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THE ROPES CREEK ASSEMBLAGE: PETROLOGY, GEOCHEMISTRY, AND TECTONIC SETTING OF AN OPHIOLITIC THRUST SHEET IN THE SOUTHERN APPALACHIANS

TERRY L. SPELL AND GREGORY T. NORRELL*

Department of Geological Sciences, State University of New York, Albany, New York 12222

ABSTRACT. **Although ophiolites are well known in the northern Applachians, their occurrence in the southern Appalachians remains poorly documented. We have examined three areas, located both northwest and southeast of the Brevard Zone in the west Georgia Piedmont, which contain a distinct lithologic assemblage (Ropes Creek) consisting of amphibolites (metabasalts, metagabbros), talc-actinolite gneisses (metamorphosed ultramafic rocks), granitic gneisses, and metalliferous quartzites. Field work to date suggests that the Ropes Creek assemblage is contained within a single thrust sheet. Stratigraphic relations indicate that the sequence (from bottom to top) is meta-ultramafic rocks, metabasalts and metagabbros, metabasalts with intercalated metalliferous quartzites, and granitic rocks. This lithologic association may represent the remnants of a disrupted ophiolite formed off the margin of North America prior to closure of the Iapetus ocean.**

Chondrite normalized REE plots suggest that some ultramafic, mafic, and felsic rocks are comagmatic. REE plots, MORB normalized multi-element plots, and tectonic discriminant diagrams indicate that metabasalts represent both IAT and MORB. Some mafic and ultramafic samples exhibit REE patterns indicative of seawater interaction. Tectonic discriminant diagrams and REE plots suggest that some granitic rocks represent ocean ridge granite (ORG). Most, however, appear to represent volcanic arc granites (VAG). Metalliferous quartzites are characterized by high abundances of FeO and MnO and are similar to hydrothermally altered sediments and Fe-Mn hydrothermal deposits found at oceanic spreading centers.

These data place constraints on tectonic settings for the formation of the Ropes Creek assemblage. The most probable origin for these rocks is as oceanic lithosphere in a back-arc basin above a seaward (east) dipping subduction zone. The lack of IAT signatures in metabasalts analyzed thusfar from the easternmost area suggests this inferred back-arc basin opened sufficiently to separate spatially the spreading center from the subduction zone as in some modern back-arc basins (for example, Mariana, Lau). The occurrence of granitic rocks with VAG signatures in the assemblage suggests that during convergence the back-arc basin lithosphere was thrust over the arc.

INTRODUCTION

Ophiolites are prominent features in the geology of the northern Appalachians. Although mafic-ultramafic assemblages occur in the south-

* Present addess: Westinghouse Savannah River Company, Environmental Protection Section, Aiken, South Carolina 29808

ern Appalachians, few have been identified as ophiolitic due to multiple deformation, high-grade metamorphism, and poor exposure. Despite these difficulties, Kite and Stoddard (1984) have reported a probable ophiolitic sequence of ultramafic rocks, gabbros, basalts, and diorites-tonalites in the Halifax County Complex of the Rayleigh belt in North Carolina. Other studies have indicated that many of the mafic rocks exposed in the southern Appalachians are metabasalts with ocean floor and island-arc affinities (Hatcher and others, 1984; Stow, Neilson, and Neathery, 1984). In addition, the Sr and Nd isotopic compositions of many mafic rocks throughout the Appalachians are characterized by the depleted mantle signature typical of modern oceanic and ophiolitic basalts (Shaw and Wasserburg, 1984).

We have studied three areas in northwest Georgia in which a distinctive lithologic association of amphibolites, ultramafic gneisses, granitic gneisses, and metalliferous quartzites occurs. These rocks are exposed on both sides of the Brevard Zone, and these rocks may comprise a single thrust sheet—the Ropes Creek (Higgins and others, 1988). This paper presents geochemical, petrologic, and structural data that constrain the origin and tectonic setting of these rocks.

GEOLOGIC SETTING

The southern Appalachian orogen is commonly divided into several northeast trending belts based on similarities in lithology, structural style, and metamorphic grade (fig. 1). Crickmay (1952) and King (1955) originally divided the southern Appalachians into the Valley and Ridge, Blue Ridge, and Piedmont. Since that time many workers have modified their original belt terminology as new data became available, and this part of the orogen became better understood (Fairley, 1973: Hatcher, 1987).

The Valley and Ridge, a sequence of folded and faulted Paleozoic sedimentary rocks, is separated from the crystalline terranes to the south and east by the Blue Ridge thrust (Hatcher and Odom, 1980). COCORP seismic reflection profiles suggest that the Blue Ridge thrust is the westernmost exposure of a major décollement upon which the allochthonous crystalline terranes to the south moved during emplacement onto the North American margin in the middle to late Paleozoic (Cook and others, 1979; Hatcher, 1987). The Blue Ridge province, situated north of the Allatoona fault and south and east of the Blue Ridge thrust, consists of Precambrian to Paleozoic metasedimentary and metavolcanic assemblages and Grenville age basement rocks. Because of the striking similarity of lithologies between the Allatoona fault and the Brevard Zone (Blue Ridge of King) with those south of the Brevard Zone (inner Piedmont) first noted by Crawford and Medlin (1973), we follow Stow, Neilson, and Neathery (1984) and McConnell and Abrams (1984) in referring to this part of the orogen as the northern Piedmont. The northern Piedmont and inner Piedmont are bounded by the Allatoona fault to the north and the Towaliga fault to the south and are separated

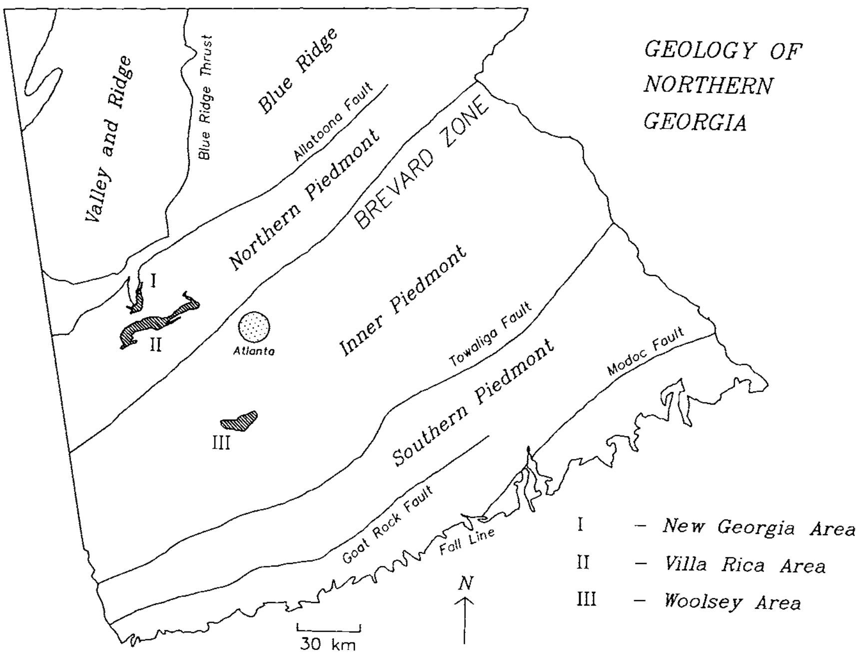

Fig. 1. Generalized geologic map of northern Georgia showing major lithotectonic subdivisions and location of study areas.

by the Brevard Zone (fig. 1). Lithologies of the northern and inner Piedmont include mafic and ultramafic metaigneous rocks, granitic-tonalitic rocks, and metasediments (Higgins and others, 1988, and references therein). The Brevard Zone is a complex shear zone consisting of a variety of mylonitized lithologies. Much controversy has surrounded the origin of the Brevard Zone. It is now considered to represent an Alleghanian dextral shear zone which may have originated as a pre-Alleghanian structure (Bobyarchick, 1988; Edelman, Lui, and Hatcher, 1987, and references therein). The southern Piedmont lies south of the Towaliga fault and consists of quartzites, marbles, schists, gneisses, and amphibolites (Stow, Neilson, and Neathery, 1984).

The three areas we have studied (fig. 1) are located within the northern Piedmont (New Georgia and Villa Rica) and inner Piedmont (Woolsey). We have done detailed mapping in the New Georgia (Norrell, 1985) and Woolsey areas and reconnaissance work in the Villa Rica area. The Villa Rica area was mapped previously by Sanders (1983) and Higgins and others (1988). A distinctive lithologic association, referred to here as the Ropes Creek assemblage, occurs in each of these areas and consists of amphibolites, ultramafic gneisses, granitic gneisses, and metalliferous quartzites. The latter are very distinctive and diagnostic of the

Ropes Creek assemblage. Higgins and others (1988) have proposed that rocks of the northern and inner Piedmont constitute a series of stacked thrust sheets and that recurring lithologic assemblages, such as the Ropes Creek, are erosional remnants of a particular thrust sheet. Thus, the Ropes Creek assemblage may represent a single thrust sheet that occurs in both the northern and inner Piedmont.

PETROLOGY

The key lithology in the three study areas (fig. 1) is the Ropes Creek amphibolite (Ropes Creek Metabasalt of Higgins and others, 1988), originally described for the type locality in Alabama (Bentley and Neathery, 1970). This rock is typically a fine-grained (1–3 mm), lineated and foliated, plagioclase-hornblende amphibolite which weathers to a dark red saprolite. Foliation is defined by compositional banding which consists of alternating hornblende- and plagioclase-rich zones ranging from 3 mm to 2 cm thick, although at some locations compositional banding is absent and the rock is massive. Metamorphic foliation and lithologic layering are generally parallel. Locally the amphibolites are extensively epidotized and in rare instances are silicified. Abundant pyrite is associated with silicified amphibolite. Pillow structures in the Ropes Creek amphibolite have been identified at several locations in Georgia (Hurst and Jones, 1973; Higgins and others, 1988). We have identified relict pillow structures in the Woolsey area (fig. 2) and have

Fig. 2. Epidotized pillow structures in metabasalts from the Woolsey area.

also observed them in other exposures of the Ropes Creek amphibolite. The presence of relict pillow structures in the Ropes Creek amphibolite, along with geochemistry discussed below, indicates a basaltic protolith as suggested by other workers (Hurst and Jones, 1973; Stow, Neilson, and Neathery, 1984; Higgins and others, 1988). Pillows in the Woolsey area have extensively epidotized cores similar to those described from the Josephine ophiolite of northern California (Harper, Bowman, and Kuhns, 1988) which are attributed to metasomatism during seafloor hydrothermal alteration. Interlayered felsic rocks are not observed except at one location in the Woolsey area.

Small discontinuous bodies of amphibolites which are distinctly more coarse-grained than typical Ropes Creek amphibolite are present as isolated exposures in the New Georgia area and especially the Woolsey area. They consist of medium- to coarse-grained (3–6 mm), usually massive, in places weakly lineated, plagioclase-hornblende amphibolites. Based on field observations and geochemistry discussed below we interpret these rocks as metamorphosed gabbros.

The most common ultramafic rocks are medium grained (2–4 mm), talc-chlorite-actinolite gneisses, which are locally schistose with higher percentages of talc. Rare olivine and pyroxene have in some instances survived metamorphism; however, the rocks are usually totally recrystallized to metamorphic mineral assemblages. The geochemistry of these rocks (discussed below) suggests that protoliths may have been cumulate mafic or ultramafic rocks. Partially serpentinized harzburgites composed of olivine, orthopyroxene, serpentine, and minor spinel have been identified only in the Villa Rica area. Exposures of ultramafic rocks range from a few square meters to bodies 600 m in length.

Leucocratic granitic gneisses are present in all three study areas. These rocks are fine grained (1–2 mm) biotite-hornblende-quartz-plagioclase gneisses which occur as large bodies in the Woolsey (fig. 3) and Villa Rica areas. At one exposure in the Woolsey area, a concordant layer of gneiss (~1 m thick) with a higher abundance of mafic phases occurs within the upper amphibolites. In the New Georgia area there are two petrographically distinct types of granitic gneiss. One is a leucocratic granitic gneiss as discussed above, whereas the other is a medium to coarse grained (2–6 mm) muscovite-plagioclase-quartz-K-feldspar gneiss that forms prominent exposures (the Mulberry Rock Gneiss of McConnell and Abrams, 1984). It has been proposed that this unit correlates with the Corbin Gneiss which is considered to be Grenville age basement (McConnell and Abrams, 1984; Higgins and others, 1988).

Magnetite quartzite, which occurs conformably interlayered with the amphibolites, is characteristic of the Ropes Creek assemblage in both Georgia (Higgins and others, 1988) and Alabama (Stow, Neilson, and Neathery, 1984). This rock is composed of coarse- to fine-grained (1 cm to <1 mm) quartz with interlayered and disseminated magnetite (up to ~1 cm) which often shows well-developed euhedral forms. Dissem-

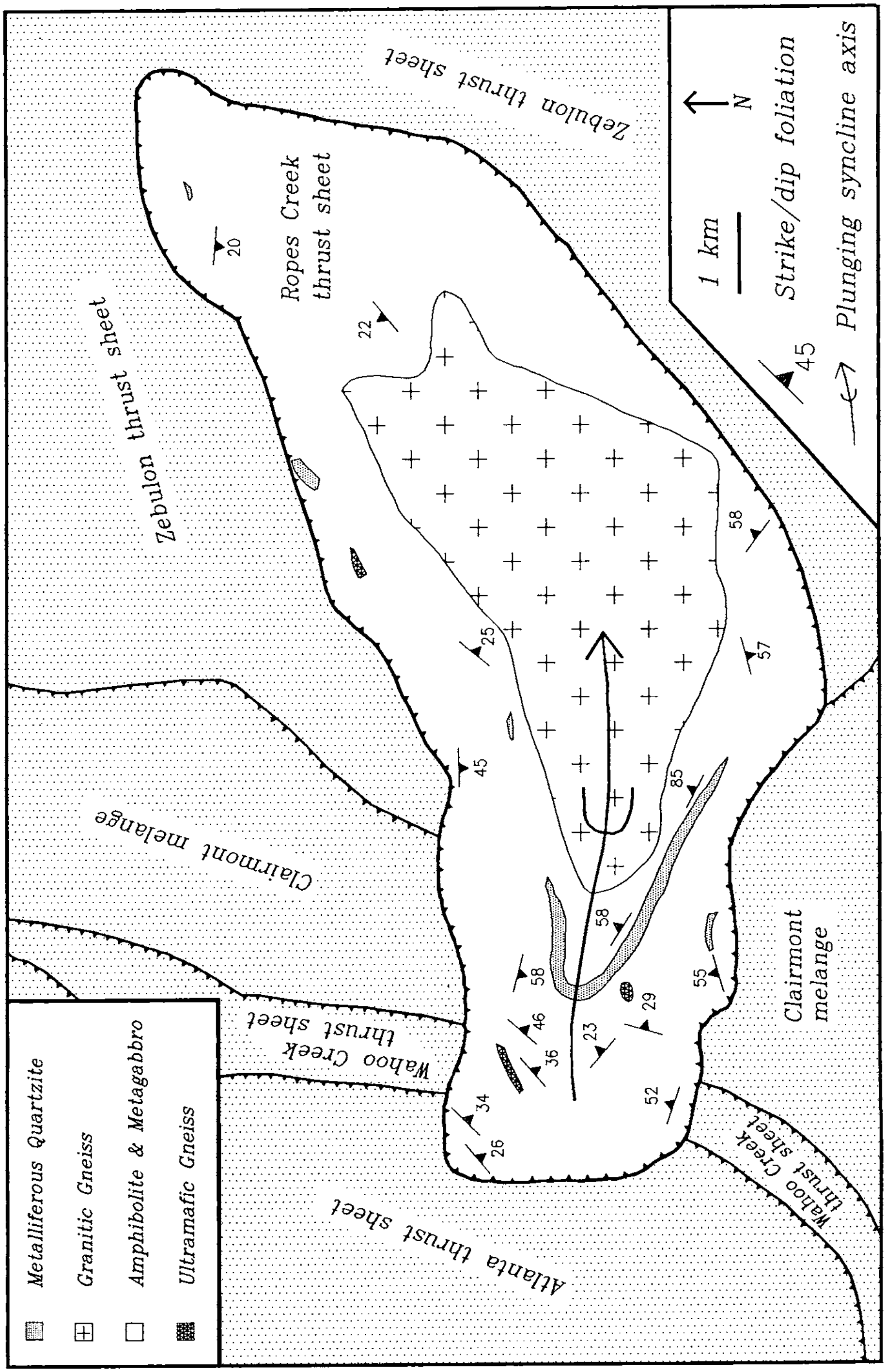

Fig. 3. Geologic map of the Woolsey area. Geology of surrounding lithologies from Higgins and others (1988).

inated pyrite is common. Quartzites are present in all three areas as bodies ranging from <100 m up to 5 km in length and 1 to 10 m thick.

STRUCTURAL RELATIONS

Rocks of the northern and inner Piedmont have been affected by polyphase metamorphism and multiple deformational events (Abrams and McConnell, 1984; Secor, Snoke, and Dallmeyer, 1986; Hatcher, 1987). The Woolsey area (fig. 3) exhibits the least structural complexity among the three we have studied. We therefore use field data from this area to attempt to constrain stratigraphic relationships among lithologic units of the Ropes Creek assemblage. Figure 3 shows the results of mapping in the Woolsey area. Lithologic units in the surrounding area, mapped by Higgins and others (1988), intersect rocks of the Ropes Creek assemblage at high angles. Where exposed, the contact between the Ropes Creek amphibolite and outlying lithologies is a thrust fault. These relationships suggest this area is a klippe. The prominent structure is an east plunging synform with the fold axis parallel to the long dimension of the klippe (generally east-west). Local variations in strike and dip of foliations suggest that other minor folds may be present, but the generally poor exposures make them difficult to discern precisely. The overall structure of lithologies below the thrust is also synformal, suggesting that the thrust sheet was emplaced prior to the last episode of folding.

The available structural data are compatible with a conformable sequence of lithologies within the Woolsey area. Meta-ultramafic rocks occur at or near the base of the exposed sequence; metagabbros discontinuously crop out immediately above. These are overlain in turn by metabasalts followed by metabasalts interlayered with magnetite quartzites near the top of the sequence. The center of the Woolsey area is occupied by a large body of granitic gneiss here designated the Woolsey Gneiss. Field relationships are inconclusive as to the nature of the contact between the granitic gneiss and the surrounding metabasalts as no cross-cutting relationships or xenoliths have been observed. Xenoliths of metabasalt have been identified in a similar gneiss body in the Villa Rica area (see below). This stratigraphic sequence is similar to what would be expected for a metamorphosed ophiolite.

Structural and stratigraphic relationships in the New Georgia area are more complex, probably due to interfering fold patterns. The Ropes Creek assemblage is interpreted to occur as a thrust slice between two other east-dipping thrust sheets to the west and east which are, respectively, the Zebulon and Paulding thrust sheets of Higgins and others (1988). At the eastern edge of the New Georgia area the thrust fault strikes north-northeast and dips 30° to 40° southeast based on outcrop patterns and orientation of mylonitic foliations at one location. Immediately to the west of the fault, ultramafic rocks—underlain (to the west) by a sequence of metabasalts underlain in turn by metabasalts with

TABLE 1 *Representative major element data for*

Sample	Type	Area	SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	MgO
RCA	Amp	All	49.60	1.32	14.81	12.50	6.90
BR-D	Amp	W	46.16	2.03	14.48	14.56	9.98
BR-C	Um	W	45.34	0.56	10.49	11.60	22.87
VRG	Gn	VR	69.72	0.25	16.60	1.78	0.67
BR-A	Gn	W	62.46	0.49	16.57	5.75	1.63
BR-F	Gn	W	70.55	0.32	15.81	2.30	0.75
MRG1	Gn	NG	75.66	0.30	12.76	0.99	0.09
MRG2	Gn	NG	70.87	0.34	15.74	1.71	0.34
BR-B	Qtz	W	69.12	0.07	0.37	27.45	0.20

Notes: All analyses in wt percent; LOI, loss on ignition; Fe_2O_3*, total Fe as Fe_2O_3; n, number of analyses; RCA, average of analyses of Ropes Creek amphibolite from Higgins and others (1988); VRG, average of analyses of Villa Rica gneiss from D. Sanders

intercalated quartzites and granitic gneisses—are exposed. This stratigraphy is similar to that in the Woolsey area except upside down, suggesting that the entire sequence is overturned in the New Georgia area, and that the Ropes Creek assemblage was orginally thrust over the Paulding suite. Higgins and others (1988) have interpreted the Ropes Creek to be in thrust contact with and overlying the Paulding thrust sheet in other parts of the Georgia Piedmont.

The basic structure of the Villa Rica area is apparently a dome or doubly plunging antiform, the core of which exposes the Villa Rica Gneiss (Sanders, 1983; McConnell and Abrams, 1984) and some ultramafic rocks. The Villa Rica Gneiss contains xenoliths of Ropes Creek amphibolite and is thus intrusive in origin (Pate, 1980; Sanders, 1983). Higgins and others (1988) have suggested that this structural feature is contained within a klippe of the Ropes Creek thrust sheet.

GEOCHEMISTRY

Analytical methods.—The geochemical data presented in this paper were compiled from three separate analytical runs. Sample material was consumed during each analytical run or was unavailable at the time of the next run, therefore samples were recollected. No sample analyzed in separate runs consisted of splits of the same material; however, in some cases samples were collected from the same outcrop area. Major element (+Cu, Cr, and Ni) analyses of 7 samples from the Woolsey area and 8 samples from the New Georgia area were done by atomic absorption spectrophotometry at West Georgia College. Representative major element analyses and selected analyses from the literature for comparison are presented in table 1. Trace element (including rare earth element (REE)) analyses were done by X-ray fluorescence and instrumental *lithologies of the Ropes Creek assemblage*

MnO	CaO	Na_2O	K_2O	LOI	Total	n	Sample
0.20	10.03	3.00	0.16	1.34	99.86	27	RCA
0.19	10.0	3.55	0.09	-	101.04	1	BR-D
0.24	7.07	0.80	0.04	-	99.01	1	BR-C
0.03	3.67	5.42	0.95	-	99.20	10	VRG
0.07	5.05	4.25	0.28	2.79	99.34	1	BR-A
0.02	1.96	7.10	0.55	-	99.36	1	BR-F
0.03	0.52	3.48	4.59	-	98.42	3	MRG1
0.02	2.21	5.00	1.57	-	97.80	5	MRG2
0.83	0.25	0.20	0.00	-	98.49	1	BR-B

unpublished data (1990); Amp, amphibolite; Um, ultramafic gneiss; Gn, granitic gneiss; Qtz, magnetite quartzite; W, Woolsey area; VR, Villa Rica area; NG, New Georgia area; All, various localities; –, not determined.

neutron activation analysis (INAA) at the United States Geological Survey facility in Reston, Virginia on 27 samples from the three study areas (table 2). Precision for INAA data as determined from duplicate analyses is generally below ± 10 percent for all elements except Sr and Ba which are ± 15 to 30 percent. Trace element and REE analyses of 8 additional samples were done by INAA at Massachussetts Institute of Technology (table 2). Precision for M.I.T. trace element data is generally better than ± 10 percent for most elements based on counting statistics alone. Exceptions to the precisions outlined here occur in some samples that contain extremely low abundances of elements such as Th, Ta, and in one case REE. These samples are noted in the following discussion; in no case does this affect our interpretations. U.S.G.S. and M.I.T. data of samples from the same outcrop area (for example, MR-8 and NG705) give consistent results on REE plots and discriminant diagrams indicating that these data are comparable.

Approach.—In any geochemical study involving rocks subjected to metamorphism and deformation, the problem of element mobility is of prime importance. Many lithologies in the southern Appalachians are considered to have originated in an oceanic environment (Stow, Neilson, and Neathery, 1984; Misra and McSween, 1984); thus, the problem is compounded by the possibility that they may have undergone seafloor alteration and hydrothermal metamorphism prior to regional metamorphism and deformation. For these reasons interpretations based solely upon major element data are of questionable value. We have thus attempted to restrict ourselves to the use of trace elements considered immobile during the processes outlined above.

TABLE 2 *Trace element data for lithologies*

Sample	Type	Area	Cr	Ni	Rb	Sr	Zr	Ba	La	Ce
VR-10	Gn	VR	5	-	14	1120	96	292	11.30	19.6
VR-12	Gn	VR	8	-	13	970	115	239	6.17	10.4
VR-15	Gn	VR	7	-	19	1000	91	443	13.02	22.3
VR-16	Gn	VR	7	-	18	1040	102	354	14.81	25.7
VR-26	Gn	VR	<2	-	32	120	172	296	3.78	17.3
VR-30	Gn	VR	4	-	17	1020	104	303	9.20	16.0
VR-32	Gn	VR	5	-	22	880	85	284	9.90	19.0
VR-35	Gn	VR	2	-	<14	280	265	78	20.20	43.5
VR-36	Gn	VR	2	-	19	850	106	217	5.33	9.4
VR-19	Gn	VR	29	-	7	810	118	123	7.74	15.0
VR-5a	Gn	VR	21	-	102	185	108	543	21.53	29.7
MR-1	Gn	NG	7	-	240	59	118	251	51.21	65.5
MR-2	Gn	NG	9	-	279	44	103	182	29.90	56.3
MR-6	Gn	NG	5	-	61	896	113	692	5.15	9.3
WG-3	Gn	W	<4	-	215	340	377	1640	92.95	203.1
WG-4	Gn	W	12	-	73	308	180	819	33.70	44.9
SM-1	Gn	W	1	-	77	225	56	950	10.00	19.1
VR-17	Amp	VR	254	109	3	139	85	39	2.38	6.6
VR-20	Amp	VR	353	80	7	300	61	80	4.05	9.7
VR-33	Amp	VR	28	17	9	235	70	95	7.62	13.4
VR-34	Amp	VR	119	67	<2	135	46	26	2.85	6.4
VR-37	Amp	VR	505	131	4	123	33	73	2.93	4.7
OC-1	Amp	C	571	219	2	440	57	50	40.13	13.0
MR-8	Amp	NG	48	22	5	400	82	112	5.83	14.2
WU-1	Um	W	1453	565	<2	9	23	44	42.61	9.1
VR-27	Um	VR	2840	1420	2	25	7	6	1.63	5.9
VR-29	Um	VR	3280	1490	3	61	9	14	2.35	7.9
BR708*	Amp	W	139	-	<13	-	-	52	4.18	14.4
BR710*	Gab	W	466	-	8	-	-	33	1.10	3.1
BR712*	Um	W	1509	-	<14	-	-	<21	1.32	3.8
BR713*	Gn	W	3	-	52	-	-	637	1.83	4.2
BR715*	Amp	W	182	-	<11	-	-	36	3.24	11.6
NG705*	Amp	NG	9	-	<13	-	-	44	3.03	12.8
NG706*	Amp	NG	16	-	<12	-	-	<67	3.65	11.1
VRUM*	Um	VR	3347	-	<12	-	-	<20	0.07	0.8

Notes: *, samples analyzed at M.I.T., others done by U.S.G.S. (see text); All analyses in ppm; Amp, amphibolite; Um, ultramafic gneiss; Gn, granitic gneiss; Qtz, magnetite

It is well established that large ion lithophile (LIL) elements such as K, Rb, Cs, Sr, and Ba may be mobile during alteration and metamorphism (Cann, 1970; Pearce and Cann, 1973; Pearce, 1983). Enrichment of the LIL elements, however, is important in identifying volcanic rocks erupted in suprasubduction zone (SSZ) environments (Pearce, 1982, 1983). Th is the only LIL element considered to be relatively immobile (Pharoah and Pearce, 1984; Saunders and Tarney, 1984); therefore, tectonic classification schemes using Th as representative of the LIL elements are most suitable. Trace elements with high ionic potential (high field strength or HFS elements) such as Ta, Nb, Hf, Zr, *of the Ropes Creek assemblage*

Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Th	Y	Nb
7.7	1.33	0.40	0.14	0.17	0.03	2.38	0.04	3.17	5	<1
6.6	1.21	0.48	0.17	0.26	0.04	2.60	0.12	1.37	<5	1.2
8.6	1.51	0.48	0.17	0.21	0.03	2.07	0.08	3.13	6	1.1
8.8	1.66	0.49	0.18	0.16	0.03	2.35	0.06	3.30	5	1.0
7.1	1.85	0.28	0.37	4.39	0.71	5.13	0.25	4.76	23	3.6
<6	1.27	0.40	0.14	<0.2	0.03	2.05	0.05	2.27	5	1.0
6.9	1.21	0.32	0.12	0.18	0.03	2.48	0.13	2.82	5	1.3
38.6	12.80	2.85	2.53	9.77	1.39	7.24	0.39	3.51	101	4.6
3.8	0.98	0.31	0.12	0.21	0.03	2.25	0.08	1.15	5	1.0
8.3	1.86	0.60	0.25	0.48	0.08	2.53	0.15	1.58	7	1.7
14.4	3.56	0.62	0.74	1.75	0.30	4.58	0.57	16.50	18	5.2
39.8	9.41	0.69	1.76	6.19	0.91	3.64	2.98	17.30	64	25.0
27.1	7.70	0.48	2.10	8.41	1.18	3.74	2.72	29.20	88	23.1
5.2	1.09	0.36	0.16	0.34	0.05	2.43	0.12	1.83	5	-
84.0	14.11	1.96	1.34	1.62	0.21	9.42	0.83	44.50	32	15.0
26.0	5.69	1.32	0.92	2.87	0.42	3.64	0.40	5.17	28	4.1
8.0	1.77	0.48	0.29	0.62	0.09	1.65	0.18	3.46	12	3.1
7.3	2.75	0.82	0.70	3.04	0.46	1.96	0.29	<0.7	28	3.4
9.6	2.83	1.05	0.67	2.53	0.39	1.47	0.19	<0.7	26	2.4
13.7	4.09	1.39	0.79	3.70	0.53	1.61	<0.2	1.11	33	1.0
6.7	1.91	0.68	0.43	1.84	2.53	1.04	0.07	0.49	18	<1.0
5.0	1.28	0.47	0.30	1.18	0.18	0.81	0.05	0.30	9	<1.0
63.0	17.50	5.02	2.89	7.49	1.02	1.51	0.06	0.77	65	<1.0
10.4	3.28	1.17	0.84	2.86	0.49	2.10	0.15	1.10	28	1.3
78.1	24.42	6.76	4.08	11.60	1.51	0.65	<0.07	<0.7	82	<1
3.0	0.43	0.32	0.07	0.31	0.04	<0.5	<0.02	<0.3	8	<1
4.6	0.84	0.21	<0.1	<0.4	0.03	<0.5	<0.03	<0.5	7	<1
15.5	4.68	1.53	1.11	4.24	0.68	3.62	0.25	<0.2	-	-
2.6	0.76	0.32	0.19	0.70	0.14	0.39	<0.15	<0.1	-	-
3.3	1.11	0.47	0.35	1.21	0.19	0.72	0.10	<0.1	-	-
1.5	0.50	0.25	0.19	1.79	0.31	3.32	0.38	9.3	-	-
12.2	3.92	1.49	1.07	1.62	0.61	2.79	0.09	<0.2	-	-
9.0	3.21	1.10	0.94	3.26	0.51	2.20	0.12	1.0	-	-
7.5	2.87	1.12	0.75	2.70	0.43	1.73	0.15	0.7	-	-
<2.2	0.03	0.01	<0.02	0.06	0.02	0.18	0.13	-	-	-

quartzite; W, Woolsey area; VR, Villa Rica area; NG, New Georgia area; C, near city of Carrollton; –, not analyzed.

Y, Cr, along with the REE are considered generally immobile (Cann, 1970; Pearce and Cann, 1973; Pearce, 1983).

REE plots may discriminate within-plate basalts (Hawaii, Columbia River Plateau) from island arc tholeiites (IAT) and mid-ocean ridge basalts (MORB) (Basaltic Volcanism Study Project, 1981). IAT and MORB, however, cannot be distinguished solely on this basis. MORB normalized multi-element plots (Pearce, 1983) allow basalts erupted in different tectonic environments to be identified on the basis of characteristic patterns. Basaltic rocks erupted in a suprasubduction zone setting are characterized by selective enrichments in the SSZ component elements (Sr, Rb, Ba, Th, Ce, Sm) relative to Ta, Nb, Hf, and Zr on MORB normalized multi-element plots (Pearce, 1983; Pearce, Lippard, and Roberts, 1984). SSZ component enrichments are thought to be caused by the transport of these elements into the overlying zone of mantle melting by aqueous fluids derived from dehydration of the downgoing slab (Hawkesworth and others, 1977; Saunders and Tarney, 1984). We have modified Pearce's original plot by omitting K and adding Cr and Ni as a fractionation index. Several tectonic discriminant diagrams have been developed for basaltic rocks. We use the Th/Yb versus Ta/Yb (Pearch, 1982) and Th-Hf/3-Ta (Wood, 1980) diagrams as these involve immobile trace elements, the most immobile LIL element — Th, and effectively discriminate between IAT and MORB. The Th/Yb versus Ta/Yb diagram may also discriminate between IAT and basaltic rocks erupted in a continental arc environment (Pearce, 1982).

Some workers have proposed using major element data for tectonic discrimination of granitic rocks (Maniar and Piccoli, 1989). The potential for element mobility, however, precludes using such an approach in areas such as the southern Appalachians. REE plots may aid in identifying granitic rocks that are differentiates of coexisting mafic rocks and can serve to identify those that have experienced similar evolutions. In a technique analogous to that applied to basaltic rocks, granitic rocks can be plotted on multi-element diagrams normalized to a hypothetical ocean ridge granite (ORG) (Pearce, Harris, and Tindle, 1984). This type of diagram can identify a SSZ component as can MORB normalized plots. Pearce, Harris, and Tindle (1984) developed a number of tectonic discriminant diagrams for granitic rocks. We use the Ta versus Yb plot, since these elements were analyzed in all our samples and are both considered immobile.

Independent evidence that extensive element mobility has not occurred may be obtained from comparison of major element data with that for inferred protoliths and from correlations between incompatible trace element abundances. For example, the major element chemistry (discussed below) of amphibolites and granitic gneisses is consistent with typical values for the inferred protoliths of tholeiitic basalts and volcanic arc granites or ocean ridge granites, suggesting that major element redistribution is minimal. Furthermore, variations in incompatible trace elements such as Y, Yb, Hf, Ta, Nb, Th, and REE are generally well correlated. In contrast, correlations between elements such as Rb, Sr, and Ba are poor, suggesting that these have been mobile.

Major element geochemistry.—A compilation of representative data on major element chemistry of the lithologies in the Ropes Creek assemblage is presented in table 1. Included in this table are averages of multiple analyses of the Ropes Creek amphibolite from Higgins and others (1988) and the Villa Rica Gneiss (D. Sanders, unpublished data, 1990) for comparison. The Ropes Creek amphibolite is characterized by low K_2O and moderate TiO_2 abundances. It is similar in major element composition to average tholeiitic basalts (LeMaitre, 1976). The actinolite gneiss (BR-C) is characterized by SiO_2 abundances slightly below the low end of the range for Ropes Creek amphibolites (Higgins and other, 1988), lower $Fe_2O_3^*$, CaO, Na_2O, and higher MgO. The abundance of Al_2O_3 in the ultramafic gneisses is relatively high, suggestive of plagioclase accumulation in the protolith. Two samples of granitic gneiss (BR-A and BR-F) from the Woolsey area are distinctly different. BR-A is from the main gneiss body at the center of the area (fig. 3) whereas BR-F is from the concordant layer of gneiss within the upper amphibolites. BR-F is higher in SiO_2 and Na_2O and lower in $Fe_2O_3^*$, MgO, and K_2O. It is very similar to the average of analyses for the Villa Rica Gneiss (table 1) with which it shares trace element characteristics (see below). Granitic gneisses in the New Georgia area are of two types, a high K_2O and a low K_2O variety (MRG1 and MRG2, respectively). The low K_2O type is almost identical in major element chemistry to the Villa Rica Gneiss average, whereas the high K_2O type is distinctly different having a higher abundance of SiO_2 and lower abundances of Al_2O_3, $Fe_2O_3^*$, MgO, and CaO. We present one analysis of a magnetite quartzite in table 1. Abrams and McConnell (1984) present an extensive list of analyses of this rock type. These rocks are highly variable in composition, with SiO_2 abundances ranging from 20.0 to 95.1 wt percent, $Fe_2O_3^*$ from 3.8 to 60.2 wt percent, and MnO abundances up to 53.7 wt percent.

Woolsey Area.—Metabasalts from the Woolsey area (fig. 4A) are characterized by REE abundances ranging from 10 to 25 × chondrite and light rare earth element (LREE) depleted patterns ($(La/Sm)_n = 0.51$ to 0.66; subscript n indicates normalized values). This type of REE pattern is typical of modern N-type MORB and basalts from many ophiolite complexes (Kay and Senechal, 1976; Sun, Nesbitt, and Sharaskin, 1979; Pallister and Knight, 1981; Norrell and Harper, 1990). REE patterns of a metagabbro and a meta-ultramafic sample (fig. 4A) also exhibit LREE depletion ($(La/Sm)_n = 0.73$ to 0.89) with abundances at 3 to 8 × chondrite. These patterns suggest the metagabbros and ultramafic rocks may be related to the basaltic rocks by fractional crystallization.

Metabasalts from the Woolsey area do not show patterns indicative of a SSZ component on MORB normalized plots (fig. 5A). Enrichment in Rb and Ba is not considered diagnostic as these elements are highly mobile and are present at or near detection limits. Th abundances are depleted relative to MORB (anomalously low) and are probably more representative of primary (igneous) LIL element values. Th abundances for Woolsey mafic samples are at detection limits; thus values plotted are maximums. Depletions in Cr suggest these samples are somewhat more fractionated than average MORB, therefore, original abundances of immobile elements may have been below MORB. Also plotted (fig. 5A) are the metagabbro and the meta-ultramafic samples shown in figure 4A. These have low abundances of the immobile incompatible elements and

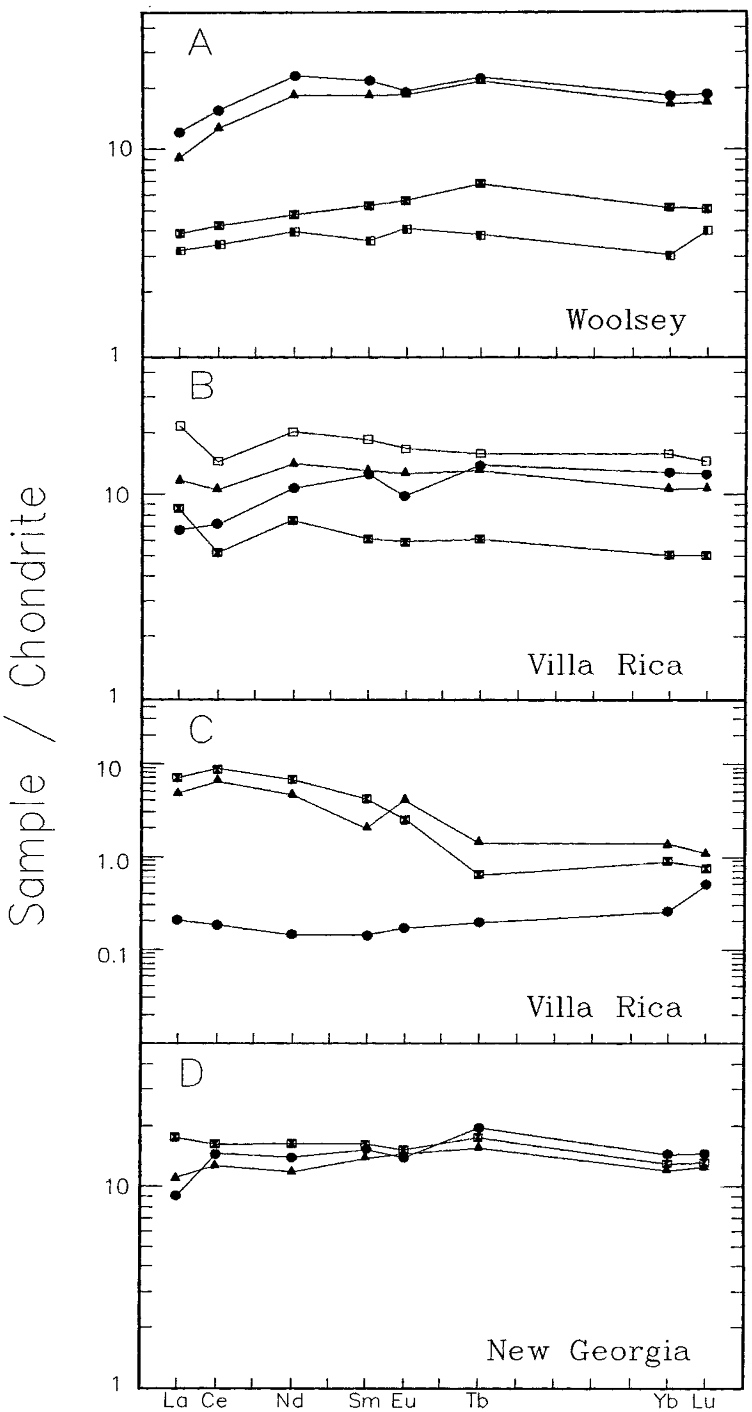

Fig. 4. Chondrite normalized REE plots of mafic and ultramafic rocks. (A) Left filled squares = metagabbro, x-filled squares = meta-ultramafic, other symbols = metabasalts; (B) all symbols = metabasalts; (C) filled circles = harzburgite, other symbols = meta-ultramafics; (D) all symbols = metabasalts. Chondrite normalization factors from Masuda, Nakamura, and Tanaka (1973).

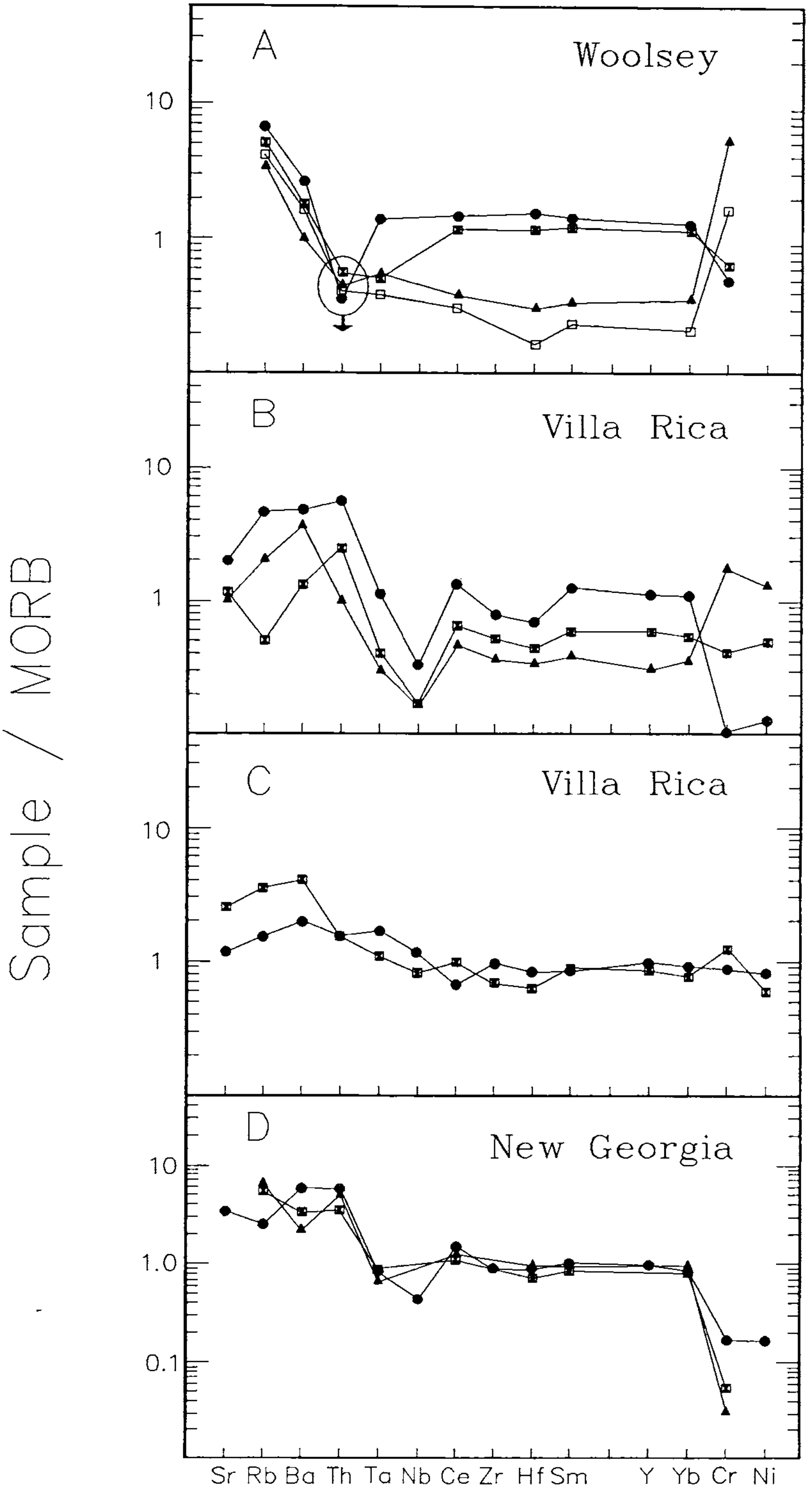

Fig. 5. MORB normalized multi-element plots of mafic and ultramafic rocks. (A) Open squares = metagabbro, filled triangles = meta-ultramafic, other symbols = metabasalts; (B,C,D) all symbols = metabasalts. Elements circled with downward arrow are plotted as maximum values (see text). MORB normalization values from Pearce (1983).

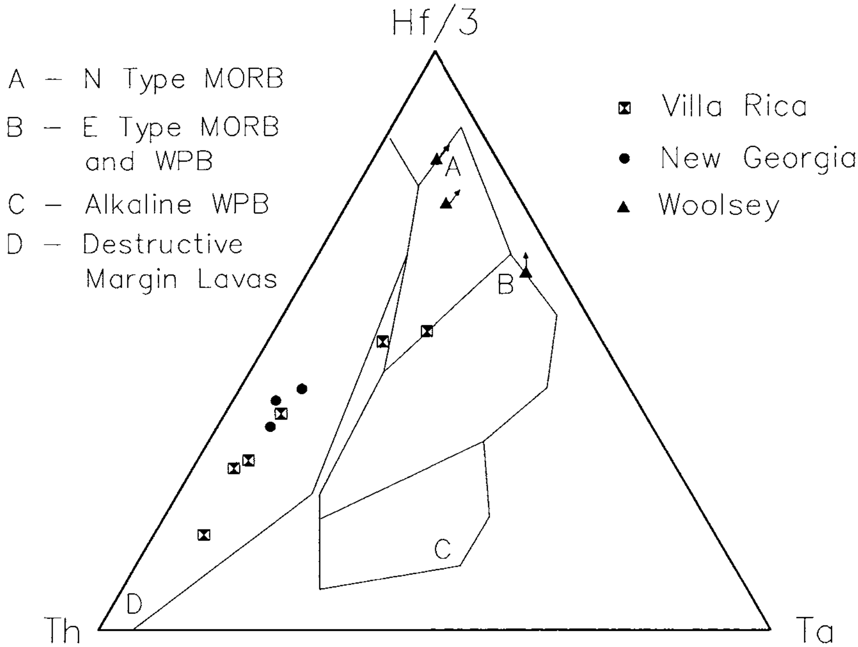

Fig. 6. Th-Hf/3-Ta tectonic discriminant diagram (after Wood, 1980) for mafic rocks. Samples with arrows are plotted as maximum values (see text).

high Cr values. These data further suggest that these samples may be related to the metabasalts by crystal fractionation or accumulation.

Metabasalts fall in the N-MORB and E-MORB fields on the Th-Hf/3-Ta diagram (fig. 6). These samples also plot in (or below in one case) in the MORB field on the Th/Yb versus Ta/Yb diagram (fig. 7). On either of these diagrams the addition of a SSZ component (represented by Th) will result in the displacement of data points into the fields of destructive margin lavas (fig. 6) or oceanic arcs (fig. 7). Th abundances plotted for these rocks are maximums, and Ta for one sample is near detection limits; lower values for these elements will result in displacement of the data points farther into the MORB fields and away from the arc fields on both diagrams (indicated by arrows).

Figure 8 shows REE plots of a meta-ultramafic sample from the Woolsey area, an epidotized amphibolite from exposures of the Ropes Creek assemblage near Carrollton, Georgia (where we have observed pillow structures), a REE pattern of average East Pacific Rise hydrothermal deposits, and a REE pattern of deep sea authigenic phillipsite (a secondary zeolite). This striking pattern, characterized by relative enrichment in the LREE over the heavy rare earth elements (HREE) and a deep, negative Ce anomaly, is typical of hydrothermal deposits at mid-

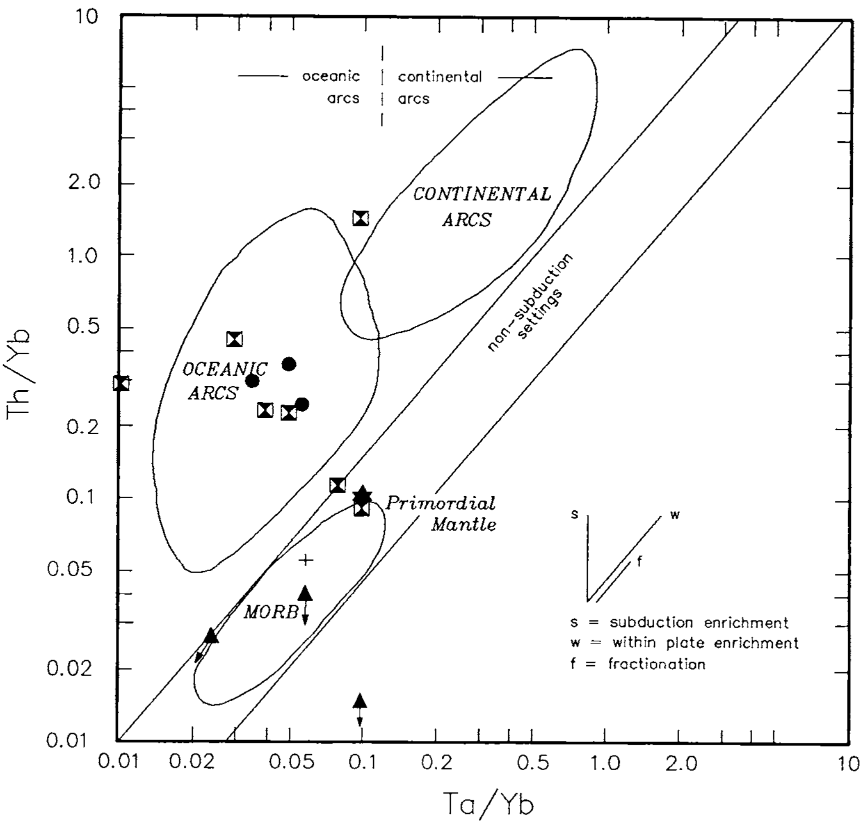

Fig. 7. Ta/Yb versus Th/Yb tectonic discriminant diagram (after Pearce, 1982) for mafic rocks. Samples with arrows are plotted as maximum values (see text). □ Villa Rica; ● New Georgia; ▲ Woolsey.

ocean ridge spreading centers (Fleet, 1983), in back-arc basins (Bonatti and others, 1979), in hydrothermally altered sediments in many ophiolites (Robertson and Fleet, 1976), and in some deep-sea authigenic minerals (Bernat and Church, 1978). Seawater has a similar chondrite normalized REE signature, but at abundances in the 10^{-5} to 10^{-6} × chondrite range (Elderfield and Greaves, 1982). The presence of this distinctive REE pattern in these rocks suggests seawater hydrothermal alteration and/or contamination with a secondary mineral such as phillipsite.

REE plots of granitic rocks from the Woolsey area show large variations in both abundances and patterns (fig. 9A). Abundances range from <10 to 280 × chondrite. All are LREE enriched, and all but one show a depletion in HREE. $(La/Yb)_n$ ranges from 38.2 to 7.8 for the

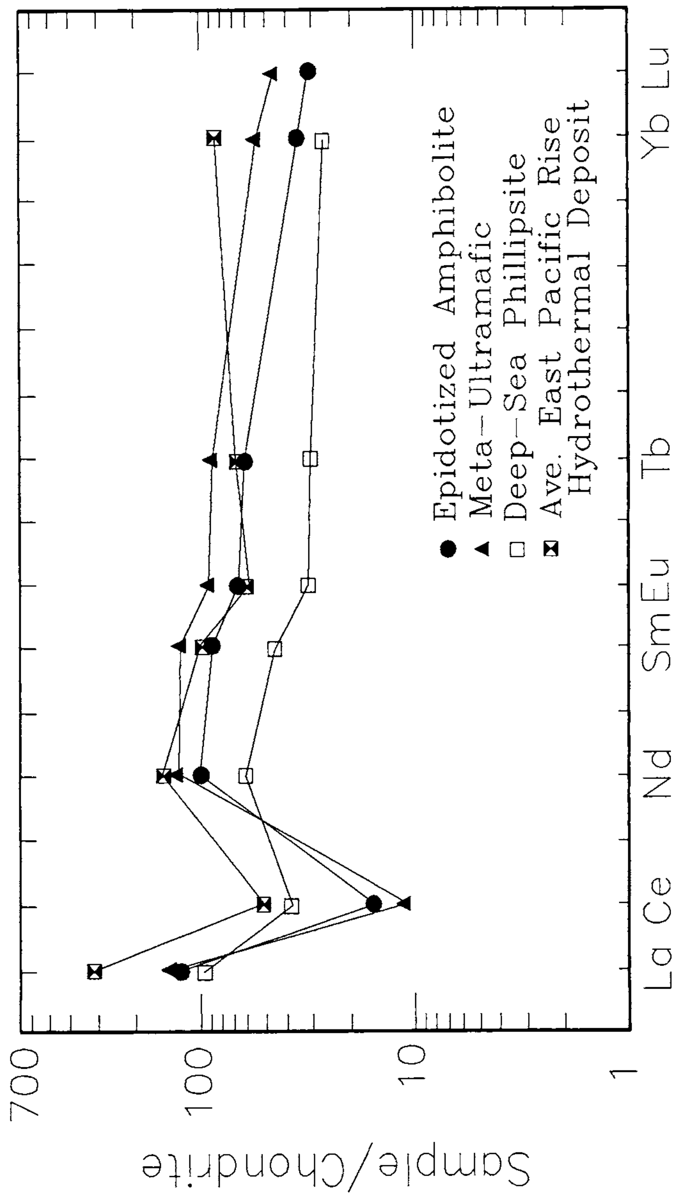

Fig. 8. Chondrite normalized REE plot of meta-ultramafic, epidotized amphibolite, average East Pacific rise hydrothermal deposit (Fleet, 1983), and deep sea authigenic phillipsite (Bernat and Church, 1978). Chondrite normalization factors from Masuda, Nakamura, and Tanaka (1973).

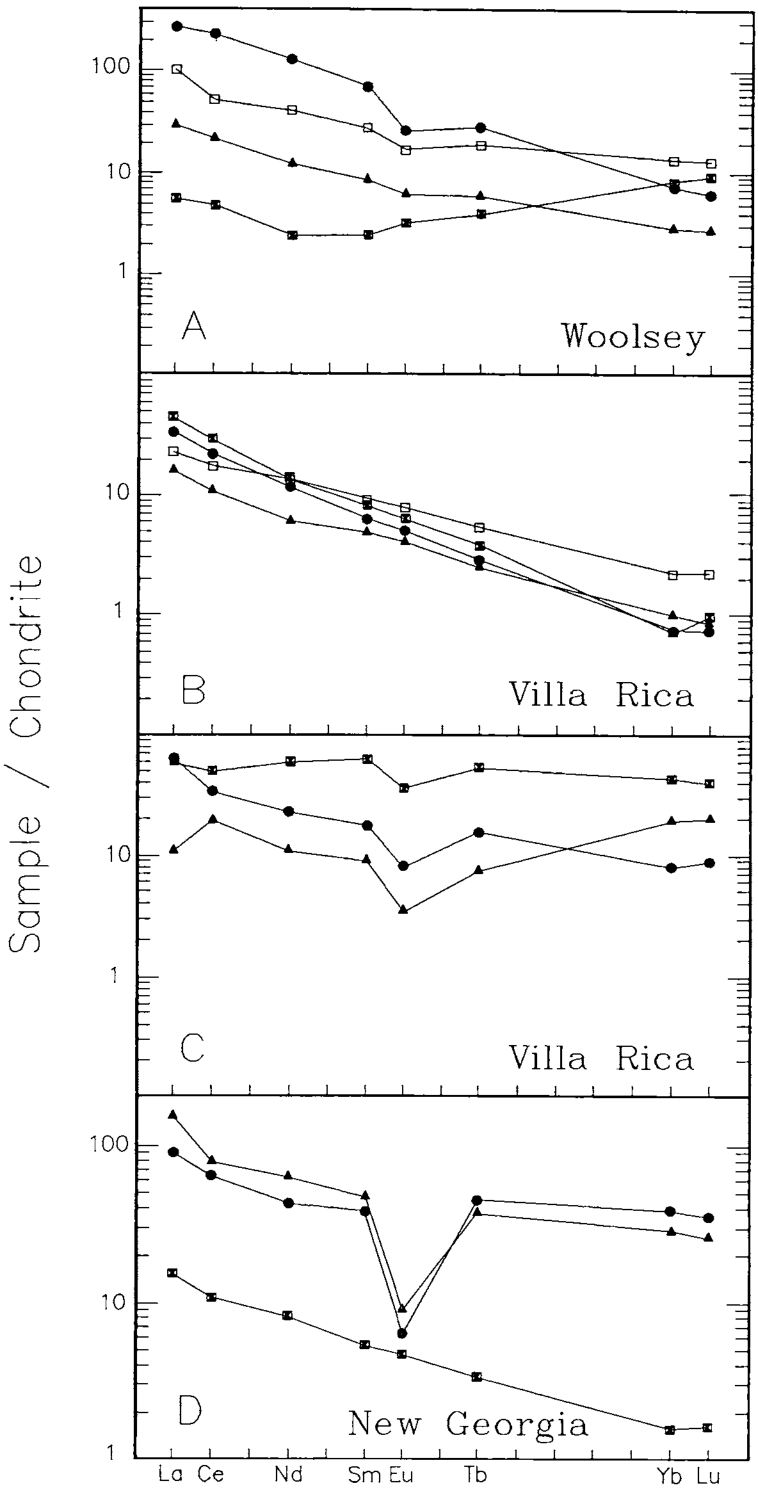

Fig. 9. Chondrite normalized REE plots of granitic rocks. Chondrite normalization factors from Masuda, Nakamura, and Tanaka (1973).

samples showing HREE depletion. The one sample with HREE enrichment is unusual for a granitic rock in that the abundances of all REE are <10 × chondrite, and the pattern is concave upward. This type of REE pattern is typical of many boninites (Hickey and Frey, 1982) and has recently been described for basalts from the Troodos ophiolite (Taylor and Nesbitt, 1988). It is conceivable that such a granitic rock could be produced by fractionation of a basaltic parental magma with a similar but lower REE profile; however, we have identified no mafic rocks with this type of pattern.

Enrichments in Th and Ce relative to Ta and Nb on ORG-normalized plots (fig. 10A) suggest a SSZ component in granitic rocks from the Woolsey area. A sample of the concordant felsic layer in the upper amphibolites has an ORG normalized pattern (as well as REE) identical to those shown by the majority of Villa Rica granitic rocks (discussed below). Depletions in Ce and Sm shown by one sample could be caused by fractionation of a minor phase such as allanite or monazite (which have high distribution coefficients for the LREE). These patterns appear transitional between those of volcanic arc granites (VAG) and supra-subduction zone ORG (Pearce, Harris, and Tindle, 1984).

All granititc rocks from the Woolsey area fall within the field of VAG on the Ta versus Yb discriminant diagram (fig. 11). The fields on this diagram have been empirically derived by plotting granites from known tectonic settings (Pearce, Lippard, and Roberts, 1984). These workers contend that rocks produced in supra-subduction zone settings are thought to be generated from higher degrees of partial melting and thus have lower abundances of incompatible elements. Therefore, a granite from a SSZ ridge segment (back-arc basin) may plot within the VAG field due to lowered abundance of Yb. This may be of importance for samples that plot at the right edge of the VAG field (fig. 11). In conjunction with the fact that these rocks appear transitional to supra-subduction zone ORG (fig. 10A), this suggests that Woolsey gneisses represent granites produced at a back-arc basin ridge segment. The low K_2O contents of these rocks (table 1) is also consistent with this interpretation as K_2O abundances <1 wt percent are considered diagnostic of oceanic granitic rocks (Coleman and Peterman, 1975).

Major element analysis of a magnetite quartzite sample from the Woolsey area is presented in table 1. These rocks contain relatively high abundances of metals such as Cu (105 ppm) and Cr (206 ppm). More extensive analyses of metalliferous quartzites from the vicinity of the New Georgia and Villa Rica areas in the northern Piedmont show these rocks contain up to ~54 wt percent MnO and 0.41 ppm Au (Abrams and McConnell, 1984). The chemistry of these rocks is similar to hydrothermally altered (low T) Fe-Mn rich sediments from spreading centers in the Atlantic and Pacific oceans, from back-arc basins, and from ophiolites (Bonatti, 1975; Bonatti and others, 1979; Robertson and Boyle, 1983).

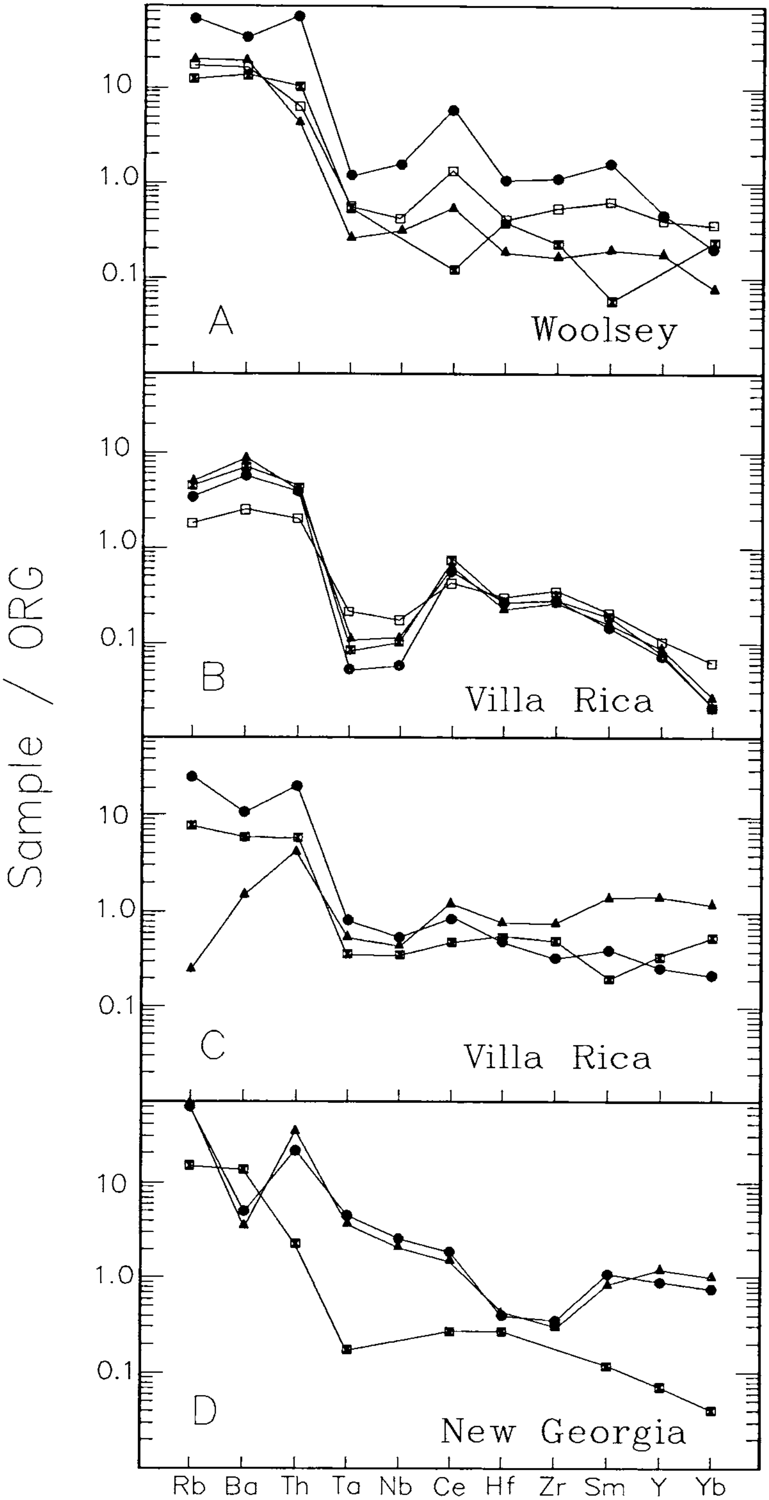

Fig. 10. ORG normalized multi-element plots of granitic rocks. ORG normalizing values from Pearce, Lippard, and Roberts (1984).

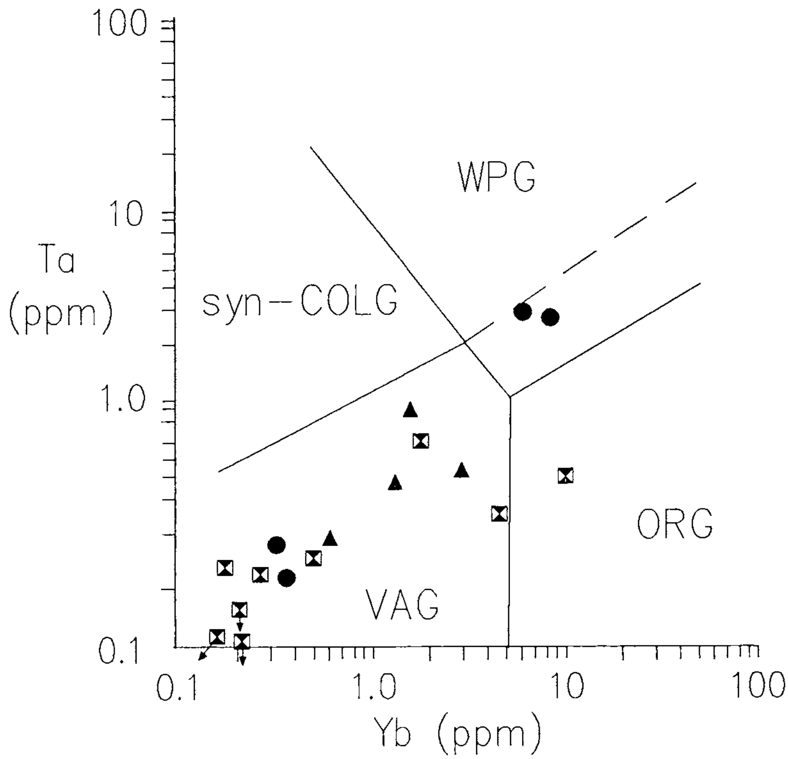

Fig. 11. Ta versus Yb tectonic discriminant diagram (after Pearce, Lippard, and Roberts, 1984) for granitic rocks. WPG = within plate granites, ORG = ocean ridge granites, VAG = volcanic arc granites, and syn-COLG = syn-collisional granites. Samples with arrows are plotted as maximum values (see text). ☒ Villa Rica; ● New Georgia; ▲ Woolsey.

Villa Rica Area.—The Villa Rica area contains mafic and ultramafic lithologies ranging from depleted metaharzburgites through metabasalts. Metabasalts are characterized by REE patterns at 5 to 25 × chondrite and range from LREE enriched to LREE depleted ($(La/Sm)_n$ = 1.41 – 0.53) (fig. 4B). LREE enriched samples have negative Ce anomalies. This suggests these rocks have experienced hydrothermal seawater alteration and/or contamination with a secondary phase (but to a lesser extent than samples shown in fig. 8). Meta-ultramafic rocks are characterized by REE abundances at 0.6 to 9 × chondrites with convex upward LREE patterns (fig. 4C). An analysis of the harzburgite shows it is extremely depleted in REE with abundances at 0.1 to 0.6 × chondrites (fig. 4C). REE abundances for this sample are at or near detection limits, thus its position on this plot is considered representative. It is, however, substantially more depleted than the other ultramafic samples analyzed during this study.

MORB normalized plots of Villa Rica area metabasalts reveal two distinct groups. One group displays a definite SSZ component (fig. 5B). The least fractionated sample (Cr and Ni neither enriched nor depleted) has abundances of the immobile elements at 0.4 to 0.6 × MORB. This is consistent with the chemistry of basalts erupted in a SSZ environment as these rocks are thought to be produced by greater degrees of melting in the mantle source (due to hydrous conditions) and thus possess lower abundances of the incompatible elements than MORB (Pearce, Lippard, and Roberts, 1984). Two samples (fig. 5C) are characterized by abundances of most elements at ~1 × MORB and show no SSZ component.

Tectonic discriminant diagrams (figs. 6, 7) substantiate results from the MORB normalized plots. The three samples that possess a SSZ component plot as arc lavas on both diagrams. Of the two samples that have MORB-like abundances on the multi-element plots one falls in the MORB fields while the other falls between the MORB and arc lavas fields. This may reflect eruption of this sample in a tectonic environment transitional between MORB and IAT (opening back arc basin).

Granitic rocks from the Villa Rica area fall into two groups based on REE patterns: those with no Eu anomaly and extreme HREE depletion, and those with relatively flat patterns and negative Eu anomalies. The majority of samples (n = 7) are characterized by abundances at 8 to 45 × chondrite (LREE) and 0.7 to 2 × chondrite (HREE), a lack of Eu anomalies, and steep negative slopes with $(La/Yb)_n$ ranging from 60.2 to 10.8 (fig. 9B). Other samples show less HREE depletion and possess negative Eu anomalies (fig. 9C). Two of this latter group have patterns similar to plagiogranites from the Troodos (Kay and Senechal, 1976) and Oman (Pallister and Knight, 1981) ophiolites.

On ORG normalized plots, samples that possess HREE depletion (fig. 9B) are characterized by a strong SSZ component (fig. 10B). Low values of Y and Yb along with negative slopes from Hf to Yb shown by these samples are characteristic of many VAG's on these plots (Pearce, Harris, and Tindle, 1984). Other samples appear more similar to ORG (fig. 10C); however, all have a SSZ component to some extent.

When plotted on the Ta versus Yb discriminant diagram, samples with HREE depletion on chondrite normalized REE plots (fig. 9B) fall well within the VAG field (fig. 11). Several of these samples have Ta and Yb abundances near detection limits, thus values plotted are considered maximums. Lower values would cause the data points to fall farther into the VAG field as indicated by arrows. Samples with relatively flat REE patterns (fig. 9C) plot near the VAG-ORG boundary with one in the ORG field. These samples appear similar to ophiolite plagiogranites on REE plots. Again, the location of these points on this plot is consistent with the interpretation that they represent ORG evolved from an original IAT melt.

New Georgia area—Metabasalts from the New Georgia area are characterized by flat REE patterns with abundances ranging from 9 to 20 × chondrite (fig. 4D). This type of REE pattern is typical of MORB which are transitional between N-MORB (derived from previously depleted mantle) and E-MORB (derived from mantle that has undergone an enrichment event) (Sun, Nesbitt, and Sharaskin, 1979).

On a MORB normalized diagram (fig. 5D) these samples show a moderate SSZ component. Abundances of the incompatible immobile elements are at ~1 × MORB: however, original values of these elements were likely lower since these samples have undergone fractionation (indicated by depletions in Cr and Ni). Tectonic discriminant diagrams further suggest that these rocks were erupted in a SSZ setting (figs. 6, 7).

As previously discussed, felsic rocks in the New Georgia area are of two petrographically distinct types. Major element analyses of the resistant, K-feldspar bearing type (Mulberry Rock gneiss) show that this lithology is distinct from samples of the fine grained K-feldspar absent type (table 1). High K_2O Mulberry Rock samples are also quite distinct from a sample of the K_2O poor type on a REE plot (fig. 9D). Whereas the K_2O poor granitic sample appears identical to the majority of Villa Rica samples (depleted HREE), the high K_2O Mulberry Rock samples are characterized by relatively high REE abundances (28–155 × chondrite) and deep negative Eu anomalies.

An ORG normalized plot further illustrates the geochemical differences between these two types of granitic rocks (fig. 10D). High K_2O Mulberry Rock samples are characterized by patterns similar to syn- and post-collisional granites (Pearce, Harris, and Tindle, 1984). The K_2O poor sample, in contrast, has a pattern similar to ORG but indicating some SSZ component and compares favorably with granitic rocks with this pattern from the Villa Rica area.

On the Ta versus Yb discriminant diagram (fig. 11), high K_2O Mulberry Rock samples plot as within plate granites whereas the low K_2O sample plots as VAG. As a whole, these data suggest the high K_2O Mulberry Rock Gneiss exposed in the New Georgia area is unrelated to the other felsic rocks exposed in the three study areas. McConnell and Abrams (1984) and Higgins and others (1988) have suggested that it is actually an exposure of Grenville age Corbin Gneiss.

It is important to note that postcollisional granites may plot in any field except that of ORG on this diagram (Pearce, Harris, and Tindle, 1984). Postcollisional granites, however, should exhibit high K_2O abundances and a lack of deformational fabric (if intruded following the final deformational event) which are not observed together in any granitic rocks in the three study areas.

DISCUSSION

The data presented are consistent with the interpretation that the three areas studied represent exposures of the same lithologic assemblage. Our mapping in the New Georgia and Woolsey areas also supports the contention of Higgins and others (1988) that these rocks are contained within a single thrust sheet. However, further investigation is required to demonstrate with greater certainty that the rocks of this study and others mapped by Higgins and others (1988) as Ropes Creek Metabasalt are contained within the same thrust sheet. The strongest evidence that the same thrust sheet is exposed in each of these areas is the distinctive lithologic assemblage. With the exception of the high K_2O phase of the Mulberry Rock gneiss in the New Georgia area and the depleted harzburgite in the Villa Rica area, the petrologic and stratigraphic sequences appear similar, although the stratigraphic sequence in the Villa Rica area is not well documented. The high K_2O Mulberry Rock Gneiss is petrographically and geochemically distinct from other felsic rocks in the study areas. Although our data do suggest that the high K_2O Mulberry Rock Gneiss is not related to the rest of the Ropes Creek assemblage, it does not necessarily support the contention that it represents an exposure of Grenville age Corbin Gneiss. Major element chemistry of the high K_2O Mulberry Rock Gneiss presented in table 1 is substantially different from that of the Corbin Gneiss published by McConnell and Abrams (1984).

Although the trace and REE chemistry of metabasalts in the three study areas is not identical, a common origin is not ruled out. The present data suggest a progression from IAT to IAT + MORB to MORB signatures in these rocks going from northwest to southeast (Woolsey — Villa Rica — New Georgia) which may place important constraints on tectonic models (discussed below). In contrast, the chemistry of granitic rocks indicates that two of the areas may contain ORG or supra-subduction zone ORG (Woolsey and Villa Rica) and that all three areas contain felsic rocks that possess a distinctive HREE depleted pattern on REE plots and appear to represent VAG on the basis of ORG normalized plots and tectonic discriminant diagrams.

The petrologic, structural, and geochemical data together suggest that the Ropes Creek assemblage represents a disrupted and metamorphosed ophiolite (or ophiolites). Complete ophiolites typically consist of depleted upper mantle rocks (lherzolites, harzburgites, dunites), a cumulate mafic-ultramafic sequence, gabbro, a sheeted dike complex, an extrusive sequence (sheet flows and pillow basalts), and an overlying sedimentary sequence which may include cherts, argillites, and volcaniclastics (Christensen and Smewing, 1981; Harper, 1984). Low-K felsic differentiates of mafic rocks (plagiogranites) are also common in many ophiolites (Coleman and Peterman, 1975). Metamorphosed equivalents of most of these lithologic components have been identified in the Ropes Creek assemblage. Primary volcanic, sedimentary, and igneous structures such as sheeted dikes would not be expected to survive amphibolite facies metamorphism. Evidently the pillow structures were preserved due to their extensive epidotization. Inferred stratigraphic relationships from the Woolsey area combined with lithologic relations from the other study areas suggest that the sequence (from bottom to top) is depleted harzburgite, cumulate ultramafic-mafic rocks, metagabbros, metabasalts, and metabasalts with intercalated siliceous sediments (magnetite quartzites). The presence of xenoliths in granitic rocks in the Villa Rica area suggests that granitic rocks are intrusive in origin.

There are several observations, aside from the stratigraphic and lithologic associations, that are important in suggesting that the Ropes Creek assemblage is a disrupted and metamorphosed ophiolite. These include the presence of epidotized pillow basalts and other evidence of hydrothermal alteration typical of spreading centers and the chemistry of mafic and felsic rocks.

Relict pillow structures have been identified in the Ropes Creek amphibolite at several locations in the west Georgia Piedmont. We have observed these structures both in the Woolsey area (fig. 2) and in another exposure of the Ropes Creek near the city of Carrollton. At both these locations the rocks are extensively epidotized with pillow cores preferentially altered. Epidotized pillow cores occur in the basal pillows of the Josephine ophiolite (Harper, Bowman, and Kuhns, 1988). The formation of epidosites is attributed to the reaction of seawater (at $\sim 250\,^{\circ}C$) with basalt at high water/rock ratios (>1000) in a sub-seafloor hydrothermal system (Seyfried, 1987; Harper, Bowman, and Kuhns, 1988). Extensive epidotization is also common in other ophiolites (for example, the Troodos ophiolite, Schiffman and others 1987; Schiffman and Smith, 1988). The extremely high water/rock ratios required for this type of epidotization indicate that it did not occur during regional metamorphism. Thus, epidotization in the Ropes Creek amphibolite is very likely the result of seafloor hydrothermal processes and was present prior to regional metamorphism.

Mafic and ultramafic samples with enriched REE abundances and deep negative Ce anomalies (fig. 8) are also important in constraining an origin for these rocks. This type of REE pattern is characteristic of seawater, hydrothermally altered sediments, and deep sea authigenic phillipsite (Bernat and Church, 1978; Elderfield and Greaves, 1982; Fleet, 1983). Deep sea hydrothermal sediments and secondary minerals such as phillipsite obtain this REE signature by scavenging REE from seawater during precipitation (Bernat and Church, 1978; Fleet, 1983).

Water/rock ratios required for the formation of these REE patterns by reaction of igneous rock with seawater alone appear to be prohibitively high ($>10^7$). This suggests that these samples may have contained some component of a secondary mineral such as phillipsite and/or hydrothermally altered sediment prior to regional metamorphism. Although the exact mechanism is unclear, these REE signatures do suggest some type of seawater interaction.

The magnetite quartzites associated with Ropes Creek amphibolites are similar in many respects to hydrothermally altered sediments found at seafloor spreading centers and in ophiolites. These rocks are commonly found in direct contact with igneous basement or immediatedly above it (Bonatti and others, 1979; Robertson and Boyle, 1983; Pinto-

Auso and Harper, 1985). Laterally continuous metalliferous sediments are common in the extrusive sequence of the Troodos ophiolite (Boyle and Robertson, 1984). They are characterized by enrichments in Fe, Mn, Zn, Ni, Co, Cu, and Cr and are produced by the precipitation of metals (particularly Fe and Mn) as oxides, hydroxides, and nontronite (a smectite group mineral) from discharging hydrothermal fluids (Bonatti, 1975; Moorby and Cronan, 1983). The high abundances of Fe, Mn, Cu, and Cr in metalliferous quartzites of the Ropes Creek assemblage along with their occurrence within sequences of metabasalts containing pillow structures are consistent with their interpretation as hydrothermally altered sea-floor sediments. The fact that these rocks occur interlayered with the metabasalts may indicate that they were formed during eruptive hiatuses.

There are several possible origins for the granitic rocks exposed in the study areas. These include fractional crystallization of relatively anhydrous melts, fractional crystallization of hydrous melts in which hornblende was a liquidus phase, and partial melting of amphibolitic source rocks.

Samples with relatively flat REE patterns and small negative Eu anomalies (fig. 9A, C) may have formed by fractional crystallization processes from an anhydrous basaltic melt. These samples have patterns similar to plagiogranites found in many ophiolites (Kay and Senechal, 1976; Pallister and Knight, 1981) interpreted to be derived from fractional crystallization of coexisting mafic rocks (Coleman and Peterman, 1975).

In contrast, granitic samples with HREE depleted patterns and little or no Eu anomaly (fig. 9A, B, D) probably were not derived directly by fractional crystallization of an anhydrous melt since such depletion in the HREE requires removal of a hydrous phase such as hornblende having high partition coefficients for these elements. On chondrite normalized REE plots, hornblendes typically show enrichment in the middle and heavy REE and negative Eu anomalies; feldspars are characterized by large positive Eu anomalies and slight enrichments in the LREE (Arth and Barker, 1976; Gromet and Silver, 1983). Removal of hornblende alone during fractional crystallization would therefore result in depleted HREE and positive Eu anomalies in the residual melt. If, however, plagioclase were also a fractionating phase the removal of Eu from the melt could offset this positive anomaly. The result would be a felsic differentiate having a negative slope (depleted HREE) and little or no Eu anomaly on REE plots as is observed (fig. 9A, B, D). Alternatively, partial melting of an amphibolite source rock leaving plagioclase and hornblende in the residue could produce these REE patterns. The absence of intermediate differentiation products (that is, andesitic compositions) suggests the partial melting origin may be more viable. Our data alone, however, are not sufficient to distinguish between the two hypotheses. If these rocks were produced by partial melting, their VAG trace element signatures and REE patterns suggest a likely origin is from melting of amphibolites at, or near the base of, an island arc.

The field, petrologic, and geochemical data presented above place important constraints on tectonic models for the southern Appalachians. We have observed the Ropes Creek assemblage to be in thrust contact with and structurally above the Paulding thrust sheet (arc complex) in the New Georgia region, and Higgins and others (1988) have observed this structural relationship elsewhere in the Georgia Piedmont. The occurrence of granitic rocks with VAG signatures in the Ropes Creek assemblage further suggests that it was thrust over an arc complex. Upon back-arc basin closure, ophiolites are often thrust over an associated arc complex (for example, the Josephine Ophiolite, Harper, 1984). The thrust sheet stacking order presented by Higgins and others (1988) suggests higher level thrust sheets are farther travelled while lower level thrust sheets originated closer to the North American continental margin. This stacking order is identical to that inferred for the Taconic Allochthon in New England and New York (Rowley and Kidd, 1981). These relationships suggest the Ropes Creek assemblage formed seaward of an island arc. Since a SSZ component is present, a subduction zone is inferred to have been dipping (to the east) beneath the spreading axis. A tectonic model consistent with these constraints should, therefore, include a seaward (east) dipping subduction zone underlying an island arc off the North American margin. Hatcher (1987) does infer this geometry. The Ropes Creek assemblage may have originated at a spreading axis just seaward of an arc and above the subduction zone such that enrichments in the SSZ elements occurred. The most viable tectonic scenario to explain these geometrical relationships is a back-arc spreading center. The suggestion of a spatial distribution of tectonic settings for mafic rocks of IAT → IAT + MORB → MORB progressing from northwest to southeast is consistent with this interpretation. The fact that mafic rocks analyzed thus far from the easternmost area (Woolsey) exhibit no SSZ component may indicate that as the inferred back-arc basin opened the spreading axis was spatially separated from the subduction zone. A possible metamorphosed ash layer present in the upper Woolsey amphibolites has identical geochemical signatures to the Villa Rica VAG suggesting that, although this area was no longer spatially above the subduction zone, it was nevertheless in close proximity. During closure of the back-arc basin, the oceanic lithosphere was apparently thrust over the arc complex where it was intruded by VAG.

CONCLUSIONS

The results of this study lead to the following basic conclusions:

1. Ophiolites do exist in the southern Appalachians, but their recognition has been hampered by poor exposures, deep weathering, and multiple metamorphic and deformational events.

2. The Ropes Creek assemblage probably represents the remnants of a disrupted, deformed, and metamorphosed ophiolite (or ophiolites).
3. Available evidence is compatible with the interpretation that rocks of the Ropes Creek assemblage represent a coherent lithologic suite contained within a single thrust sheet.
4. The most likely tectonic environment for formation of the Ropes Creek assemblage is in a back-arc basin above an eastward dipping subduction zone off the margin of North America.
5. The present structural, petrological, and chemical relationships suggest that during convergence back-arc basin lithosphere (Ropes Creek assemblage) was thrust over an associated arc, and volcanic arc granites were emplaced into it.

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