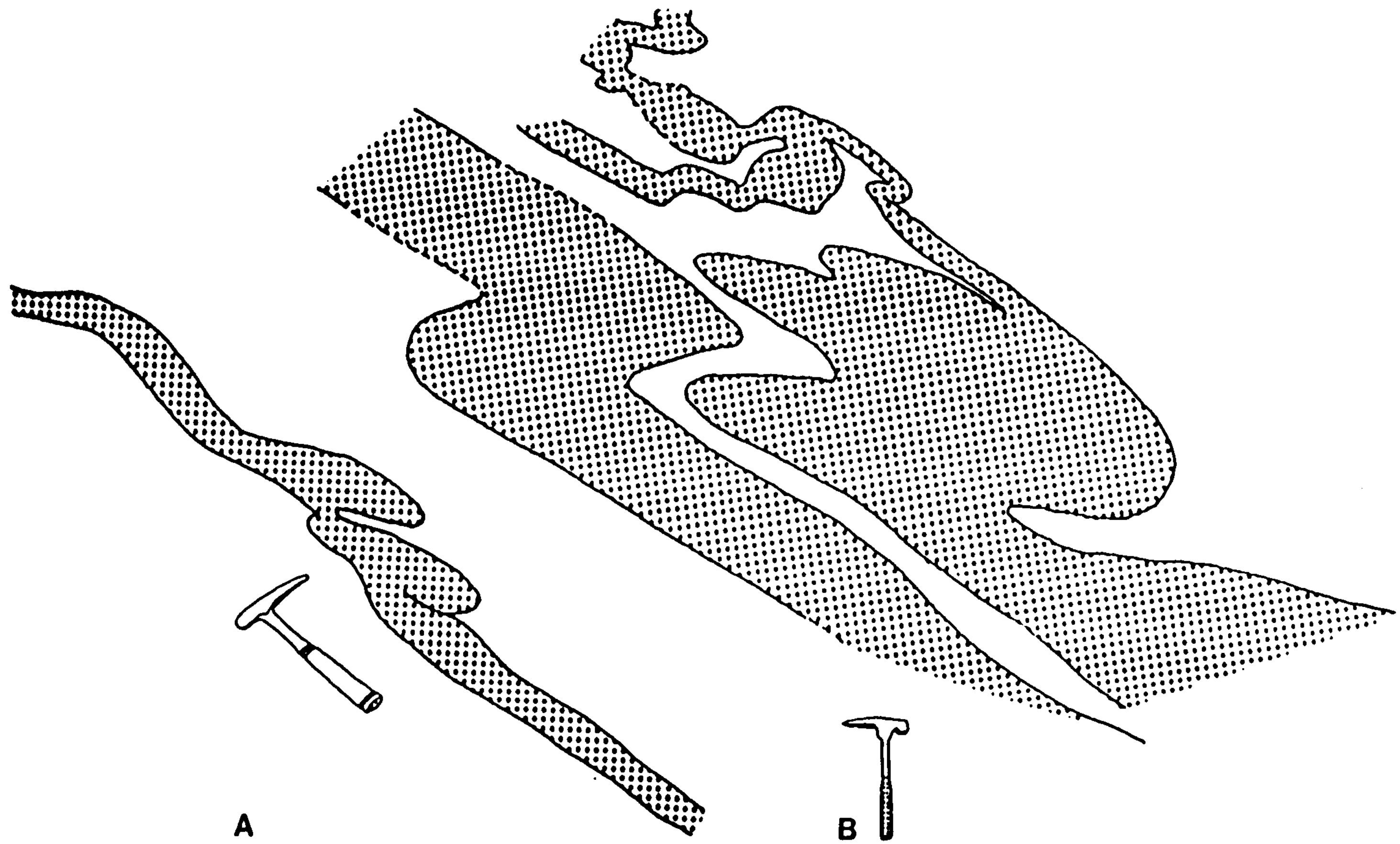

Figure 8: F_2 folds with vergence downward toward the southeast, and interpreted as reversed vergence folds (see Figure 7). Folds in (b) exhibit possible F_1/F_2 interference. Rock is Upper Hyco Formation dacite (dotted) interlayered with more biotitic layers (plain). Hammers in both (a) and (b) are approximately 30 cm in length.

of the Republican Grove syncline. The northwest-dipping southeast limb will be seen at stop 17 (RB7-177).

The moderate (about 30°) southeast dips are of magnitude between the subhorizontal dips at Stop 1 (RB6-45), and the 50° southeast dips found by Gates and others (1986) for the Brookneal shear zone in the Melrose Granite, illustrating partitioning of strain at the southeast margin of the zone.

Go south from Brookneal, VA, over the Roanoke (Staunton) River, and past North Halifax, VA. About 0.3 miles past Highway 638 on the right (northwest), pull off at a dirt road near a gate right before crossing Bentley Creek (Brookneal Quadrangle). Walk down the dirt road a few hundred feet, and turn left (south) onto Bentley Creek (Brookneal Quadrangle).

Stop 4 (RB6-151) - F_1/F_2 folds within the Catawba Creek Amphibolite

Exposures along the creek bed are of lichen covered, but fresh, Catawba Creek Amphibolite with F_2 folds folding S_1 foliation.

Portions of these outcrops are closed F_2 folds. Lichen and weathered coatings make viewing difficult at first, but broken off parts of the crop show the folds nicely. Axial planes of the F_2 folds are parallel with the regional S_2 foliation. L_2 intersection lineations are commonly seen, and are parallel with the F_2 axes. Within the earlier F_1 foliation (light and dark banding), several of the light bands can be seen to have been folded into F_1 isoclines parallel with S_1.

This is one of about 50 localities in the Charlotte belt where the earlier S_1 foliation (light and dark banding) is not parallel to the regional S_2 foliation.

From Stop 4, continue south on Highway 501 about 5 miles to Volens, VA (Republican Grove Quadrangle). Turn right (west) onto Highway 603. Go about a mile and bear right (north) onto Highway 690. Continue about 1.6 miles to a dirt road on the left. Depending on whether a chain is across the dirt road or not, either park along the road here, or turn left onto the dirt road and continue down to where the dirt road crosses the Long Branch of Childrey Creek. The stop is about 800 feet downstream (north).

Stop 5 (RB7-177) - F_4 parasitic folds on the southeast limb of the Republican Grove syncline

As the walk downstream to these crops is made, the Lower Hyco volcanic rocks can be seen, and it will be observed that the rocks all dip toward the northwest. On the other side of the Republican Grove quadrangle, the dip is uniformly to the southeast, as noted at Stop 3 (RB6-11) indicating the synformal nature of the large Republican Grove structure.

Excellent, relatively fresh exposures of rhyolite (plagioclase K-spar quartz gneiss) within the Lower Hyco may be viewed at the stop. Rhyolites are subordinate in both the Lower and Upper Hyco, but become more common in the Upper Hyco.

Exposed here are nice F_4 closed parasitic folds on the southeast limb of the quadrangle-scale Republican Grove syncline. The Republican Grove syncline is so prominent that it can be seen by its topographic expression on the Republican Grove quadrangle map.

Return to Highway 501. Turn left (north) and go for about 3 miles. Turn right onto Highway 626 (Nathalie Quadrangle). After about 1.5 miles, turn left (north) onto Highway 636. After about a mile, bear right onto Highway 634. After about 0.7 miles, stop where the road crosses Little Childrey Creek. Go upstream (south) about 800 feet.

Stop 6 (RB6-179) - Upper Hyco Formation

This stop illustrates the nature of the Upper Hyco dacite (biotite plagioclase quartz gneiss). Some small amphibolite sills(?) can also be seen. The biotite gneiss characterizes the predominant lithology of both the Lower and Upper Hyco.

From Stop 6, continue east on Highway 634, and turn left onto Highway 632. After about 0.6 miles, stop at a lumber company gate on the right. Walk about 400 feet south of road on the path up a low hill, and past an old homesite with a fieldstone chimney still standing (Nathalie Quadrangle). Exposures of hydrothermally altered volcanics are at ground level at the top of the hill. The chimney also consists of altered volcanic gneiss.

Stop 7 (RB6-270) - Hydrothermally Altered Volcanic Rocks

The alteration probably took place near a volcanic center within the original volcanic pile, and may be related to adjacent Blackwater Creek Gneiss volcanism. Circulating hydrothermal waters have leached out nearly all of the feldspars, leaving mostly quartz and some muscovite (originally clay). A few sulfides are present, pyrite, with minor chalcopyrite and sphalerite, and at location RB6-375, the zinc spinel gahnite occurs.

This crop represents the southeastern margin of the rocks affected by Brookneal shearing. The prominent lineation on the cleavage surface is the intersection between the S and C surfaces and, upon close inspection, aligned micas at 90° to the intersection lineation define the direction of shear movement. Only a couple of minor instances of shearing are seen between here and the Clover shear zone some 25 km to the southeast.

Unlike the portion of the Brookneal shear zone to the northwest of here which averages N40E, 50SE for C (Gates et al, 1986), the sheared layered volcanic rocks lie nearly horizontal. The interpretation is the same as that for Stop 1 (RB6-45), that is, (1) that strain related to Brookneal shearing was partitioned along the earlier S_2 foliation planes, and (2) that the sub-horizontal foliation is evidence that the Charlotte belt is a large recumbent fold nappe (see Stop 1 description for more details).

From Stop 7, turn around on Highway 632, and go back (south) to Highway 626 and turn left (east). Continue about 4 miles on 626, and take a left (east) onto Highway 625. Continue about 0.6 miles to Ellis Creek (Conner Lake quadrangle). Parking is either beside the road, or along a dirt road immediately to the right (south). Go downstream (north) about 300 feet for good fresh exposures of Ellis Creek Gneiss.

Stop 8 (RB6-191) - Xenoliths of Catawba Creek Amphibolite in the Ellis Creek Gneiss

The Ellis Creek Gneiss is a coarse-grained hornblende tonalite gneiss. It contains at least three fine-grained mafic xenoliths at this location, one of which is about two feet in diameter. Because of its coarse-grained texture, and because of the presence of xenoliths of another type of rock, it is interpreted to be intrusive. It is stratigraphically close to the similar, but finer-grained volcanic unit, the Blackwater Creek Gneiss, and is probably the intrusive equivalent of it. As the Ellis Creek is intrusive into the Catawba Creek Amphibolite (Figure 1, Plate 1a), the mafic xenoliths are most likely from the Catawba Creek.

Downstream about another hundred feet is a nice exposure of a probable F_2 fold, with northeast-trending axis, and northwest vergence.

Continue southeast on Highway 625 for less than a mile and turn left (northeast) onto Highway 624. Continue for about 1.9 miles. A house is on the left (northwest) at about 1.75 miles. Pull off the road at the dip in the road just past the house (Conner Lake Quadrangle). Follow the depression to the left (north-northeast) of the road until the valley becomes a small creek.

About 1300 feet from the road is the stop. The exposure occurs on the northeastern wall of the stream cut.

Stop 9 (RB6-209; Optional) - F_1 fold hinge in the limb of an F_2 fold

The fold seen here is not very spectacular, and occurs within saprolitic metagabbro, again, a typical Charlotte belt exposure. This metagabbro may be the intrusive equivalent of the Catawba Creek Amphibolite.

Because the rock is a metagabbro with no original S_0, the foliation is interpreted to be dynamothermal. Within the limb of the fold, the layering can be seen to double back into another fold (Figure 9). The intralimb fold is interpreted to be F_1 and the later fold, F_2. The F_2 fold itself is broadly folded around a northeast-trending F_4 axis.

Other evidences for both the D_1 and D_2 events include, for instance, two intersecting cleavages at RB6-363 (not-scheduled) in a granitic stringer. Although no fold hinges are seen there, two cleavages in a rock with no original S_0 also argue for two deformations. Regional cleavages are apparently not related to either D_3 or D_4. S_3 occurs only within the Clover and Brookneal shear zones, and is readily distinguishable from S_2. An S_4 foliation is seen to develop only locally in hinges of F_4 satellite folds on the southeast limb of the Republican Grove syncline.

Continue on Highway 624. After about a mile, the stream makes a sharp bend to the right (south). After about 2 miles, there will be a house on the right (west), and a gravel road to the left (east). Drive down to the end of the dirt road (Conner Lake Quadrangle). Park. Walk east down to the stream, and go downstream (north) to the steep cut bank on the left (west) where the exposures are.

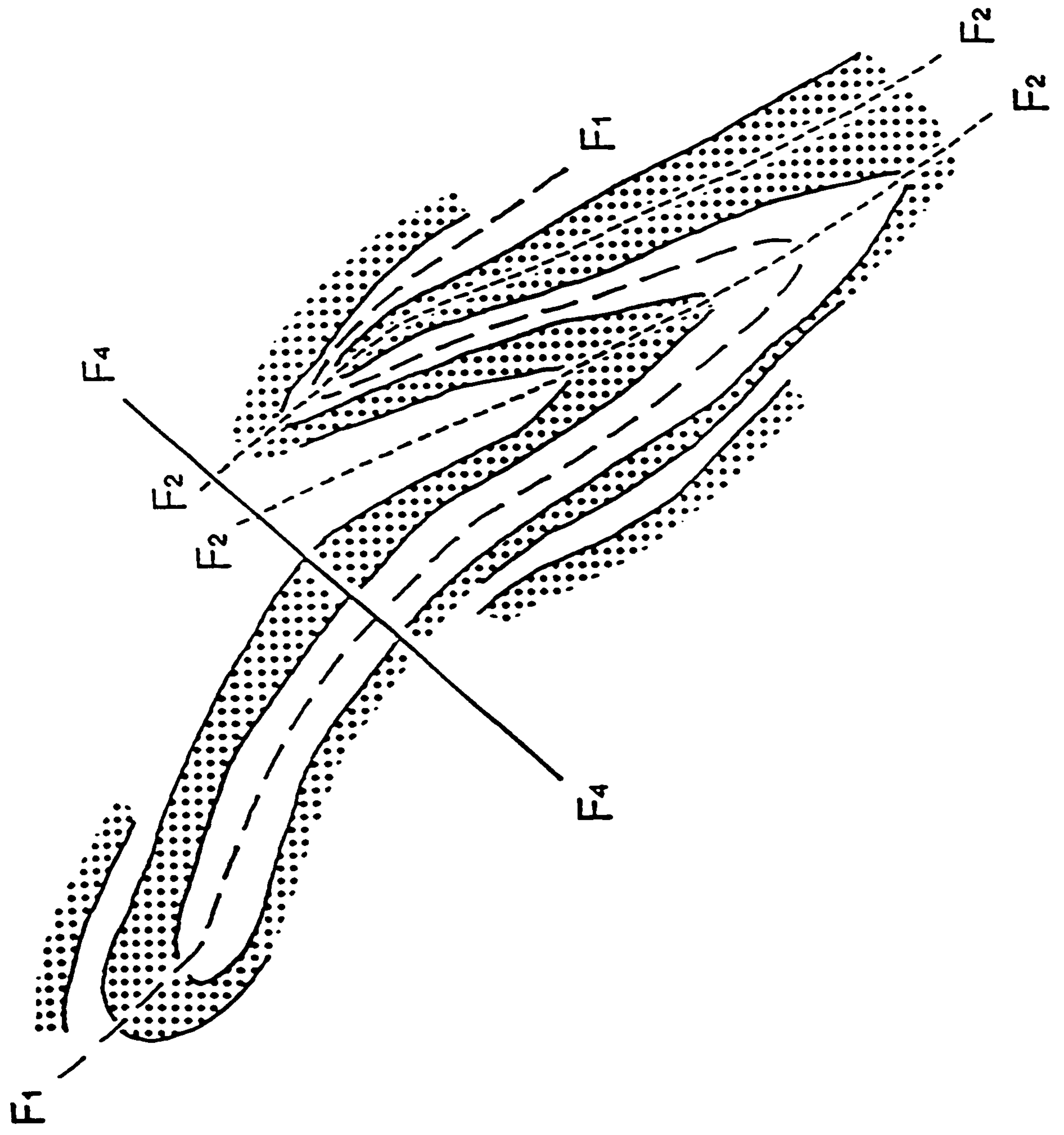

Figure 9: F_1 isoclinal fold refolded by F_2 tight fold. Later F_4 warping is also apparent. Length of fold shown is approximately one meter. Rock is metagabbro with mafic (dotted) and felsic (plain) banding.

Stop 10 (RB6-277) - F_3 folds and S_2 isoclinal folds

This is a somewhat weathered (though good for the Charlotte belt!) outcrop of Catawba Creek Amphibolite with some felsic volcanic interlayers. Nice examples of F_3 folds may be seen.

The vergence of the folds is about N5W, making these F_3 folds. This orientation is quite consistent with orientations of F_3 fold axes found by Gates (1987) to the northwest in Altavista. This illustrates very well the inferred east-west compressive stress field during D_3. Within the S_2 foliation, F_2 isoclines may also be seen.

Continue south on Highway 624 to Providence, VA. Turn right (west). Turn left (east) by the store (on left) at the triangle intersection onto Highway 619. Turn left (east) at the intersection with Highway 603. Continue on 603 to Neals Corner, VA. Continue on 603 about a mile farther to the intersection with Highway 746 at Mt. Laurel, VA. Turn left (northeast). Go about 2 miles to Highway 780. 780 is paved, but shown as unimproved on the topographic map. Go about 0.6 miles or so. Stop where the highway crosses Race Branch (Conner Lake Quadrangle). Go downstream (east). Within a few hundred feet, exposures of cataclasite can be seen, and in about a thousand feet, Triassic conglomerate is exposed.

Stop 11 (RB6-604; RB6-822) - Cataclastic rocks and Triassic conglomerate of the Mt. Laurel basin

Exposures of fractured cataclastic Charlotte belt rocks are seen, related to Mesozoic rifting of Laurentia. Various scales of fracturing can be seen, and quartz veining is common. The rock is a typical cataclasite. Pseudotachylite veins, indicative of paleoseismic faulting, have been found in two localities (not scheduled).

Farther downstream are exposures of red Triassic terrestrial conglomerates containing various Charlotte belt clasts.

Return to Highway 746. Go southwest past Mt. Laurel, VA to the town of Clover, VA. Turn left (north) onto Highway 92 at Clover, and proceed about 0.4 miles. Take the first left (west) turn that crosses the railroad tracks and park at the edge of the field (Clover Quadrangle). Walk east until reaching one of the headwater streams of Black Walnut Creek by crossing the fence. Tanyard Branch Granitic Gneiss can be seen along this creek.

Stop 12 (RB6-681; Optional) - Tanyard Branch Granitic Gneiss

The exposures are small, but the moderately coarse-grained intrusive nature of the rock is evident. The Tanyard is foliated here, but grades to nearly massive at other locations. The foliation is concordant with the regional S_2 foliation, indicating that is is probably a syn- to post-tectonic granite and, as such, may be related to the Shelton. The Tanyard intruded along the zone of weakness near the Charlotte belt/Carolina slate belt boundary.

Go back south on Highway 92 into Clover, VA. Bear left onto Highway 716 that accesses the major Highway 360. Turn left (east) onto 360. Cross the Roanoke River, and go about 1.7 miles farther. Park at the intersection of Highway 92 to the left (northwest). Walk downhill (north) to a small tributary to the Roanoke River. Red Oak Granite is exposed in the stream bed (Clover Quadrangle).

Stop 13 (RB7-155) - Clover shear zone within the Red Oak Granite

This easily accessible portion of stream is within the Clover shear zone portion of the Red Oak Granite, and covers the freshest outcrops within the sheared Red Oak Granite. All other streams examined consist only of pebbly arkosic gravel. A couple of old quarries exhibit only very weathered crumbly material.

The attitude of the sheared rock here is about N30E, 55SE, and is the result of D_3 Alleghanian shearing. C and S bands are discerned with slight effort here, due to the original coarse grained nature of the granite. The rock is mostly sheared, but smaller portions intervene downstream that are nearly undeformed. This leads to the conclusion that large shear zones, such as the Clover zone, actually consist of a series of smaller anastomosing zones.

Go back west on Highway 360. About a mile after crossing the Roanoke River again, turn right (north) onto Highway 715. After about 0.3 miles, stop at the far (northeastern) end of a field, and walk northwest about 700 feet downhill to a tributary to Clover Creek. For the next mile or so along Clover Creek, there are good exposures of sheared Carolina slate belt Upper Hyco Formation (Clover Quadrangle).

Stop 14 (RB6-660) - Clover shear zone within the Hyco Formation

Excellent exposures of sheared Hyco may be viewed along Clover Creek over the next mile-and-a-half or so downstream.

The strikes along the stream are about N31-47E, with dips from 51-69SE. Compare this with the sub-horizontality of the Charlotte belt. In outcrops of the Hyco containing original phenocrysts, asymmetric feldspar augen demonstrate the right-lateral sense of the zone. Shearing was facilitated along the original S_2 foliation because one of the two conjugate planes of shear during Alleghanian compression was oriented an average of only 16° away from the attitude of the S_2 foliation. Average original S_2 foliation for the Clover zone was about N31E, 46SE. As shearing proceeded, S_2 (now C) was rotated toward the conjugate plane of shear to the present average C orientation of N37E, 51SE. Post-shearing kinks are commonly seen in these outcrops, and are themselves rotated about a northwest-trending axis, and are thus a later part of D_3.

Return to Highway 360. Turn right (southwest). Go about 0.7 miles, and turn left (south) onto Highway 716. Continue about 3 miles and bear left onto Highway 719. Continue on 719 an down a steep grade for about 1.3 miles to where the road crosses Difficult Creek. Stop. Within 800 feet upstream from the road, there are several good outcrops of Virgilina Formation greenstone (Clover Quadrangle).

Stop 15 (RB6-767) - Virgilina Formation

Good crops of Virgilina can be seen just west of the road, along Difficult Creek. A variety of Virgilina lithologies can also be seen as float, including rocks with flattened lapilli, etc. In thin-section, the Virgilina can be seen to be somewhat sheared with rotated epidote porphyroblasts, indicating that this is still within the Clover shear zone.

Return to Highway 360. Turn left (southwest) and proceed about 1.5 miles. Turn left (south) onto an unimproved road, and continue about 0.4 miles. Stop and walk to the left, south of a large pond, about 1000 feet down to Opossum Branch (Clover Quadrangle). Fair exposures of St. Matthews Church Amphibolite may be seen.

Stop 16 (RB6-725; Optional) - St. Matthews Church Amphibolite

This hornblende amphibolite occurs just northwest of the Charlotte belt/Carolina slate belt boundary. Immediately southeast of this boundary can be seen epidotes containing local relict hornblende cores. Farther southeast, no hornblende is seen at all. Furthermore, the Charlotte belt/Carolina slate belt boundary coincides with the northwestern Clover shear zone boundary. This indicates that the nature of the boundary is merely a metamorphic one related to the shearing.

Return to Highway 360. Turn left (southwest), and proceed about 10 miles to where 360 goes over a railroad (0.45 miles before crossing the Bannister River; Halifax Quadrangle). Pull off into the front yard of an abandoned house to the right (north). Walk about 200 feet east down to the railroad track. An excellent example of a core structure in granite can be seen.

Stop 17 (RB7-211; Optional) - Core Structure

As a granite cools, it often develops orthorhombic joint sets due to contraction. Later, percolating groundwater can attack the granite along these joints and begin to weather the cubic blocks into more rounded shapes. The process is called spheroidal weathering, and forms a core structure. Often the structure is seen by concentric color bands representing chemical changes across the block. This is the best example of a core structure ever seen by the author, either in outcrop or photograph, as the bands actually stand out in relief. It is oval in shape, being about 8 feet by 16 feet, and occurs within a medium-grained granitic gneiss, similar to, and possibly related to, the Tanyard Branch granitic gneiss.

CONCLUSIONS

The major conclusions from the study of the Charlotte belt/Carolina slate belt of this area are as follows.

(1) The central Charlotte belt and the eastern Charlotte belt/Carolina slate belt have similar lithologies and stratigraphic sequences (Figure 3). These sequences are considered as correlative.

(2) The Charlotte belt shows evidence for four deformational events. Reasoning for this is as follows. There is a regional foliation across the area. Locally, an earlier foliation is

found. The earlier foliation is named S_1, and is interpreted as having resulted from a D_1 event. This makes the later regional foliation an S_2, resulting from a D_2 event. Shearing in the Brookneal and Clover shear zones affects the earlier D_2 fabrics and, as such, is D_3 Regional scale folding affects the earlier D_2 and D_3 fabrics and is assigned to a D_4 event.

(3) The structure of the Charlotte belt is that of a large recumbent fold nappe (Figure 2, Plate 1b). This is based on (a) the 34 km wide area of Charlotte belt with sub-horizontal foliation, and (b) local occurrences of reverse vergence folds.

Minor conclusions of the study are:

(1) A component of strain related to Brookneal shearing is distributed as foliation slip along the sub-horizontal foliation adjacent to the zone.

(2) A Later Paleozoic dextral shear zone. the Clover shear zone, is described. The D_3 Clover shear zone formed under M_2 greenschist grade conditions, and overprinted and retrograded earlier M_1 Taconic amphibolite grade rocks in the area of the zone. Thus, the boundary between the Charlotte belt and Carolina slate belt is the boundary between M_1 prograde amphibolite grade rocks and M_2 retrograde greenschist grade rocks.

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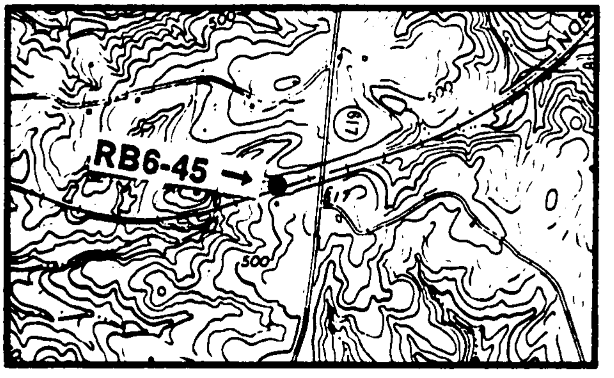
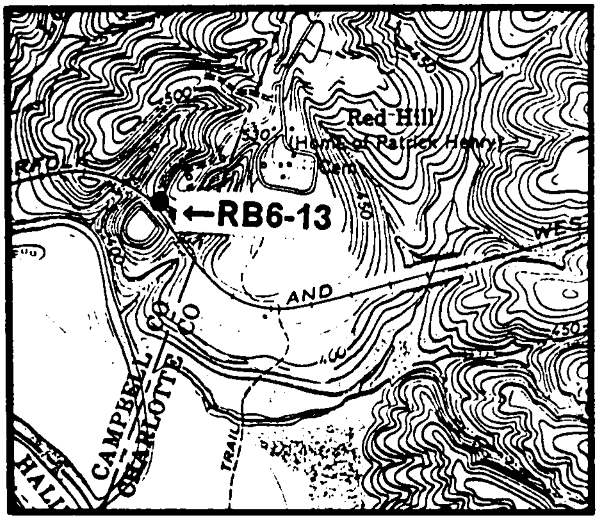
DETAILED FIELD STOP LOCATIONS

Stop 1 (RB6-45) -
Aaron Formation muscovite biotite schist in the Charlotte belt. Foliation is gentle. Along-foliation shearing has occurred related to shearing on the adjacent Brookneal shear zone. **(Aspen Quadrangle).**

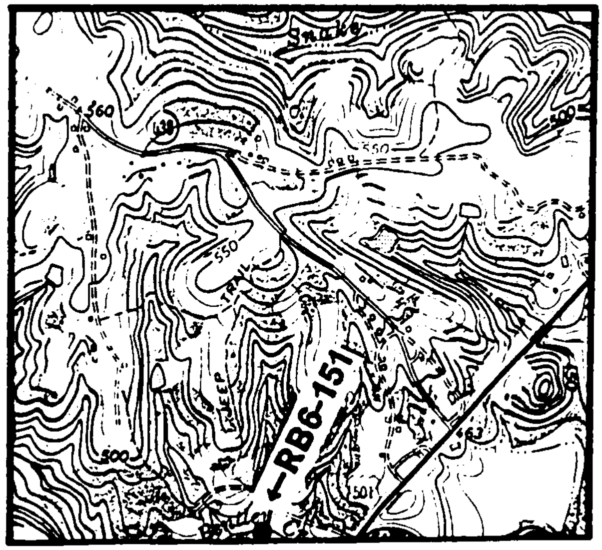


Stop 2 (RB6-13) -
Reversed vergence S_2 folds related to D_2 nappe thrusting. **(Brookneal Quadrangle).**

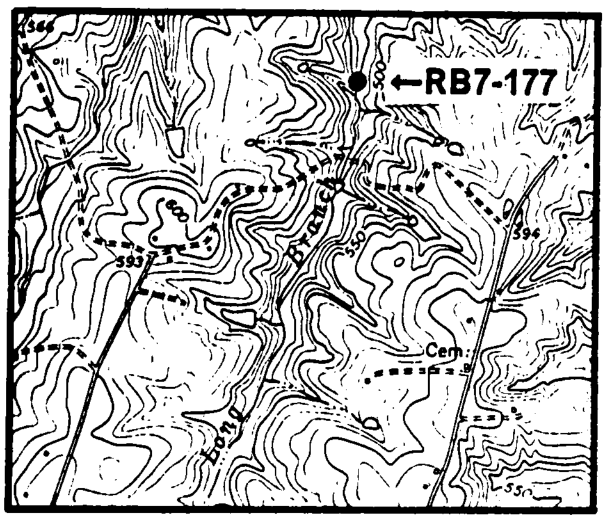


Stop 3 (RB6-11) -
Brookneal shear zone. Good exposures of sheared Shelton granite and Arvonia schist. (Brookneal Quadrangle).

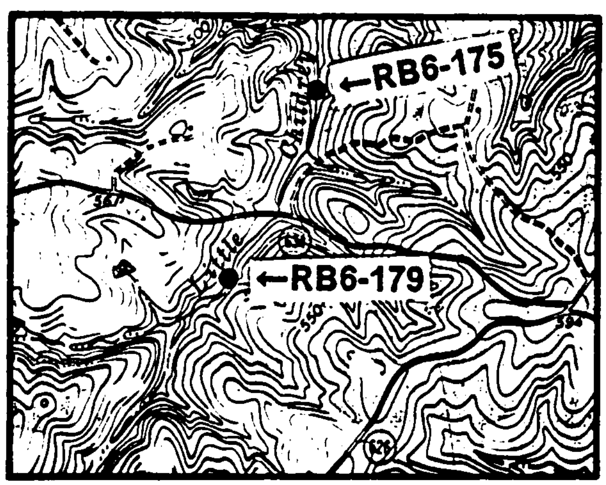
Stop 4 (RB6-151) -
F_2 folds in the Catawba Creek Amphibolite. Outcrop exhibits good S_1 and S_2 foliations, and the intersection lineation, L_2. (Brookneal Quadrangle).



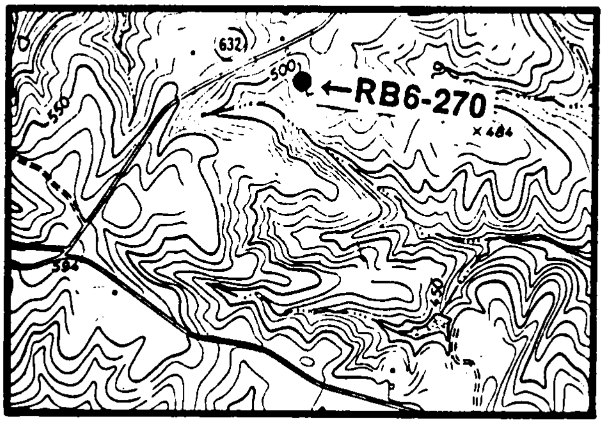
Stop 5 (RB7-177) -
F_4 parasitic folds in Lower Hyco rhyolite on the southeast limb of the Republican Grove Syncline. (Republican Grove Quadrangle).



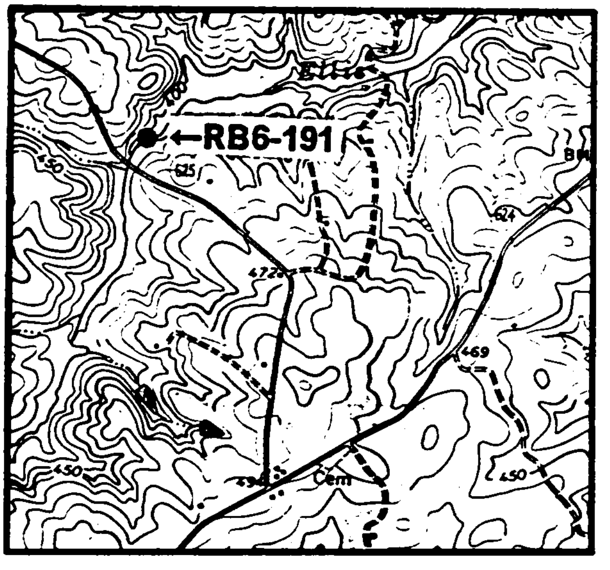
Stop 6 (RB6-179) -
Dacite of the Charlotte belt Upper Hyco Formation. (Nathalie Quadrangle).



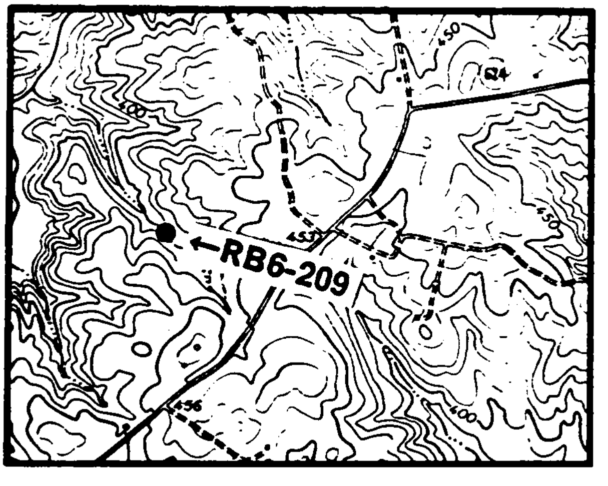
Stop 7 (RB6-270) -
Hydrothermally altered Upper Hyco volcanic rocks. (Nathalie Quadrangle).



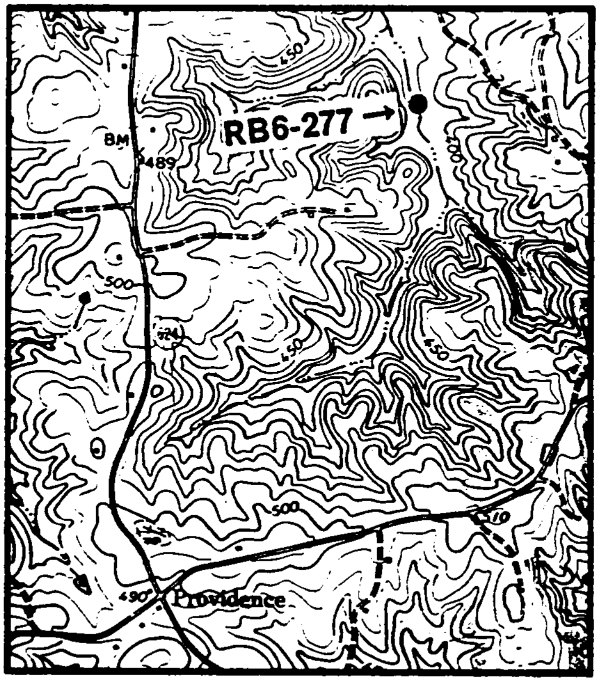
Stop 8 (RB6-191) -
Xenoliths of Catawba Creek Amphibolite in the Ellis Creek Gneiss. Farther downstream is exposure of an F_2 fold. (Conner Lake Quadrangle).



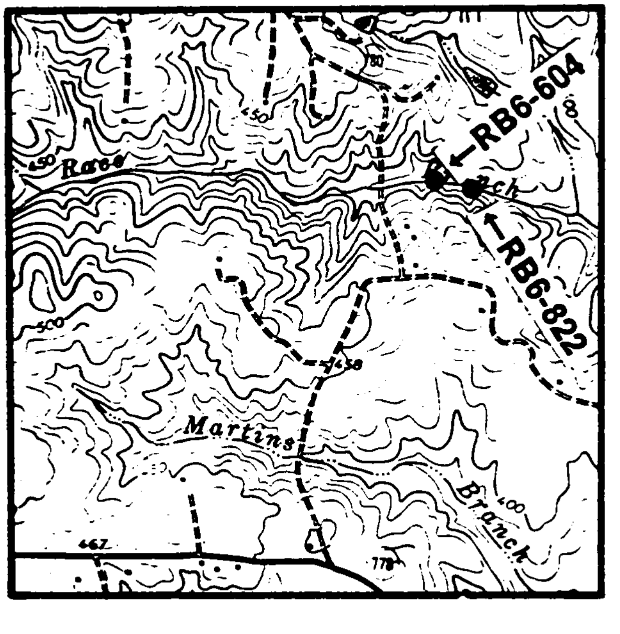
Stop 9 (RB6-209) -
F_1 in limb of an F_2 fold. (Conner Lake Quadrangle).



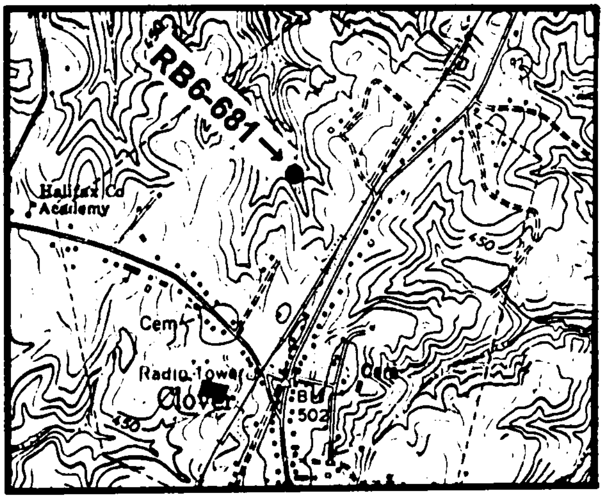
Stop 10 (RB6-277) -
F_3 fold. (Conner Lake Quadrangle).



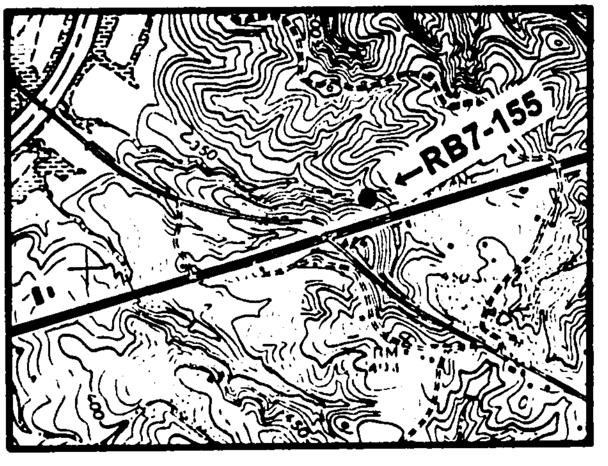
Stop 11 (RB6-604; RB6-822) -
Cataclastic rocks and Triassic conglomerate of the Mt. Laurel Triassic basin. (Conner Lake Quadrangle).



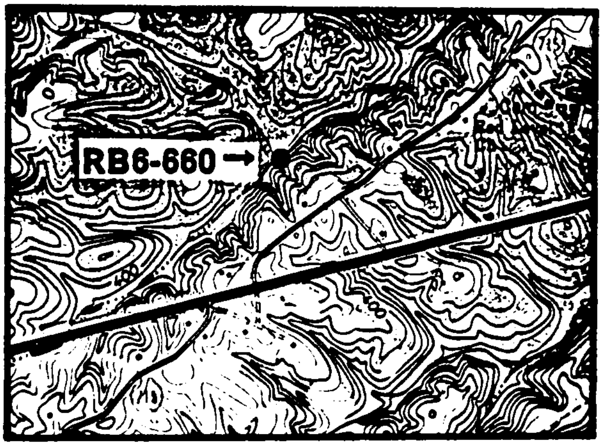
Stop 12 (RB6-681) -
Tanyard Branch Granitic Gneiss. (Clover Quadrangle).



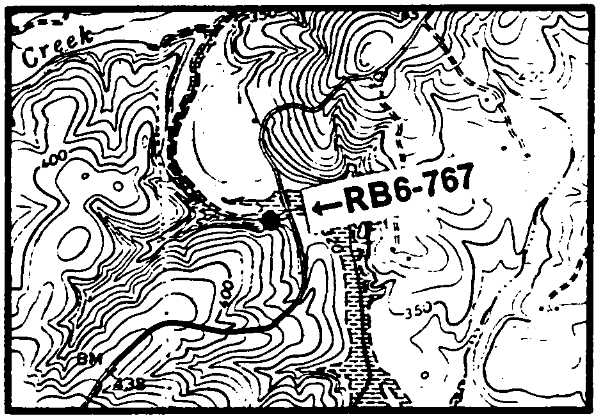
Stop 13 (RB7-155) -
Clover shear zone within the Red Oak Granite. (Clover Quadrangle).



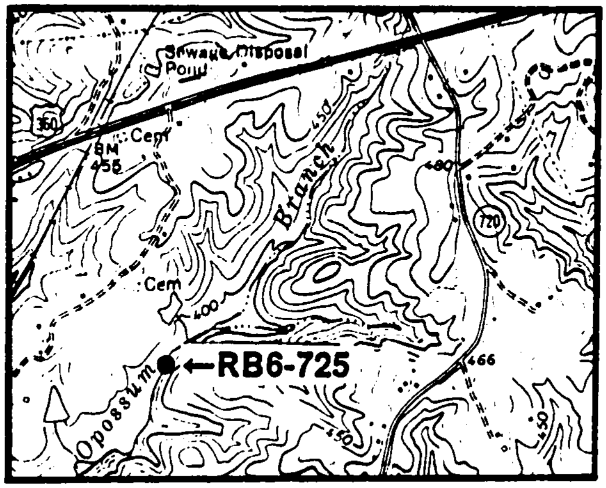
Stop 14 (RB6-660) -
Clover shear zone within the Upper Hyco Formation of the Carolina slate belt. (Clover Quadrangle).



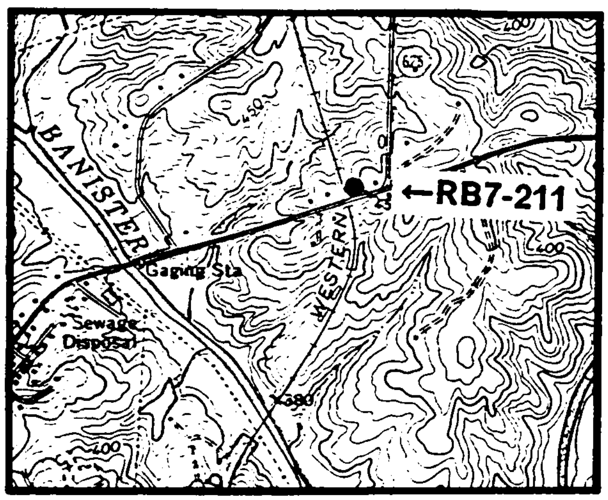
Stop 15 (RB6-767) -
Virgilina Formation. (Clover Quadrangle).



Stop 16 (RB6-725) -
St. Matthews Church Amphibolite. (Clover Quadrangle).



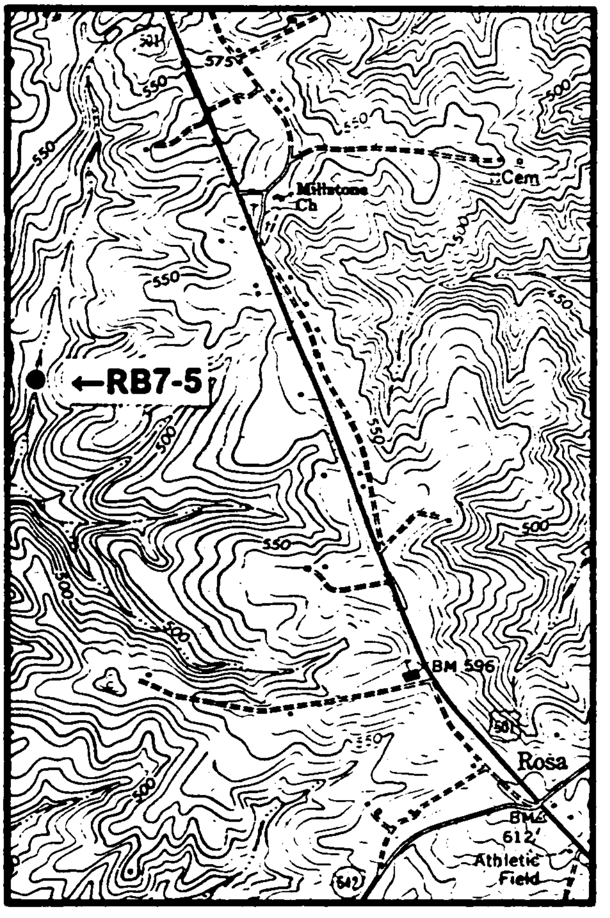
Stop 17 (RB7-211) -
Core structure in granite gneiss similar to the Tanyard Branch. (Halifax Quadrangle).



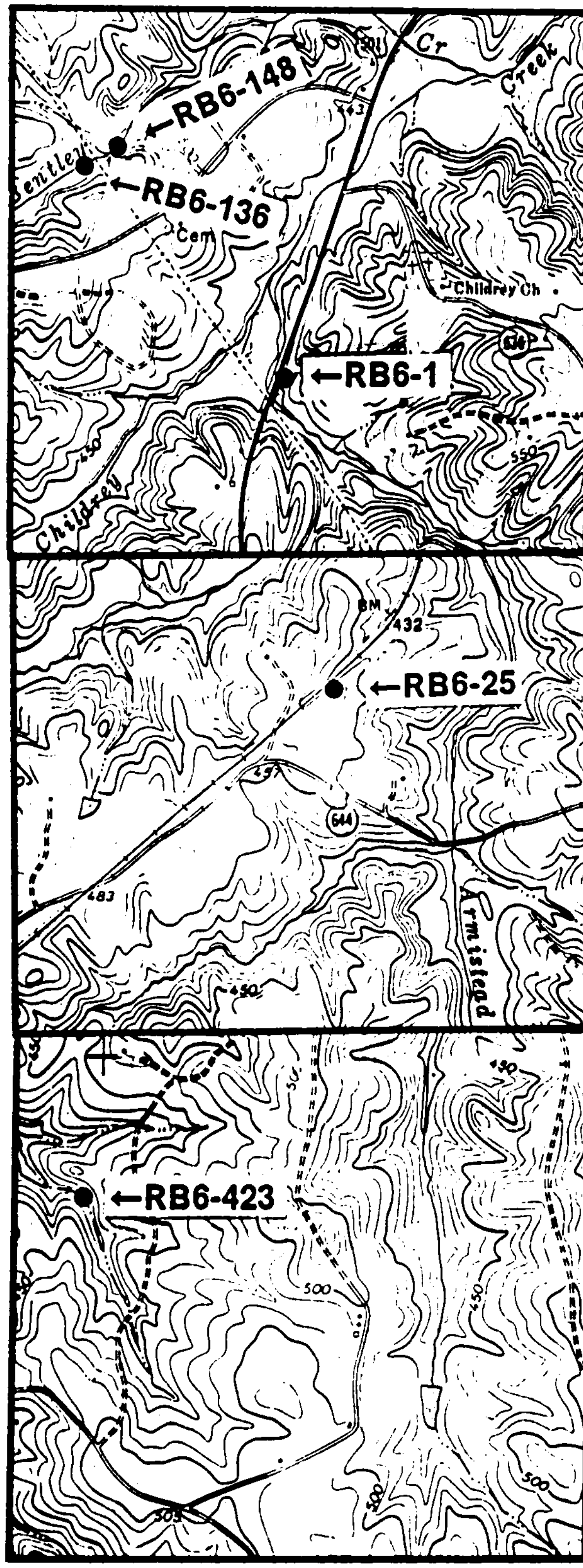
APPENDIX 2
DETAILED SAMPLE LOCATIONS FOR CHARLOTTE BELT CHEMICAL ANALYSES

LOWER HYCO FORMATION RHYOLITE

RB7-5 -
From Rosa, Virginia (Vernon Hill Quadrangle), go about a mile north on Highway 501. Sample location is on a tributary to the Banister River about 0.5 miles west of the highway.



CATAWBA CREEK AMPHIBOLITE MEMBER OF THE HYCO FORMATION



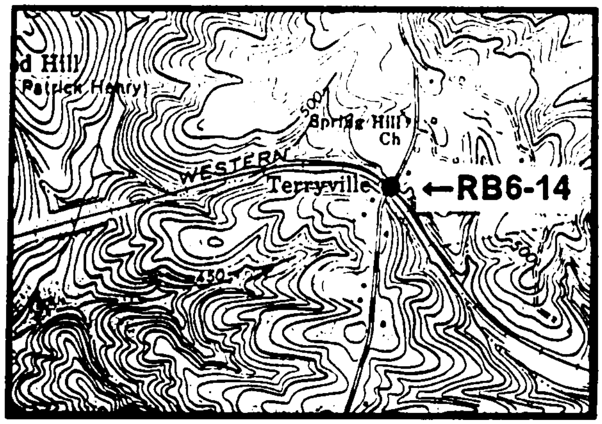
RB6-1 -
Sample location is on the east side of Highway 501 (Nathalie Quadrangle) about 5 miles south of Brookneal, Virginia.

RB6-25 -
About 1.4 miles north of Nathalie, Virginia (Nathalie Quadrangle) along Highway 644, the road makes a bend to the right (southeast). An unimproved road bears off to the left (north) across the Norfolk and Western railroad tracks. The outcrop is in a railroad cut on the right (southeast) side of the tracks about 700 feet northeast of where the unimproved road crosses the railroad track.

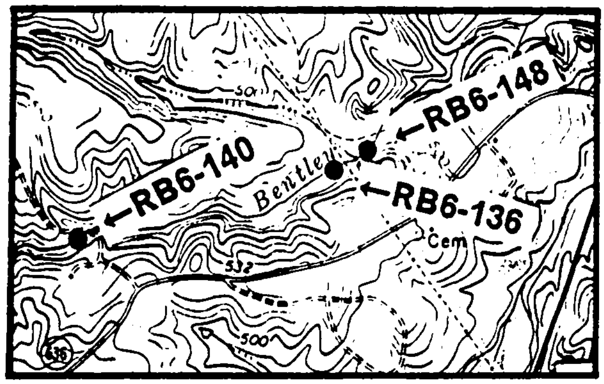
RB6-423 -
About 2.3 miles north of Nathalie, Virginia (Nathalie Quadrangle) along Highway 644, there is an unimproved road to the left. At about 0.3 miles from Highway 644 along the unimproved road, there is a stream. The outcrop is about 1300 feet downstream from the road.

UPPER HYCO FORMATION DACITE

RB6-14 -
From Brookneal, Virginia, take Highway 40 east. Bear right onto Highway 600 after crossing the Falling River. After about 2.3 miles, bear right onto Highway 619. After another 2.3 miles, Highway 619 makes an overpass over the Norfolk and Western railroad tracks. The railroad cut is one of the best in the area with extensive exposures of rock.

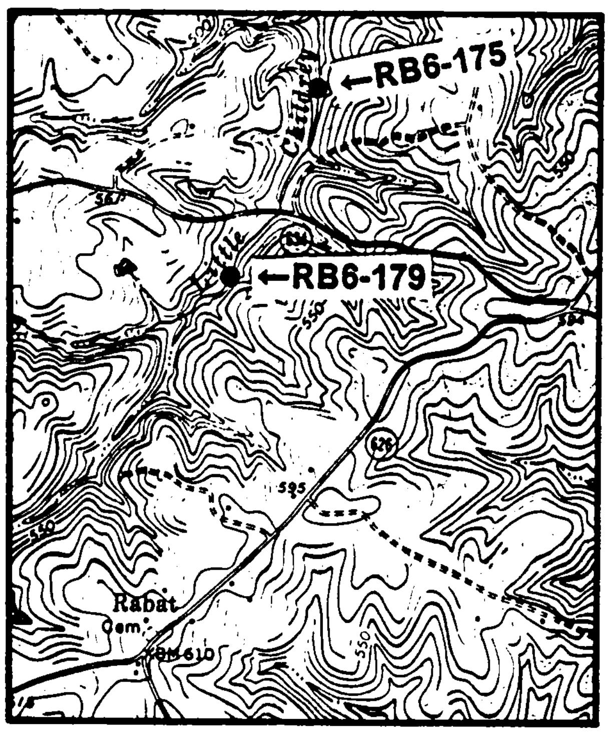


RB6-140 -
Just inside the Nathalie Quadrangle on Highway 501, about 4.4 miles south of Brookneal, Virginia, go west onto Highway 636 for about a mile. Unimproved road on the right (northwest) leads to Bentley Creek. Sample is from outcrops just upstream from where the unimproved road crosses the creek.

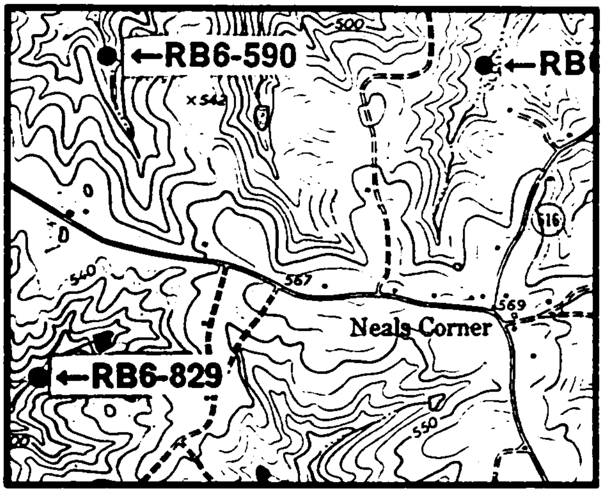


RB6-175 -
Go on Highway 501 about 4.6 miles south of Brookneal, Virginia. Take a left (east) onto Highway 636 (Nathalie Quadrangle). After about 1.2 miles, bear left onto Highway 633/634. After another 0.5 miles, bear right onto Highway 634. Go another 0.7 miles, and stop where the road crosses Little Childrey Creek. Outcrop sampled is about 1300 feet downstream.

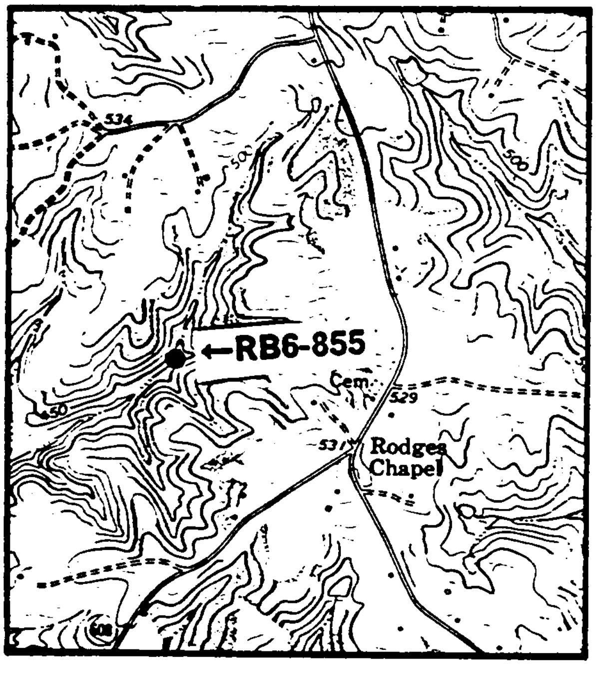
RB6-179 -
Follow directions for RB6-175 to Childrey Creek and Highway 634. Go about 900 feet upstream to outcrops.



RB6-590 -
From Neals Corner, Virginia, go about 0.7 miles to the west on Highway 603. Walk north into the woods until the depression becomes a stream. Outcrops are about 2000 feet from the road.

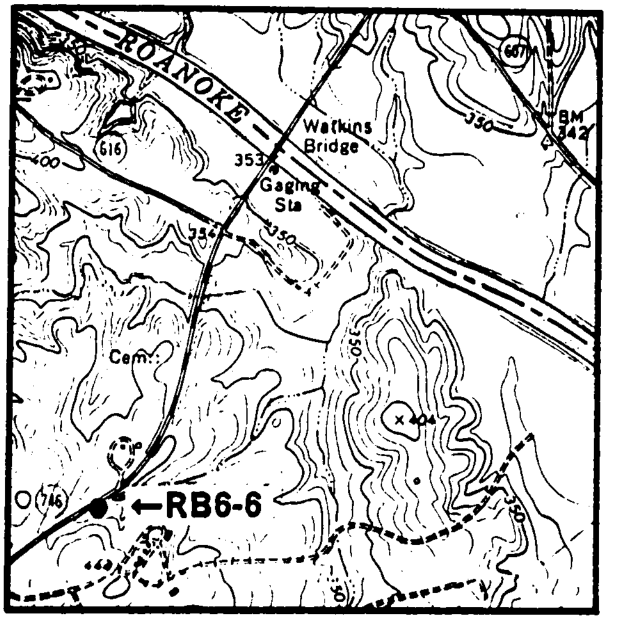


RB6-855 -
From Rodges Chapel, Virginia (Scottsburg Quadrangle) walk into the fields/woods about 2000 feet WNW to a stream juncture of a tributary leading to the East Prong of Difficult Creek. Outcrops are at this juncture.

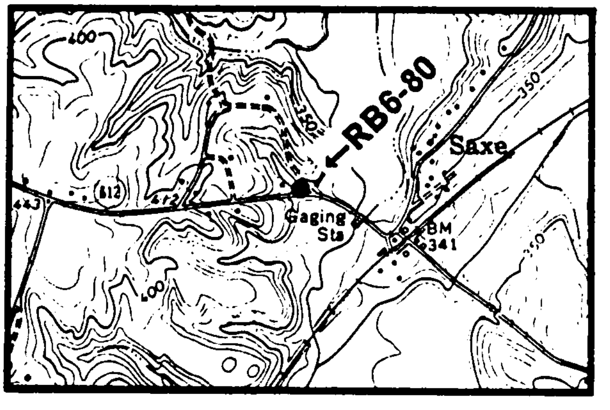


UPPER HYCO FORMATION RHYOLITE

RB6-6 -
From Mt. Laurel, Virginia (Conner Lake Quadrangle), go about 3.3 miles northeast on Highway 746. About 0.2 miles inside the Saxe Quadrangle, there is a small roadside outcrop on the right (southeast).



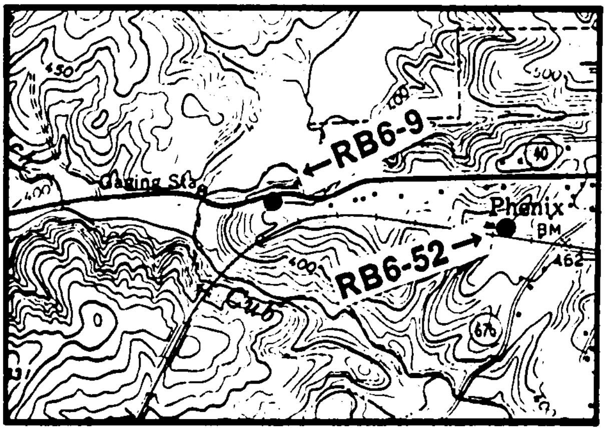
RB6-80 -
From the intersection of Highways 637 and 612 at Saxe, Virginia (Saxe Quadrangle), go about 0.2 miles WNW on Highway 612. There is a small roadcut outcrop on the right.



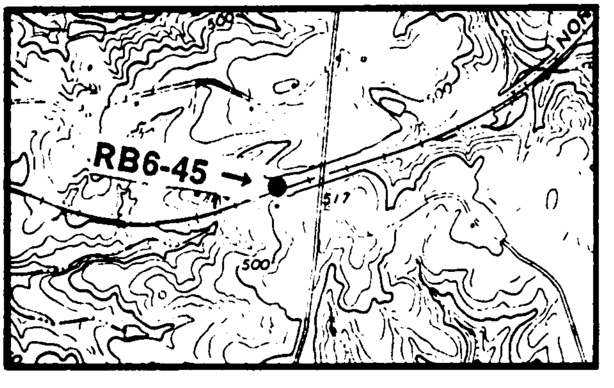
RB6-136 -
(See map for RB6-1). Just inside the Nathalie Quadrangle on Highway 501, about 4.4 miles south of Brookneal, Virginia, go west onto Highway 636 for about 0.6 miles to where the large power lines cross the road. Walk northwest along the power lines for about 800 feet to Bentley Creek. Outcrops are about 100 feet upstream.

AARON FORMATION EPICLASTIC ROCKS

RB6-9 -
in Phenix, Virginia (Charlotte Court House Quadrangle), go about 0.85 miles west on Highway 40. Fair exposures may be seen in the roadcut on the left (south) side of the road prior to crossing Cub Creek (Aspen Quadrangle).

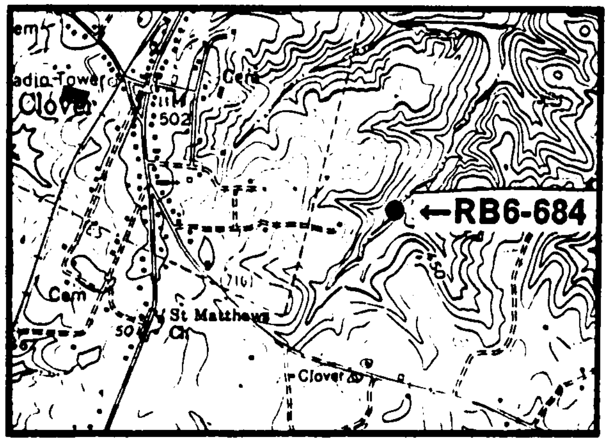


RB6-45 -
Take Highway 617/675 south off of Highway 40 about 2.5 miles west of Phenix, Virginia. After about 0.5 miles, turn right onto Highway 617. After 0.8 miles, 617 crosses over a deep railroad cut. Access roads may be walked to get onto the tracks. Extensive exposures occur along the tracks.

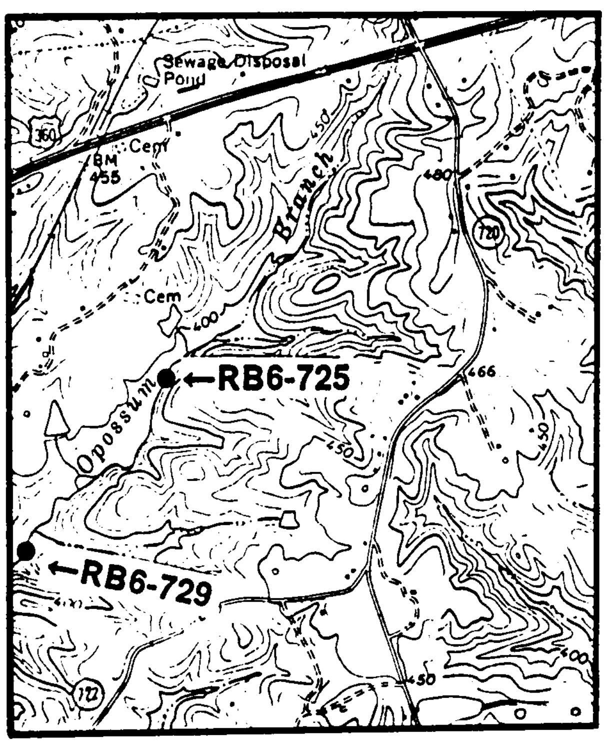


ST. MATTHEWS CHURCH AMPHIBOLITE

RB6-684 - From the intersection of Highways 716 and 92 in Clover, Virginia (Clover Quadrangle), go about 0.1 miles south on Highway 716, and turn left (east) onto an unimproved road. Continue about 0.3 miles to the end, and go downhill to the east to Clover Creek for the outcrops.

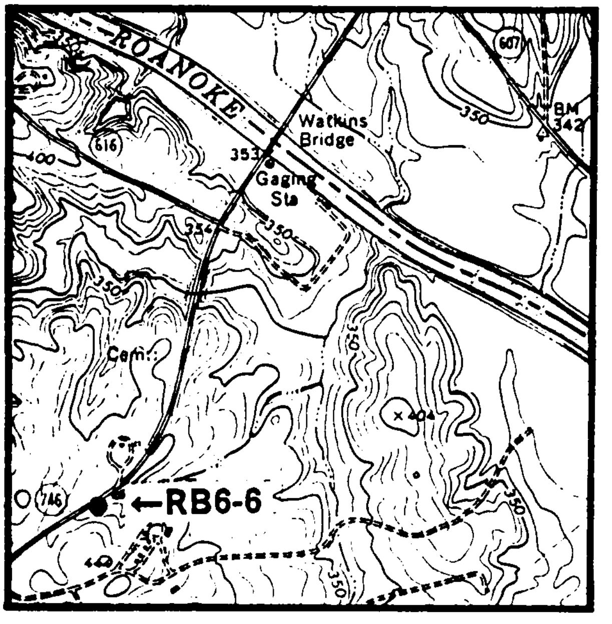


RB6-729 -
Start at the intersection of Highways 360 and 92 about a mile south of Clover, Virginia (Clover Quadrangle). Highway 92 changes to Highway 720 on the south side of Highway 360. Continue south on Highway 720 for about 1.1 miles and bear right onto Highway 722. Go another 0.4 miles. Walk into the woods to the right (WNW) into the depression that eventually becomes a small stream. Upon intersecting Opossum Branch, go about 300 feet downstream to the outcrops.

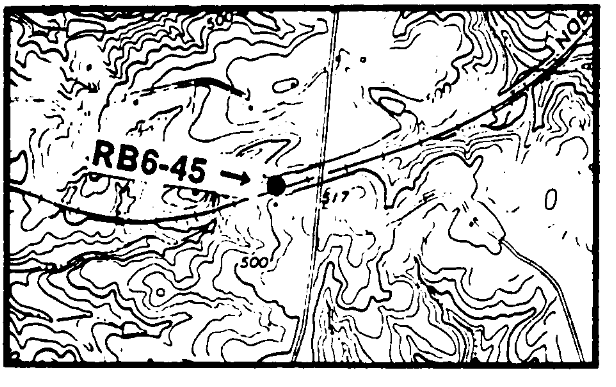


APPENDIX 3
DETAILED SAMPLE LOCATIONS FOR CHARLOTTE BELT MICROPROBE ANALYSES

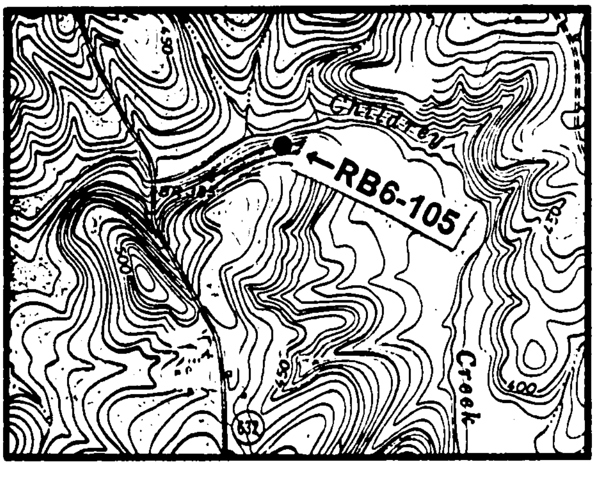
RB6-6 -
On Highway 746, go about 0.85 miles southwest of the Roanoke River (Saxe Quadrangle). Sample is from small cut in Upper Hyco Formation on the left (southeast) of the road.



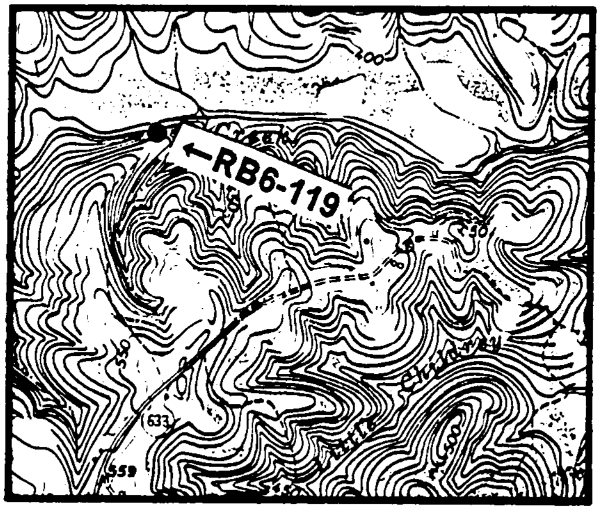
RB6-45 -
About 2.5 miles west of Phenix, Virginia, go southeast on Highway 617/675 (Aspen Quadrangle). After about 0.5 miles, turn right onto Highway 617. Go for 0.85 miles to where Highway 617 crosses a deep Norfolk and Western Railroad cut. Access roads lead to the railroad tracks where extensive exposures of Aaron Formation schist are found.



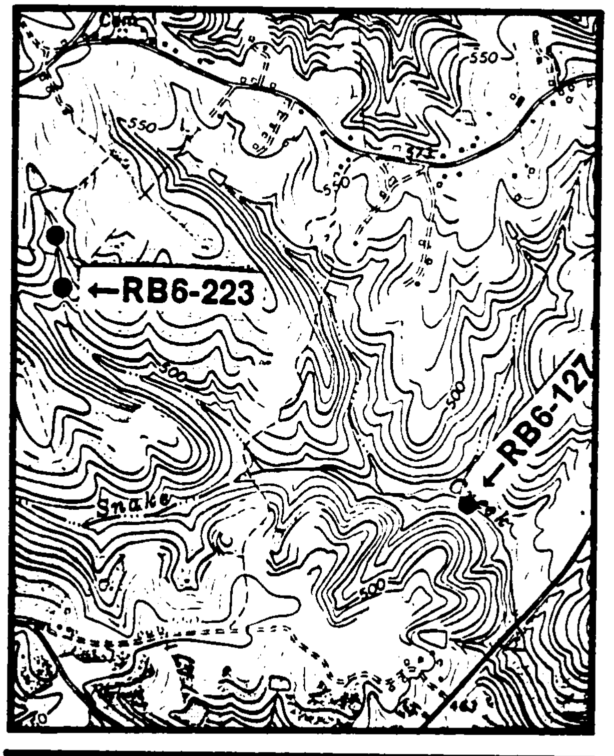
RB6-105 -
From North Halifax, Virginia (Brookneal Quadrangle), about 2 miles south of Brookneal, Virginia on Highway 501, go east onto Highway 632. Continue for about 2.7 miles to Childrey Creek. Go left (east) along Childrey Creek for about 1300 feet. The outcrops are on the hillside above the creek in the Upper Hyco Formation.



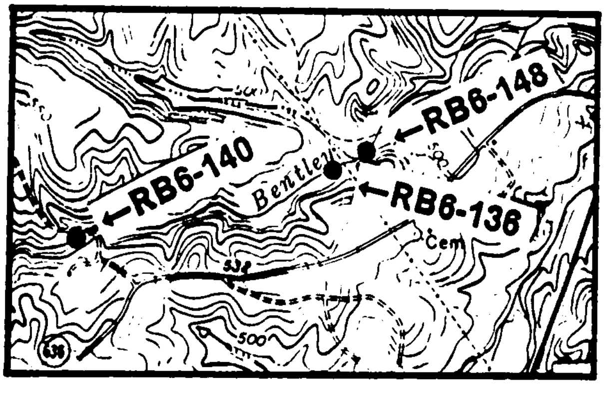
RB6-119 -
From Highway 501, about 4.6 miles south of Brookneal, Virginia, turn left onto Highway 636 (Nathalie Quadrangle). After 1.2 miles, bear left on Highway 633/634. After 1.55 miles (Brookneal Quadrangle), there is a jeep trail or path leading off to the left (northwest) across from a house. This leads nearly down to the stream where the outcrop is located.



RB6-127 -
About 1.3 miles south of North Halifax, Virginia (Brookneal Quadrangle), Highway 501 crosses Snake Creek. About 1400 feet upstream (NNE) along Snake Creek is the outcrop.

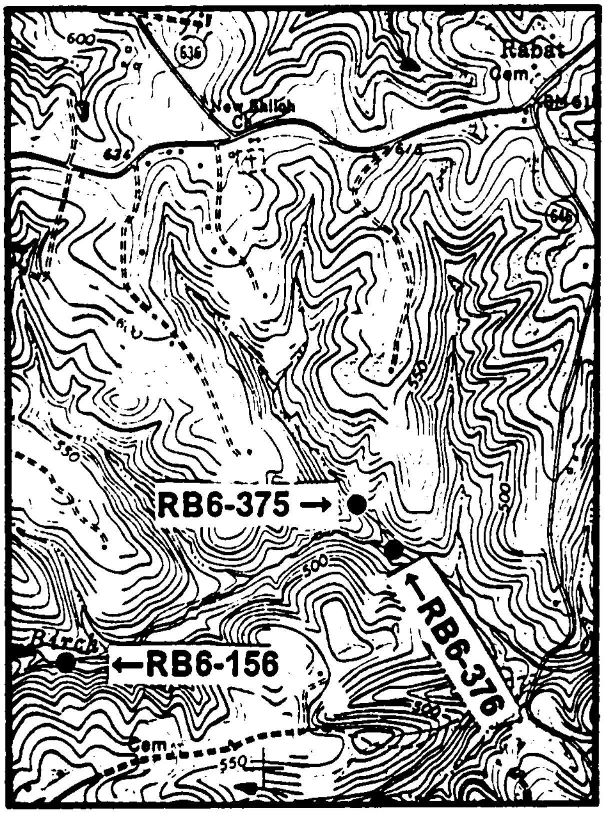


RB6-136 -
Just inside the Nathalie Quadrangle on Highway 501, about 4.4 miles south of Brookneal, Virginia, go west onto Highway 636 for about 0.6 miles to where the large power lines cross the road. Walk northwest along the power lines for about 800 feet to Bentley Creek. Outcrops are about 100 feet upstream.

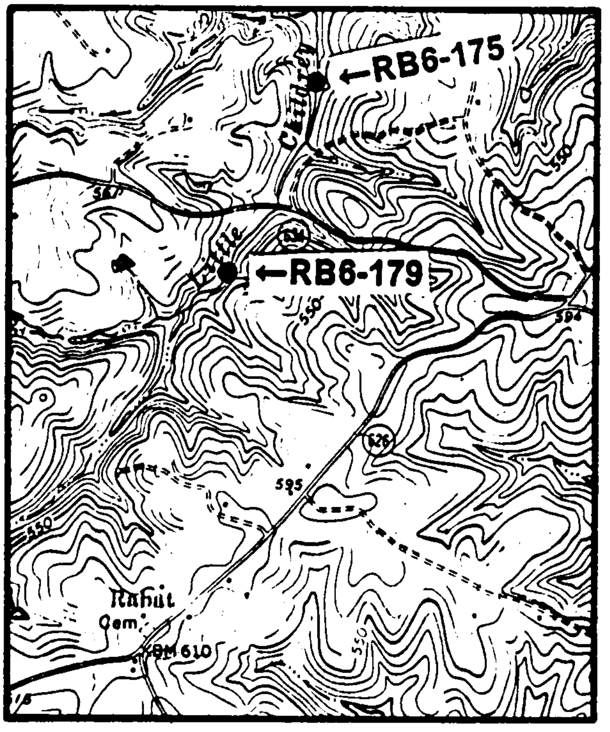


RB6-148 -
(See map for RB6-136 above). Just inside the Nathalie Quadrangle on Highway 501, about 4.4 miles south of Brookneal, Virginia, go west onto Highway 636 for about 0.6 miles to where the large power lines cross the road. Walk northwest along the power lines for about 800 feet to Bentley Creek. Outcrops are about 250 feet downstream.

RB6-156 -
From the intersection of Highway 501 and Highway 645 at Acorn, Virginia (Nathalie Quadrangle), go southeast on Highway 645 for about a mile. Turn left (northeast) onto an unmarked (on topo map) road. Proceed about 0.5 miles. Walk nearly due north across a field and into the woods for about 1400 feet. Outcrop is in the stream bed.



RB6-175 -
Go on Highway 501 about 4.6 miles south of Brookneal, Virginia. Take a left (east) onto Highway 636 (Nathalie Quadrangle). After about 1.2 miles, bear left onto Highway 633/634. After another 0.5 miles, bear right onto Highway 634. Go another 0.7 miles, and stop where the road crosses Little Childrey Creek. Outcrop sampled is about 1300 feet downstream.

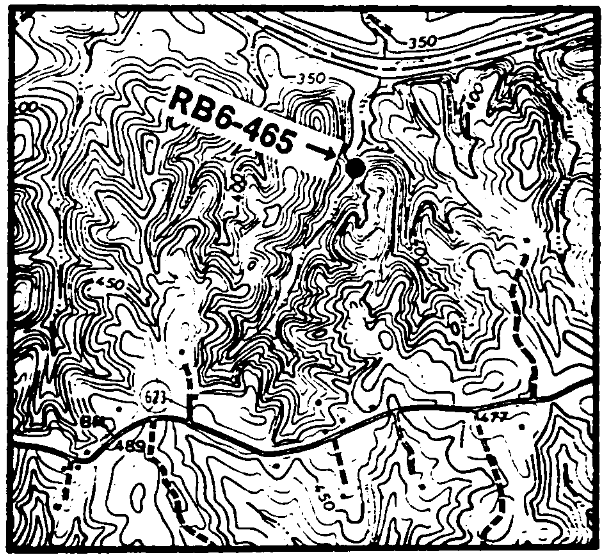


RB6-223 -
(See map above for RB6-127). From North Halifix, Virginia (Brookneal Quadrangle), take Highway 40 east for about 1.6 miles (about 0.1 miles past the intersection to the right with Highway 808. Stop, and walk south across a large field down to a pond. About 1000 feet south of the pond along a tributary to Snake Creek is the outcrop.

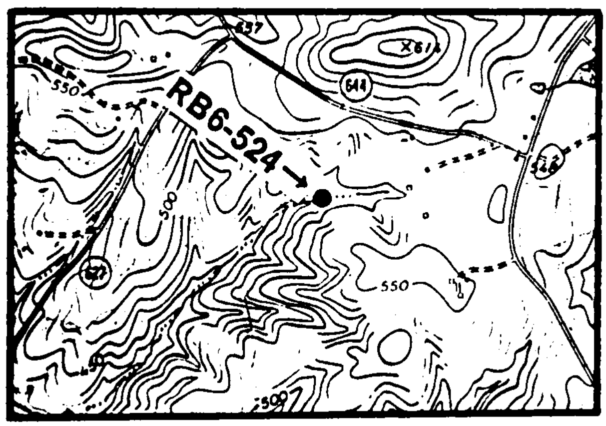
RB6-375 -
(See map for RB6-156). From the intersection of Highway 501 and Highway 626 at Acorn, Virginia, go east on Highway 626 for about 1.2 miles. Turn right (south) onto an unimproved road. Proceed to the end of the road (about 0.65 miles). Walk due east about 800 feet down to the stream. Go down stream another 600 feet to the outcrops.

RB6-376b -
(See map for RB6-156). From the intersection of Highway 501 and Highway 626 at Acorn, Virginia, go east on Highway 626 for about 1.2 miles. Turn right (south) onto an unimproved road. Proceed to the end of the road (about 0.65 miles). Walk due east about 800 feet down to the stream. Go down stream another 1200 feet to the outcrops at the intersection of this tributary with Birch Creek.

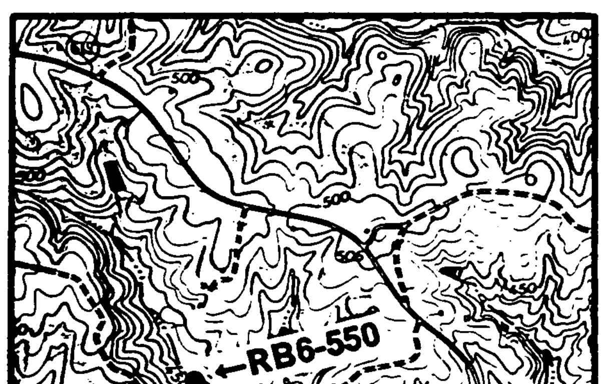
RB6-465 -
From Providence, Virginia (Conner Lake Quadrangle), go about 1.8 miles east on Highway 623. Stop on the left about 0.1 miles past an unimproved driveway on the left. Go left (north) across the field and down a stream that empties into the Roanoke River. About 3700 feet from the road is the crop.



RB6-524 -
Take Highway 627 north where it branches to the right about 0.5 miles north of Lennig, Virginia (Nathalie Quadrangle). About 0.8 miles after crossing Armistead Branch, take a right (east) onto Highway 644. After 0.25 miles, stop at the large field, and proceed left (south) downhill to a tributary to Armistead Creek. The crop is approximately where the creek is entered.

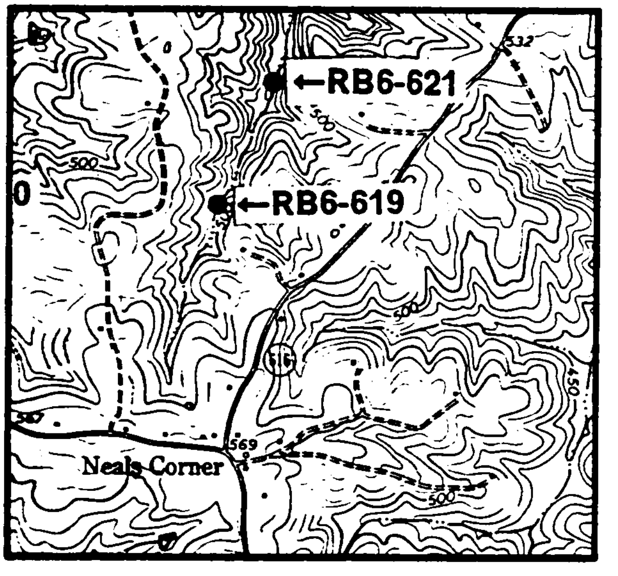


RB6-550 -
From Crossroads, Virginia (Conner Lake Quadrangle), go east on Highway 619 for about 0.65 miles. Turn right (south) onto an unimproved road, go as far as possible, and stop. Walk nearly due south. The crop is approximately where the stream is intersected.



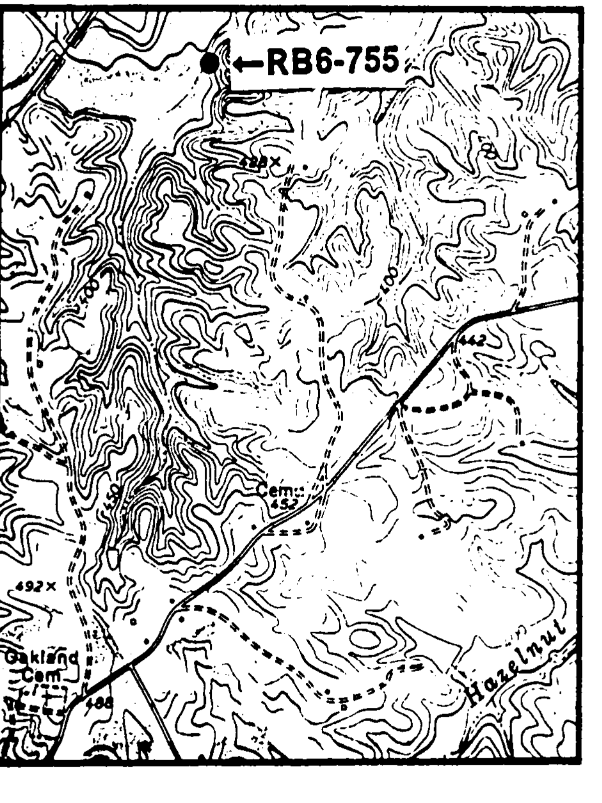
RB6-553 -
Follow the directions to RB6-550. Proceed another 1500 feet downstream to the crop.

RB6-619 -
Take Highway 619 north from Neals Corner, Virginia (Conner Lake Quadrangle) about 0.35 miles and take a left (northwest) on an unimproved driveway. From the house, go NNW to the stream. The crops are approximately where the stream is entered.

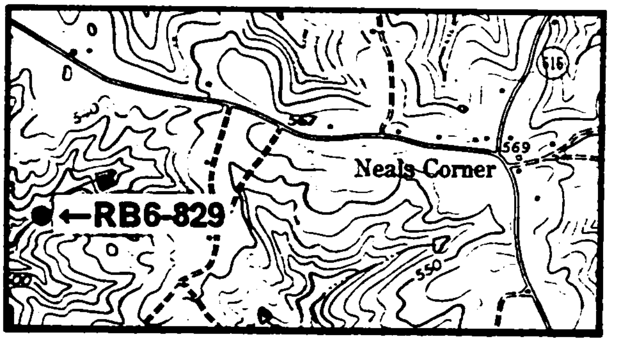


RB6-621 -
Follow the directions to RB6-619. Continue another 1300 feet downstream to the crop.

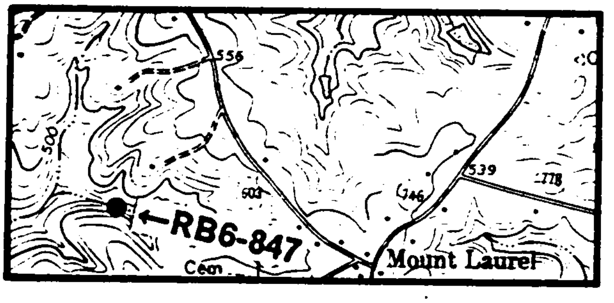
RB6-755 -
From Scottsburg, Virginia, take Highway 720 east. After about a mile, Oakland Cemetery is on the left. Continue another 0.65 miles, and take a left (north) on an unimproved road next to another small cemetery. Go as far as the road goes (about 0.8 miles), and stop. Go northwest over the hill and down to Difficult Creek where it flows closest to the hillside (about 1300) by a small, crumbly crop.



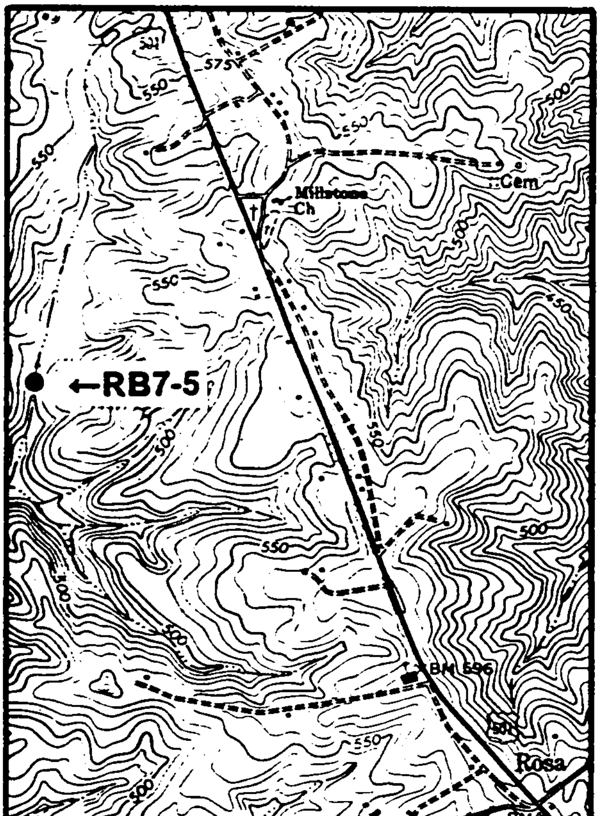
RB6-829 -
From Neals Corner, Virginia (Conner Lake Quadrangle), go west on Highway 603 for about 0.75 miles. Walk south (left) about 900 feet to a pond. The crop is about 650 feet downstream from the pond.



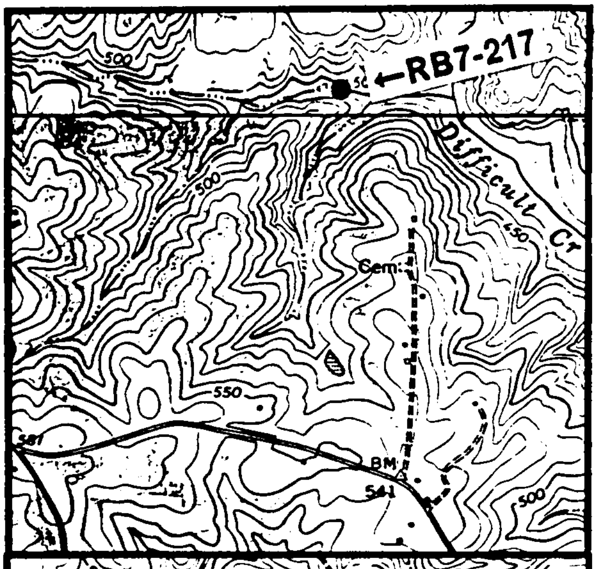
RB6-847 -
From Mount Laurel, Virginia, take Highway 603 northwest and turn on an unimproved driveway to the left (southwest). Stop at the house, and walk about 550 feet farther southwest to the stream. The crop is about where the stream is entered.



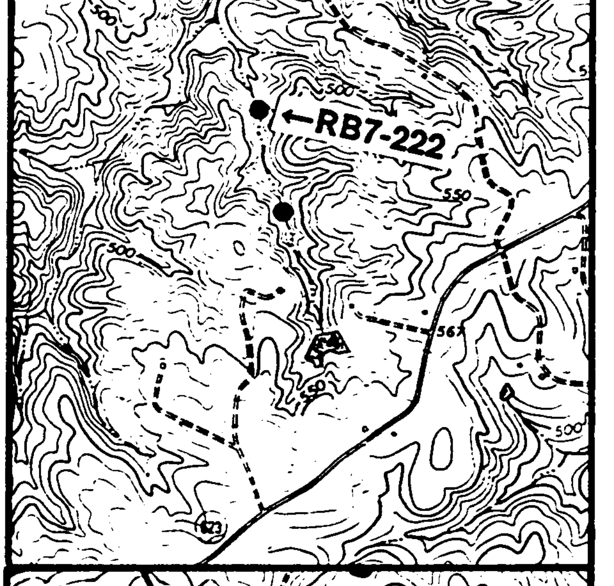
RB7-5 -
From Rosa, Virginia, proceed NNW on Highway 501 about 1.5 miles (0.2 miles past Millstone Church). Turn left (west) onto an unimproved driveway. From the house, go due west to a tributary to the Bannister River. Go downstream about 2500 feet to the crop.



RB7-217 -
From the intersection of Highway 621 and Highway 626 about a mile north of Crystal Hill, Virginia (Halifax Quadrangle), go right (east) on 621 about 1.6 miles and turn on an unimproved road to the left. Continue to end of road (about 0.6 miles). Walk due north about 1200 feet to a tributary to Difficult creek (now in Nathalie Quadrangle). Go upstream (west) about 750 feet to the crop.



RB7-222 -
From the intersection of Highway 603 and Highway 623 (Conner Lake Quadrangle), go northeast on Highway 623 about 0.6 miles. Go northwest about 900 feet to a large pond. About 2400 feet downstream from the pond is the crop.



RB7-242 -
From the intersection of Highway 615 and Highway 626 about 0.4 miles north of Dudley, Virginia (Halifax Quadrangle), go east on Highway 615 about 1.6 miles. Stop, and walk across the field to the right (due east) about 1600 feet to a tributary of Winn Creek. The crop is about where the stream is entered.

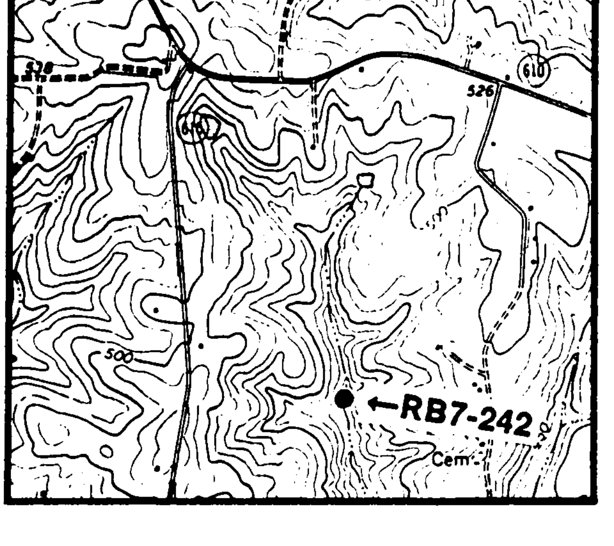


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Plate 1a

GEOLOGY OF THE CHARLOTTE BELT - SOUTH-CENTRAL VIRGINIA

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STRATIGRAPHY

Tr — *Triassic sequence:* red arkoses and conglomerates; poorly sorted; clasts to over 0.5 m

OSa — *Arvonia Formation:* pelitic unit; silver-gray graphitic muscovite quartz schist

O(?)tb — *Tanyard Branch Granitic Gneiss:* granitic intrusive unit; leucocratic; quartz-plagioclase-K-feldspar ± muscovite ± biotite assemblage; possibly related to the Shelton Formation granite; undated

Os — *Shelton Formation:* granite intrusive unit; leucocratic; quartz-plagioclase-K-feldspar ± muscovite ± biotite assemblage; extremely lineated in all exposures examined; dated at 425 Ma by Rb-Sr, estimated to be ca. 450 Ma with allowance for cooling to blocking temperature

Єm — *Melrose Granite:* granitic intrusive unit; dated at 512 ± 5 Ma (U-Pb)

Є(?)ro — *Red Oak Granite:* granitic intrusive unit; undated, but cuts all older slate belt units; possibly related to young slate belt volcanism

pЄv — *Virgilina Formation:* lower basaltic unit: greenish gray; greenstone of epidote-chlorite-quartz-plagioclase composition; upper epiclastic unit similar to the Aaron Formation

pЄa — *Aaron Formation.*

Charlotte belt: pelitic unit; medium to dark gray biotite schist; plagioclase-quartz-biotite-muscovite ± garnet composition;

Carolina slate belt: epiclastic unit; greenish silver slate to volcanic wacke; plagioclase-quartz-muscovite-chlorite-epidote ± biotite assemblage

pЄuh — *Upper Hyco Formation:*

Charlotte belt: rhyodacitic volcanic unit; primarily salt and pepper appearing dacite of composition, and subordinate tan to leucocratic rhyolite of quartz-plagioclase-K-feldspar-muscovite ± biotite ± epidote ± garnet composition; rhyolites, while still subordinate, are more common than in the Lower Hyco; dacites are commonly more biotitic than in the Lower Hyco

Carolina slate belt: rhyodacitic volcanic unit; locally porphyritic; plagioclase-quartz-muscovite-chlorite-epidote ± biotite composition

pЄav — *Altered volcanic rocks:* hydrothermally-altered volcanic rocks; leucocratic; 2/3 quartz and 1/3 muscovite; quartz-muscovite ± biotite ± garnet assemblage; pyrite, chalcopyrite, sphalerite, and the zinc spinel, gahnite, occur locally; probably originally dacites of the Upper Hyco

pЄbc — *Blackwater Creek Gneiss:* dacitic volcanic unit; salt and pepper appearance; plagioclase-quartz-hornblende ± biotite ± epidote ± garnet assemblage

pЄec — *Ellis Creek Gneiss:* tonalite intrusive unit; leucocratic; plagioclase-quartz-hornblende-biotite-epidote assemblage

pЄsmc — *St. Matthews Church Amphibolite Member of the Hyco Formation:* basaltic volcanic unit; dark green to black; hornblende-plagioclase-quartz-epidote ± biotite assemblage; interlayered with dacites similar to those of the Blackwater Creek Gneiss; possible equivalent of the Catawba Creek Amphibolite

pЄcc — *Catawba Creek Amphibolite Member of the Hyco Formation:* basaltic volcanic unit; dark green to black; hornblende-epidote-plagioclase-quartz ± sphene assemblage; possible equivalent of the St. Matthews Church Amphibolite

g — *Gabbroic rocks:* coarse-grained amphibolite, compositionally similar to the Catawba Creek Amphibolite and possibly the intrusive equivalent of it; occurs within the Hyco Formation of the Charlotte belt

pЄlh — *Lower Hyco Formation:* rhyodacitic volcanic unit; primarily dacite of plagioclase-quartz-biotite ± muscovite ± epidote ± hornblende ± garnet composition, and subordinate rhyolite of quartz-plagioclase-K-feldspar-muscovite ± biotite ± epidote ± gt composition

pЄpel — *Pelitic rocks:* quartz-feldspar gneiss with discontinuous layers of pelitic schist and less common calc-silicate gneiss (Tobisch and Glover, 1971)

pЄiv — *Intermediate volcanic rocks:* interlayered hornblende-plagioclase gneiss and quartz-feldspar gneiss (Tobisch and Glover (1971)

FOLIATIONS AND LINEATIONS

- strike and dip of S_0 sedimentary bedding
- strike and dip of S_1 foliation
- strike and dip of S_2 regional foliation
- strike and dip of S_3 foliation related to shearing event
- strike and dip of S_4 cleavage axial planar to F_4 folds
- strike and dip of shear bands in previously foliated rocks
- strike and dip of shear bands in previously isotropic rocks
- trend and plunge of L_1, S_0/S_1 intersection lineation
- trend and plunge of L_2, S_1/S_2 intersection lineation
- trend and plunge of L_3, S_2/S_3 intersection lineation
- trend and plunge of L_4, S_2/S_4 intersection lineation
- trend and plunge of shearing mineral elongation lineation

FAULTS AND SHEAR ZONES

- trace of brittle faults; block on downthrown side; dashed where approximate
- D_3 shear zone boundary; both boundaries of each zone shown; dashed where approximate

CONTACTS

- lithologic contact; dashed where approximate

REGIONAL-SCALE FOLDS

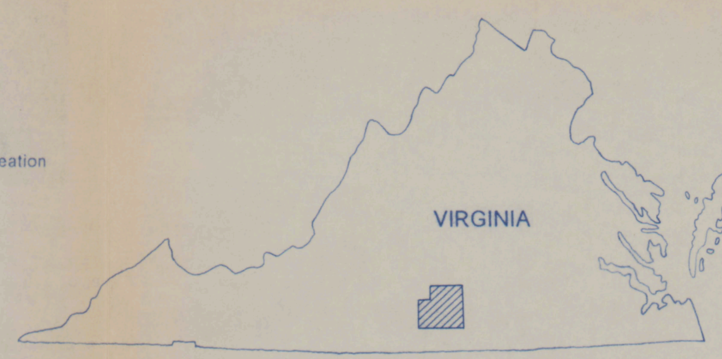
- trend of regional-scale antiform; X = 1-4
- trend of regional-scale synform; X = 1-4
- trend of overturned antiform; X = 1-4

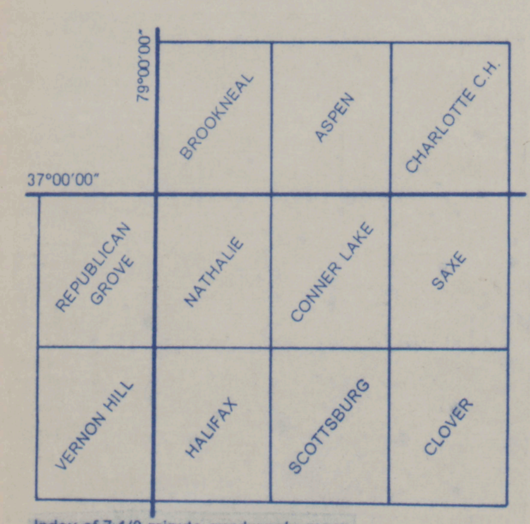
MESOSCOPIC FOLD AXES

- trend and plunge of F_1
- trend and plunge of F_2
- trend and plunge of F_3
- trend and plunge of F_4

FOLDING STYLE (plotted on fold axis symbols)

- broad open folds or warps up to several 10s of meters in wavelength
- mesoscopic open folds up to a few meters in wavelength
- mesoscopic tight/close folds
- mesoscopic isoclinal folds





Index of 7-1/2 minute quadrangle maps

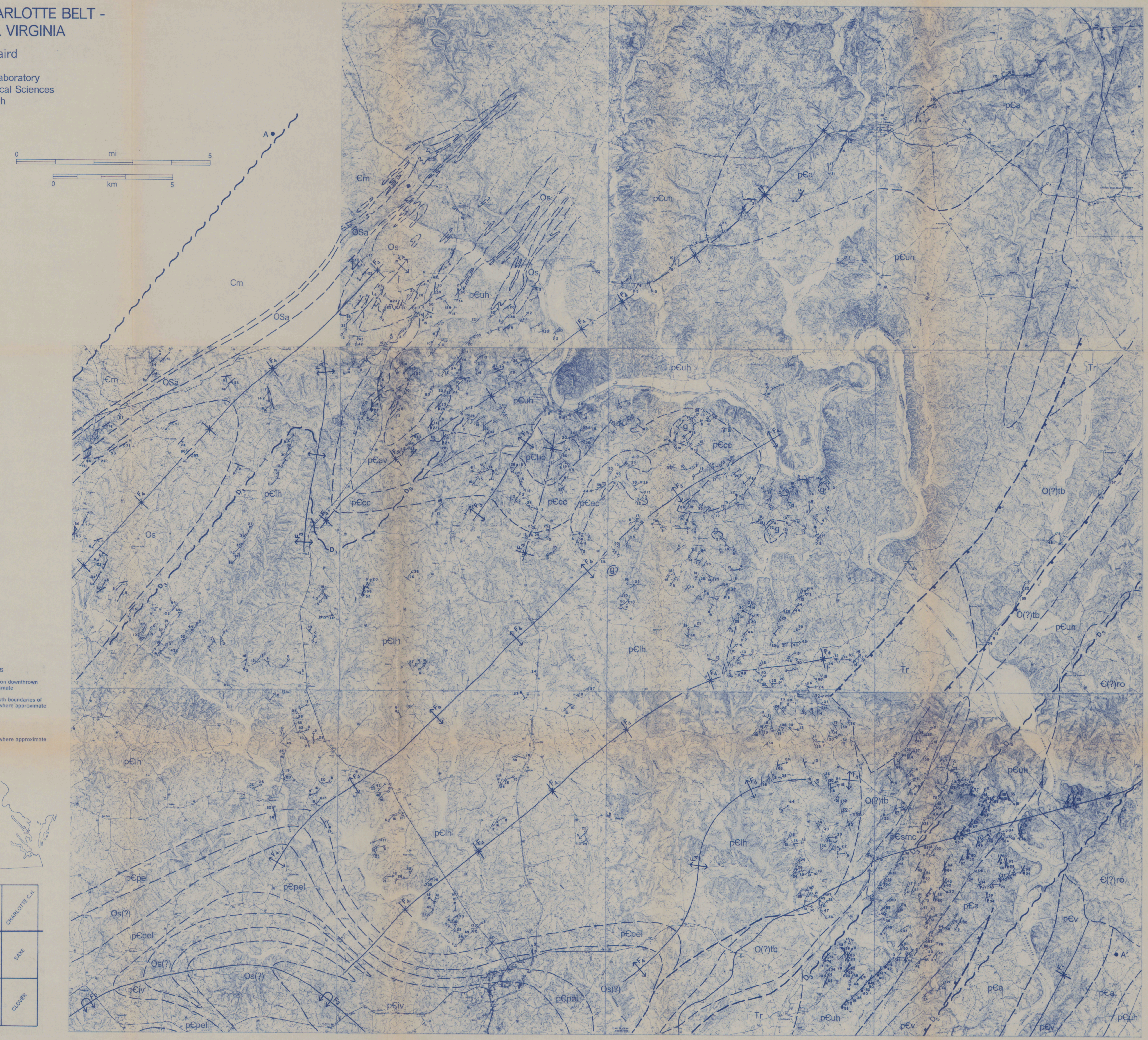


Plate 1b

Cross-Section A - A′