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GEOLOGICAL SURVEY

Bedrock geology and geochemistry of the Anacoco Sur II area, Bolivar State, Venezuela

by

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ABSTRACT

The Anacoco Sur II area lies in an Early Proterozoic greenstone terrane of the Guayana Shield in eastern Bolivar State, Venezuela. Two stratigraphic units comprise the bedrock: an older greenstone succession and a younger ferruginous siltstone (limolita) succession. The greenstone succession include mafic to felsic metavolcanic flows, metatuffs, and associated volcaniclastic metasedimentary rocks. The greenstone rocks are weakly foliated and have been regionally metamorphosed to greenschist facies. These supracrustal rocks are tentatively assigned to the Early Proterozoic Caballape Formation of the Botanamo Group. The ferruginous siltstone succession is made up of fine-grained, massively bedded, unfoliated, and unmetamorphosed rocks that unconformably overlie the greenstone rocks. Stratigraphic correlation of the ferruginous siltstone is uncertain; their age is thought to be Middle Proterozoic (pre-Roraima) in age.

Metavolcanic and volcaniclastic rocks make up 80 percent of the greenstone succession, with volcanogenic metagraywacke and volcanic breccia comprising the remaining part. Minor pillow lavas and metagraywacke occur in the greenstone succession and indicate that the primary depositional environment was in part subaqueous. In addition, the presence of crystal and crystal-lithic andesitic to dacitic metatuff indicates that the Anacoco Sur II area was proximal to an evolving volcanic complex or complexes. The lack of strong penetrative structural fabric in the greenstone rocks implies a low to moderate degree of regional deformation. No evidence for a shear zone was observed.

There is a systematic variation in composition in the volcanic rocks, which range from calc-alkaline basalt to andesite, dacite and rhyolite. The compositional continuum can be explained qualitatively by fractional crystallization of a common calc-alkaline basaltic (or basaltic andesite) parental magma. Early fractionation of mafic minerals depleted subsequent liquids in the major elements iron, magnesium, titanium, and phosphorous and the trace elements manganese, zinc, and ytterium and enriched the liquids in the trace elements strontium, zirconium, barium, and cerium. Fractional crystallization of plagioclase was continuous throughout the evolving magmatic system; fractionation of early anorthite-rich plagioclase caused depletion of calcium and enrichment of aluminum, sodium and potassium.

INTRODUCTION

This work is an outgrowth of the cooperative project between the Corporacion Venezolana de Guayana-Tecnica Minera (CVG-Tecmin) and the U.S. Geological Survey (USGS) (Sidder and others, 1988). Geologic mapping was started in the western part of the study area during April, 1987, by W.C. Day (USGS) and Luis Franco Martinez and Enot Quintana (both of CVG-Tecmin) and was continued eastward from May to August, 1987, by Martinez and Quintana. Exploration geochemistry (soil sampling) was conducted by Ibel Romero (CVG-Tecmin). This report covers the geology and bedrock geochemistry in the western part of the field area visited by W.C. Day.

The Anacoco Sur II area is located on the eastern border of the State of Bolivar, Venezuela, along the Zone in Reclamation, a border zone in dispute with Guyana (pl. 1). The area lies between 61°03′ and 61°05′ west longitude and between 6°43′ and 6°47′ north latitude and is north and adjacent to the

Rio Cuyuni near the village of San Martin de Turumban. The village is approximately 85 kilometers (km) southeast of the town of Tumeremo.

Geological studies have concentrated on two areas. Earlier work on the Anacoco Sur I area was completed west of 61°05' west longitude, northwest of San Martin de Turumban by Sardi (1985) and Simoza (1985). This report focuses on the Anacoco Sur II area east of 61°05' west longitude, which is northeast of San Martin de Turumban. No previous detailed geologic work has been reported for this study area.

The Anacoco Sur II area lies within a terrain of rolling hills with 200-300 m local relief and is covered by dense virgin jungle. Access to the study area is limited to either helicopter, by foot from San Martin de Turumban (8 km), or by boat from the Rio Cuyuni. Our work was conducted primarily along ejes and picas (traverses) cut through the jungle at 1 km spacing. Outcrops are poor and are primarily boulder piles that occur approximately 1/2 to 1 km apart. However, each bedrock unit has a distinctive soil that aids in delineation of map units.

GEOLOGY

Regional geologic setting

Three broad lithotectonic terranes make up the Venezuelan Precambrian Shield, a northern Early Archean terrane, a central and eastern Early Proterozoic terrane, and a central and western Early to Middle Proterozoic terrane. The Anacoco Sur II area lies within the central and eastern terrane. The northern terrane, the Early Archean Imataca Complex, is made up dominantly of granulite, granitic gneiss, amphibolite, and minor iron-formation, metasedimentary rocks, and dolomitic marble (Gibbs and Barron, 1983). The protoliths for the quartzo-feldspathic and mafic granulite and gneiss of the Imataca Complex have a calc-alkaline affinity and are similar to continental igneous rocks (Dougan, 1977). Montgomery and Hurley (1978) dated the protolith of the gneissic rocks at 3.4-3.7 Ga (thousand million years). The Early Archean rocks of the Imataca Complex underwent a regional metamorphic and igneous event possibly during the Late Archean (2.7 Ga). During the Early Proterozoic Trans-Amazonian Orogeny (approximately 2.0 Ga) the Imataca Complex was metamorphosed to granulite facies and intruded by granitoids. (Kalliokoski, 1965; Montgomery and Hurley, 1978; and Gibbs and Barron, 1983).

The central and eastern terrane of the Guayana Shield of Venezuela is underlain by an Early Proterozoic Trans-Amazonian (approximately 2.3-1.9 Ga) granite-greenstone sequence (Gibbs and Barron, 1983) belonging to the Pastora Supergroup and the Botanamo Group. The older Pastora Supergroup granite-greenstone sequence includes basaltic to silicic flows and tuffs, subvolcanic intrusive rocks, and volcanogenic and chemical sedimentary rocks (Case and others; 1984), which have been isoclinally folded and metamorphosed to greenschist and locally to amphibolite facies.

Structurally overlying the Pastora Supergroup in the Anacoco area are the greenstone rocks of the Botanamo Group (Benaim, 1972). The oldest unit in the Botanamo Group is the Caballape Formation, which is composed dominantly of moderately metamorphosed basalt, andesite, dacite, and interlayered graywacke. Andesitic tuff as well as volcanic and tuffaceous breccia are common. The youngest unit in the Botanamo Group is the Los Caribes Formation and is composed of schist, meta-arenite, polymict metaconglomerate, and abundant intermediate to felsic volcanic fragmental rocks (Benaim, 1972; Sardi, 1985).

Early to Middle Proterozoic platform cover rocks (1.9 to 1.5 Ga) form the third major terrane and are located in the central and western part of the Venezuelan Guayana Shield. These rocks include thick sequences of continental sedimentary rocks and anorogenic volcanic and associated intrusive rocks that were deposited on and intruded into the Early Proterozoic greenstone rocks (Gibbs and Barron, 1983). The oldest Middle Proterozoic anorogenic magmatism is represented by the felsic volcanic and associated granitic rocks of the Cuchivero Formation (approximately 1.9-1.7 Ga), which are overlain by the thick sequence of continental sedimentary rocks of the Roraima Group. The Roraima Group (1.75-1.65? Ga) dominantly consists of quartzites and conglomerates with minor interlayered felsic volcanic rocks. The youngest Middle Proterozoic rocks in the Venezuelan Guayana Shield are in the western part and are represented by the anorogenic Parguazan granites (1.55-1.45 Ga).

Local geologic setting

Two major Proterozoic rock types underlie the Anacoco Sur II study area; older greenstone rocks (Caballape Formation) and younger ferruginous siltstone (limolita). The greenstone rocks are made up of about 80 percent basaltic to dacitic metavolcanic flows and associated metapyroclastic rocks, and about 20 percent metavolcanic breccia and metagraywacke. The greenstone rocks have been metamorphosed to greenschist facies (low grade).

The contact of the greenstone rocks with the overlying ferruginous siltstone (limolita) is poorly exposed. However, it is horizontal and thought to be an angular unconformity. The siltstone is unmetamorphosed and unfoliated, and, therefore, is not part of the Early Proterozoic Botanamo Group as suggested by Sardi (1985). Instead, it is correlative with the (pre-Roraima Group) Early to Middle Proterozoic platform cover rock sequence, or with the Middle Proterozoic Roraima Group.

Stratigraphic succession within the greenstone rocks is difficult to determine. Due to the jungle conditions, there is only one outcrop in the study area that yields a reliable strike and dip. Therefore, the local structural setting and stratigraphy for the supracrustal rocks is poorly known and can only be inferred.

The one good outcrop of the supracrustal rocks is of a metagraywacke, located on the western margin of the study area with approximately a north-south strike and 70° west dip (pl. 1). Within the graywacke, primary cut-and-fill sedimentary structures and locally developed graded bedding suggest that the unit is upward-facing and becomes younger to the west. This implies that if the stratigraphic sequence is homoclinal in the study area, the rocks in the eastern part of the study area are stratigraphically lower than those to the west. The range of volcanic rock types provides indirect evidence that supports a westward-younging sequence. Basalt and andesite are common in the east, whereas dacite and rhyolite, as well as volcanogenic graywacke and polymict volcanic breccia, are present along the western part of the area (pl. 1). This is consistent with a model presented by Goodwin (1978) for volcanic succession in greenstone belts in which he noted that typically the lower part of a volcanic succession consists of ultramafic to mafic rocks that evolve upward into more intermediate to felsic rocks.

Description of rock units

Metabasalt, observed in the eastern and central part of the study area (pl. 1), forms flows with locally preserved pillow lavas). Petrographic examination shows that the metabasalt is medium-to fine-grained, dark green, and is non- to weakly-foliated. Phenocrysts include plagioclase, diopside, and Fe-Ti oxide(s). In sample WDV-43A (tables 1 and 2) minor hornblende is present, but is thought to be secondary. Regional greenschist facies metamorphism has developed chlorite, epidote, sericite, quartz, calcite, and Fe-oxide.

Meta-andesite is located in the central and eastern part of the study area and occurs (tables 1 and 2) as crystal tuff (samples WDV-56, WDV-43B, WDV-48, WDV-58, and WDV-59A), crystal-lithic tuff (samples WDV-18, WDV-51, and WDV-24), and crystal-lithic tuff breccia (sample WDV-13). At one locality, the meta-andesite forms a pillowed flow (sample WDV-39). The meta-andesitic metatuff is generally medium to dark green, unfoliated, and has a fine-grained groundmass supporting medium-grained phenocrysts. Phenocrysts include plagioclase and either diopside or hornblende that commonly occur as broken crystal fragments. Autoclasts and lithic fragments are common. The regional metamorphic mineral assemblage includes chlorite, epidote, sericite, calcite, and Fe-oxide(s).

Felsic rocks, present in the western part of the study area, are metadacitic (sample WDV-16) to metarhyolitic (sample WDV-50) crystal tuff (both tables 1 and 2). They are light green with a fine-grained groundmass containing phenocrysts of plagioclase and minor quartz. The phenocrysts occur as medium-grained broken crystal fragments. Locally, clots of fine-grained sericite give the felsic rocks a spotted texture. Sericite and minor epidote and calcite are commonly developed as a result of the greenschist facies metamorphism.

Metagraywacke is present in the westernmost part of the study area. It is greenish gray, unfoliated, fine-grained, and beds range from 1 to 10 cm in thickness. Graded bedding is poorly developed. The matrix is fine-grained and appears to be tuffaceous. The clasts are medium- to fine-grained, angular, moderately to poorly sorted, and include feldspar and mafic mineral (hornblende?) fragments. The contact with the underlying meta-andesitic pyroclastic rocks is gradational, with lithic fragments being common in the lower basal beds. The upper contact of the metagraywacke is poorly exposed but appears to grade into both polymict volcanic breccia and andesitic to dacitic pyroclastic rocks. The regional greenschist facies (low-grade) metamorphism produced only sericite and minor amounts of biotite.

The volcanic breccia, which appears to overlie the metagraywacke, is poorly sorted and poorly bedded. The clasts are polymict, dominantly volcanic and tuffaceous lithic fragments (andesitic to dacitic in composition) with minor metachert and are matrix-supported, angular, and range from 0.5 to 15 cm in diameter. The matrix is tuffaceous. No tectonic fabric, such as foliation or lineation, is developed. The breccia is a volcanogenic sediment that conformably overlies the metagraywacke. Regional greenschist facies metamorphic minerals include sericite and minor chlorite and epidote.

Ferruginous siltstone (limolita) is present throughout the study area. The unit is relatively resistant to weathering and forms steep-sided hills. The siltstone is reddish-brown to orange, fine-grained, well-sorted, with poorly developed massive bedding. The unit is flat-lying and rests with angular discordance on the underlying greenstone rocks. Petrographic

Table 1. Major and trace element abundances for Anacoco Sur II area

[A. Bartel, W. Day, P. Hageman, D. Siems, and J. Taggart, analysts]

	Gabbro	Basalt		Andesite										Dacite	Rhyolite	Graywacke
Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field No.	WDV-41	WDV-43A	WDV-55	WDV-56	WDV-43B	WDV-48	WDV-18	WDV-39	WDV-58	WDV-59A	WDV-51	WDV-24	WDV-13	WDV-16	WDV-50	WDV-23
Major oxides, in weight percent																
SiO_2	51.2	49.9	51.8	53.7	54.9	57.0	57.1	58.5	58.8	59.3	59.4	59.5	60.0	63.0	67.5	55.3
Al_2O_3	14.2	16.5	15.1	16.0	16.1	16.4	15.9	15.8	16.0	15.2	17.7	14.8	13.8	16.5	16.4	16.8
Fe_2O_3t	9.87	13.60	10.80	10.40	10.10	8.43	7.97	8.41	7.59	6.39	6.78	6.67	6.74	5.39	3.67	9.26
MgO	9.22	4.43	5.66	4.01	4.14	3.41	3.93	4.76	4.80	4.55	2.16	5.42	6.17	2.38	1.31	3.86
CaO	7.76	7.26	9.99	9.87	7.52	6.09	7.39	4.24	4.75	7.02	4.11	6.32	5.50	4.31	2.43	5.58
Na_2O	3.48	2.55	1.53	1.94	2.80	3.20	3.41	3.86	4.46	3.50	5.37	3.25	3.21	4.54	6.19	3.77
K_2O	0.24	0.20	<0.02	0.16	0.06	0.65	0.04	0.19	0.25	0.45	0.79	0.54	1.05	0.73	0.35	1.52
TiO_2	0.76	1.19	0.78	0.79	1.16	0.91	0.72	1.22	0.73	0.60	0.80	0.57	0.47	0.68	0.45	0.95
P_2O_5	0.14	0.28	0.10	0.13	0.19	0.18	0.15	0.11	0.14	0.12	0.17	0.12	0.10	0.15	0.10	0.29
MnO	0.15	0.14	0.17	0.14	0.15	0.18	0.13	0.08	0.11	0.09	0.09	0.12	0.12	0.05	0.06	0.14
LOI	3.24	4.34	4.25	3.33	3.32	3.72	3.50	3.05	2.50	2.93	2.29	2.85	2.85	2.05	1.37	2.39
TOTAL	100.26	100.39	100.18	100.47	100.44	100.17	100.24	100.22	100.13	100.15	99.66	100.16	100.01	99.78	99.83	99.86
Mg-number	68.8	43.5	55.3	47.6	49.2	48.8	53.8	57.2	59.9	62.7	42.9	65.7	68.4	51.1	45.7	49.6
Trace elements, in parts per million																
Au (ppb)	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Rb	14	<8	<8	<8	<8	21	<8	<8	12	13	26	19	30	18	15	41
Sr	371	326	95	263	574	413	210	328	500	395	296	343	364	468	330	476
Y	11	23	20	17	23	18	28	16	16	10	22	12	8	10	9	19
Zr	65	123	70	62	121	124	102	119	100	80	141	94	75	146	139	143
Nb	<3	7	<6	<6	6	8	9	<6	<6	<6	7	<3	3	7	<3	6
Zn	112	127	111	98	94	144	108	106	116	108	124	95	103	74	65	103
Ba	129	112	14	124	66	338	77	139	123	167	138	215	314	284	315	792
Ce	18	37	17	21	30	31	38	26	28	25	37	25	25	40	35	55

Mg-number=$Mg/(Mg+Fe^{+2})$, where $Fe^{+2}/Fe^{+3}=0.85$

Table 2. Normative minerals, cation proportions, and differentiation index (D.I.) for the Anacoco Sur II area rocks

[Values calculated assuming all volatiles are H_2O and $Fe^{+2}/Fe^{+3}=0.85$]

	Gabbro	Basalt		Andesite										Dacite	Rhyolite	Graywacke
Column No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Field No.	WDV-41	WDV-43A	WDV-55	WDV-56	WDV-43B	WDV-48	WDV-18	WDV-39	WDV-58	WDV-59A	WDV-51	WDV-24	WDV-13	WDV-16	WDV-50	WDV-23
Quartz		6.19	10.73	12.54	12.68	14.16	13.42	15.54	11.10	14.57	10.32	15.18	14.48	18.95	21.57	6.28
Corundum								1.81	0.09		0.96			0.77	1.67	
Orthoclase	1.43	1.19	0.12	0.95	0.36	3.87	0.24	1.13	1.47	2.67	4.71	3.21	6.25	4.35	2.08	9.08
Albite	29.65	21.78	13.06	16.50	23.82	27.25	29.01	32.86	37.97	29.75	45.90	27.63	27.34	38.70	52.66	32.23
Anorthite	22.57	33.29	34.57	34.66	31.35	28.65	28.11	20.44	22.79	24.55	19.47	24.32	20.27	20.55	11.46	24.68
Wollastonite	6.38	0.51	6.16	5.73	2.05	0.24	3.24			4.03		2.67	2.73			0.57
Enstatite	18.48	11.14	14.22	10.04	10.37	8.55	9.84	11.97	12.03	11.38	5.43	13.56	15.47	5.97	3.28	9.71
Ferrosalite	9.27	15.64	12.80	12.18	11.20	9.56	9.18	8.84	8.67	7.30	7.50	7.76	8.02	5.83	4.03	10.52
Forsterite	3.25															
Fayalite	1.80															
Magnetite	2.13	2.94	2.34	2.25	2.17	1.82	1.72	1.81	1.63	1.38	1.47	1.44	1.46	1.17	0.79	2.01
Ilmenite	1.45	2.28	1.49	1.51	2.22	1.74	1.38	2.33	1.40	1.15	1.54	1.09	0.90	1.30	0.86	1.82
Apatite	0.33	0.67	0.24	0.31	0.45	0.43	0.36	0.26	0.33	0.27	0.41	0.29	0.24	0.36	0.24	0.69
TOTAL	96.74	95.63	95.73	96.67	96.67	96.27	96.50	96.99	97.48	97.05	97.71	97.15	97.16	97.95	98.64	97.59
Salic	53.65	62.45	58.48	64.65	68.21	73.93	70.78	71.78	73.42	71.54	81.36	70.34	68.34	83.32	89.44	72.27
Femic	43.09	33.18	37.25	32.02	28.46	22.34	25.72	25.21	24.06	25.51	16.34	26.81	28.82	14.63	9.20	25.32
Barth's Cations																
Si	48.67	49.76	51.51	52.84	53.68	55.76	55.45	56.35	55.86	56.88	56.49	57.01	57.43	59.98	63.07	53.15
Al	15.91	19.39	17.70	18.55	18.55	18.91	18.20	17.94	17.91	17.18	19.84	16.71	15.57	18.51	18.06	19.03
Fe^{+3}	1.04	1.51	1.20	1.14	1.10	0.92	0.86	0.90	0.80	0.69	0.72	0.71	0.72	0.57	0.38	0.99
Fe^{+2}	5.93	8.56	6.79	6.47	6.24	5.21	4.89	5.12	4.56	3.87	4.07	4.04	4.07	3.24	2.16	5.63
Mg	13.06	6.58	8.39	5.88	6.03	4.97	5.69	6.83	6.80	6.50	3.06	7.74	8.80	3.38	1.82	5.53
Ca	7.90	7.76	10.64	10.41	7.88	6.38	7.69	4.38	4.83	7.21	4.19	6.49	5.64	4.40	2.43	5.75
Na	6.41	4.93	2.95	3.70	5.31	6.07	6.42	7.21	8.21	6.51	9.90	6.04	5.96	8.38	11.21	7.03
K	0.29	0.25	0.03	0.20	0.07	0.81	0.05	0.23	0.30	0.55	0.96	0.66	1.28	0.89	0.42	1.86
H	20.54	28.87	28.19	21.86	21.65	24.27	22.67	19.60	15.84	18.75	14.53	18.21	18.20	13.02	8.54	15.32
Ti	0.54	0.89	0.58	0.58	0.85	0.67	0.53	0.88	0.52	0.43	0.57	0.41	0.34	0.49	0.32	0.69
P	0.11	0.24	0.08	0.10	0.16	0.15	0.12	0.09	0.11	0.10	0.14	0.10	0.08	0.12	0.08	0.24
Mn	0.12	0.12	0.14	0.12	0.12	0.15	0.11	0.07	0.09	0.07	0.07	0.10	0.10	0.04	0.05	0.11
D.I.	31.08	29.17	23.91	29.99	36.86	45.28	42.67	49.53	50.56	46.99	60.93	46.02	48.06	61.99	76.30	47.57

examination shows no metamorphic minerals nor tectonic fabric in the unit, indicating that the unit was not affected by the Lower Proterozoic regional greenschist facies metamorphic and tectonic event. It is not metalimolita as suggested by Sardi (1985).

GEOCHEMISTRY

Analytic methods

Collection of rock samples in the Anacoco Sur II study area for chemical analysis was almost entirely restricted to float samples along ridges or sides of hills. Weathering has produced a thick lateritic soil horizon and, hence, good outcrops are rare. The float samples generally have a thin weathering rind, which was removed before geochemical analysis. Samples chosen for geochemical analysis were 5-10 kg in size and were crushed and ground to -100 mesh powder. The major element oxides SiO_2, Al_2O_3, total Fe (reported as Fe_2O_3t), MgO, CaO, Na_2O, K_2O, TiO_2, P_2O_5, and MnO were analyzed by wavelength-dispersive X-ray fluorescence using the procedure of Taggart and others (1987). The volatile elements H_2O, CO_2, F, and Cl were not analyzed separately, but the reported loss on ignition at 900°C (LOI) is a measure of their total bulk abundance. The trace elements Rb, Sr, Y, Zr, Nb, Zn, Ba, and Ce were analyzed by energy-dispersive X-ray fluorescence and followed the procedure outlined by Johnson and King (1987). Au was analyzed by graphite furnace atomic-absorption after a hydrobromic acid digestion following the method of O'Leary and Meier (1986). However, the Au content of every sample is below the detection limit (<0.002 ppm). The major and trace element abundances are listed in table 1 and the normative mineral abundances (calculated with total volatiles as H_2O and $Fe^{+2}/Fe^{+3}=0.85$) are given in table 2.

Analytic results

In the Anacoco Sur II area all of the Lower Proterozoic supracrustal rocks have experienced regional greenschist facies metamorphism. Therefore, the primary chemical makeup of the rocks probably has been altered and a certain amount of caution must be used in interpreting the chemical analyses. The volcanic rock classification of Jensen (1976), which is based on the less mobile elements Al_2O_3, MgO, FeO, TiO_2, and Fe_2O_3, has been used in order to minimize the effects of alteration due to metamorphism and chemical weathering. As shown in figure 1, the volcanic rocks are dominantly calc-alkaline and range from basalt to rhyolite. The volcanic rocks are all quartz-normative (table 2) and some of the andesitic samples (WDV-39, WDV-58, and WDV-51), as well as the dacitic and rhyolitic samples (WDV-16 and WDV-50), are corundum-normative. The basaltic and andesitic rocks are metaluminous, whereas the dacitic and rhyolitic samples are slightly peraluminous.

Gabbro crops out in the southeastern part of the study area (pl. 1) and may intrude the volcanic rocks. It has a tholeiitic affinity, is olivine-normative (sample WDV-41; table 2, column 1), has a relatively high Mg-number (68.8), and is metaluminous. Using the classification of Jensen (1976), the gabbro is equivalent in composition to high-magnesian basalt (fig. 1).

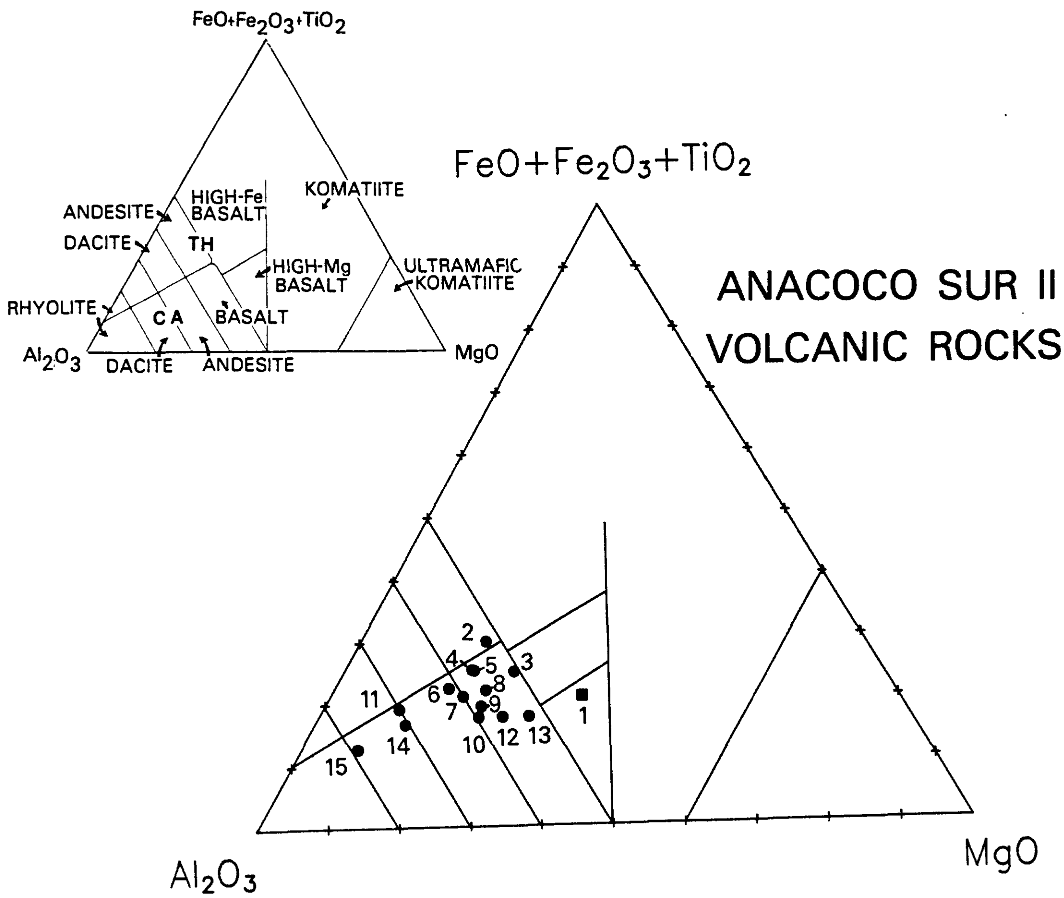

Figure 1. Jensen (1976) diagram showing distribution of the Anacoco Sur II volcanic rocks (dots) and gabbro (square) relative to cation proportions of Al_2O_3 (Al), MgO (Mg), and $FeO+Fe_2O_3+TiO_2$ ($Fe^{+2}+Fe^{+3}+Ti$). Sample numbers refer to the column numbers in table 1. Rocks within the CA field are calc-alkaline and those in the TH field are tholeiitic.

Although some alteration of the primary igneous geochemistry occurred, consistent variations within the data suggest that the volcanic rocks within the Anacoco Sur II area are genetically related. Abundances of the major element oxides--Fe_2O_3t (total iron as Fe_2O_3) and MgO (fig. 2a), TiO_2 and P_2O_5 (fig. 2b) systematically decrease with increasing SiO_2 content--corresponding to a decrease in the modal abundance of the mafic minerals clinopyroxene and hornblende (observed petrographically) as the rocks evolved from basalt to andesite and dacite.

The magnesium number [Mg-number=Mg/(Mg+Fe^{+2})x100] listed in table 1 is a measure of the degree of evolution for a given volcanic rock. In general, less evolved mafic magmas have a higher Mg-number, and become more Fe-rich as the magma becomes more felsic, producing lower Mg-numbers due to fractionation of Mg-Fe silicate minerals (see Grove and Kinzler, 1986). However, the Mg-numbers for the basalt samples are relatively low (43.5 and 55.3), and they actually increase to higher, seemingly more primitive values with increasing SiO_2 content of the andesite. For example, basalt sample WDV-43A has a Mg-number of 43.5 with 49.9 wt. percent SiO_2 (table 1, column 2), whereas andesite sample WDV-13 has a Mg-number of 68.4 with 60.0 wt. percent SiO_2 (table 1, column 13). This is the reverse of typical tholeiitic or primitive calc-alkaline magmatic systems (Grove and Kinzler, 1986). However, fractionation of magnetite, which is common in evolved calc-alkaline systems, would deplete the liquid in Fe, thus causing the Mg/(Mg+Fe) ratio and the Mg-number to increase during evolution of a magma system. Evidence for magnetite fractionation can be seen in the decrease in normative magnetite with increasing SiO_2 content for the basalts and andesites (tables 1 and 2). The decrease in normative magnetite abundance may indicate that magnetite was removed from the evolving parental magma as a result of fractional crystallization and (or) increasing fugacity of oxygen.

A gradual increase in Al_2O_3, Na_2O, and K_2O content and a sharp decrease in CaO abundance also occurs with increasing SiO_2 content (fig. 2c). The concentration of these elements is dominantly controlled by both the fractionation and compositional changes of plagioclase during magma evolution. The plagioclase composition would be more anorthitic in equilibrium with basalt during the early stages of igneous evolution. As CaO was removed from the liquid by fractionation of anorthite-rich plagioclase, the subsequent magmas would become depleted in CaO and relatively enriched in the alkali elements (Bowen, 1956). Therefore, the later cogenetic magmas would be lower in CaO and higher in Na_2O and K_2O, as is seen in the Anacoco Sur II andesitic and dacitic rocks.

Trace element abundances also show systematic variations with evolution of the volcanic rocks. Mn and Zn decrease with increasing SiO_2 content (fig. 3a), whereas the abundances of the lithophile elements Sr (fig. 3b), Ba, and Ce increase (fig. 3c). These variations can be explained by the partitioning of Mn and Zn into the mafic minerals (pyroxene, hornblende, and (or) magnetite) during the early stages of fractionation. The systematic increase in Sr, Ba, and Ce content is common in evolving igneous systems; lithophile elements are not partitioned into the early crystallizing mafic mineral phases but remain in the more felsic liquid. Plagioclase is the only major mineral observed in the Anacoco Sur II igneous rocks that has a high partition coefficient for Sr (Arth, 1976). However, the slight increase in Sr abundance observed (fig. 3b) implies that, although as suggested by the CaO data (fig. 2c) plagioclase was in a liquidus phase, significant quantities of plagioclase

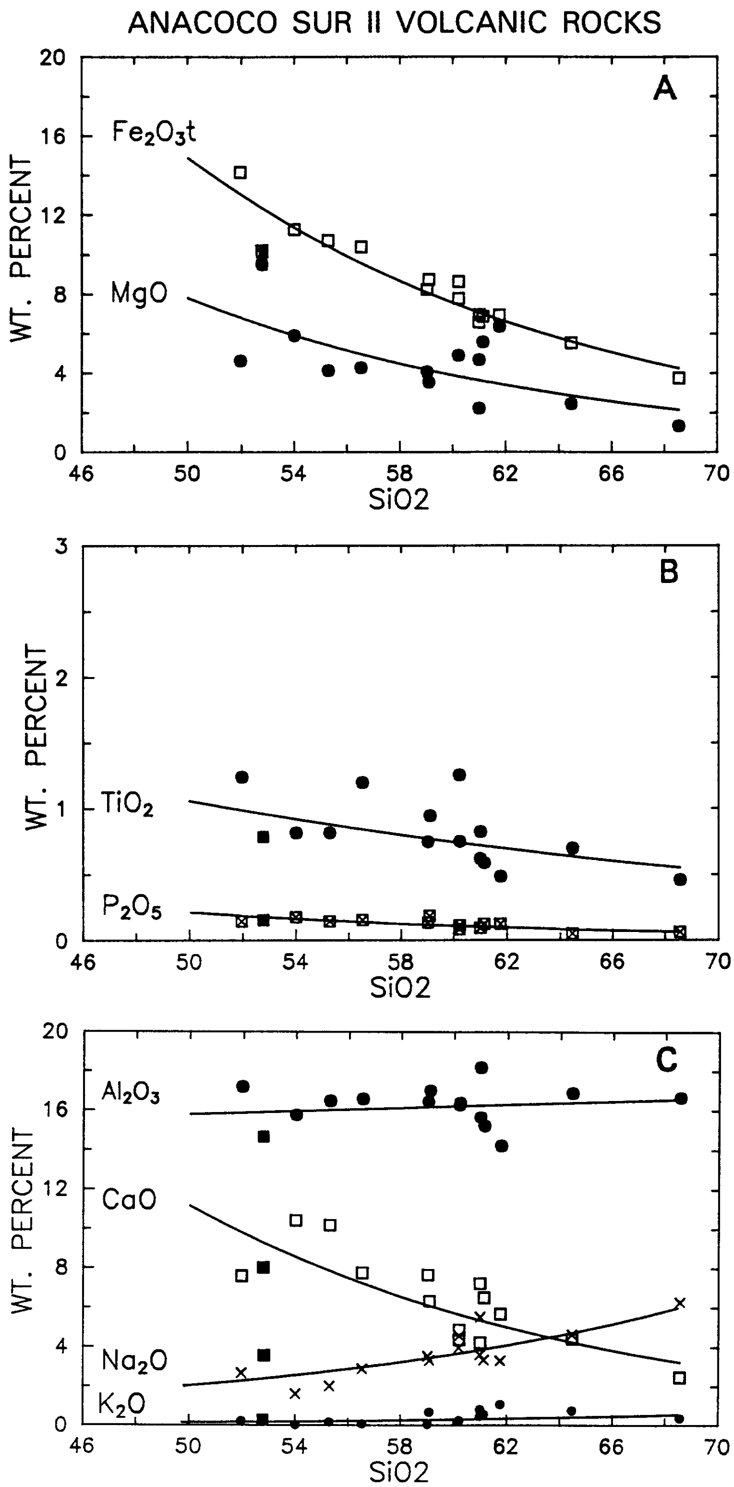

Figure 2. Major element Harker diagram (volatile-free) for the volcanic rocks and gabbro (square) of the Anacoco Sur II area. Figure 2a is SiO_2 vs. Fe_2O_3t (open squares) and MgO (dots), figure 2b is SiO_2 vs. TiO_2 (dots) and P_2O_5 (boxes), and figure 2c is SiO_2 vs. Al_2O_3 (dots), CaO (open squares), Na_2O (x's), and K_2O (small dots).

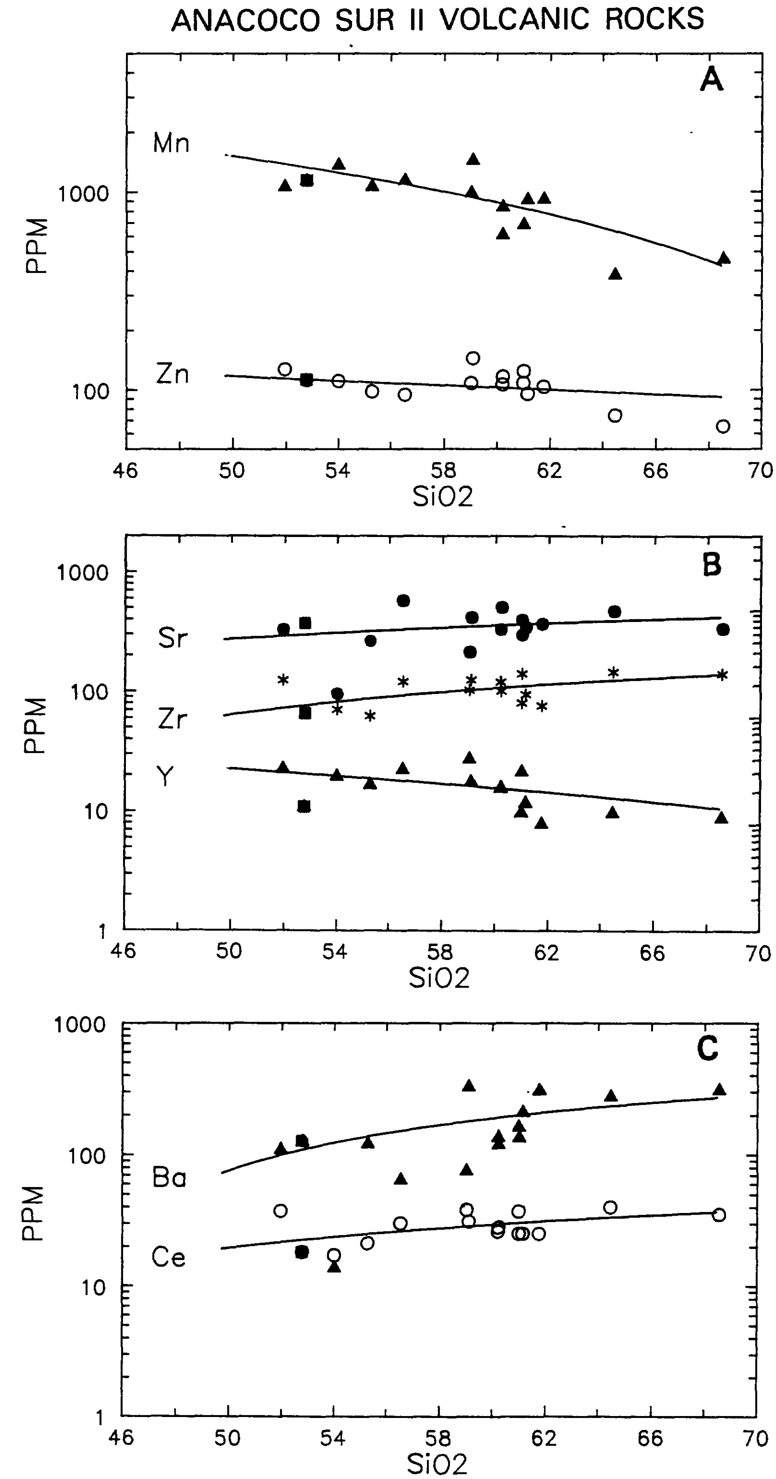

Figure 3. Trace element Harker diagram (SiO_2 volatile-free) for the volcanic rocks and gabbro (square) of the Anacoco Sur II area. Figure 3a is SiO_2 vs. Mn (triangles) and Zn (circles); figure 3b is SiO_2 vs. Sr (dots), Zr (stars), and Y (triangles); figure 3c is SiO_2 vs. Ba (triangles) and Ce (circles).

were not removed from the system in order to have depleted the remaining liquid in Sr.

The high-field-strength elements Zr and Y were geochemically decoupled during evolution of the igneous system; abundances of Zr increase whereas Y adundances decrease with increasing SiO_2 content. This suggests that zircon was not in a liquidus phase, because zircon fractionation would have depleted the evolving magma in both Zr and Y.

One possible explanation for the geochemical decoupling of Zr and Y is the fractionation of hornblende. Hornblende has a higher mineral-liquid distribution coefficient (Kd) for Y than for Zr (the ratio of $Kd_{Y/Zr}^{hbl/l}>1$, where hbl=concentration of the element in hornblende; l=concentration of the element in the liquid) in basaltic through felsic igneous systems. For example, the Kd for Y in basalt is 1 ($Kd_{Y}^{hbl/l}=1.0$), whereas the Kd for Zr is 0.5 ($Kd_{Zr}^{hbl/l}=0.5$). In felsic igneous systems, the hornblende Kd for Y increases to 6 ($Kd_{Y}^{hbl/l}=6$) and that of Zr increases to 4 ($Kd_{Zr}^{hbl/l}=4$) (Pearce and Norry, 1979). Therefore, crystal fractionation of hornblende would result in preferentially depleting the evolving magma in Y relative to Zr.

CONCLUSIONS

The greenstone rocks present in the Anacoco Sur II area are correlated with the Early Proterozoic Caballape Formation of the Botanamo Group. Volcanic and pyroclastic rocks make up about 80 percent of the greenstone rocks, with the volcanogenic metagraywacke and volcanic breccia comprising the remaining part. The presence of pillowed metabasalt and meta-andesite, as well as metagraywacke, indicates that the primary depositional environment was dominantly subaqueous. As stated above, the volcanic and pyroclastic rocks appear to become more felsic to the west (up section?). Additionally, the presence of interlayered meta-andesitic to metarhyolitic crystal and crystal-lithic tuff suggests that these rocks were deposited near to an evolving volcanic complex(s). The absence of volcanic vent-facies rocks, such as coarse felsic volcanic fragments, implies that the volcanic rocks were deposited on the flank(s) of a volcanic complex, and not in the central vent portion. The gradational lower and upper contact of the volcanogenic metagraywacke with the pyroclastic rocks, as well as its immature sedimentologic nature, suggests that the metagraywacke was deposited near its source terrane. No chemical nor iron-rich sediments were observed, implying that the sedimentary environment was dominated by the high-energy input of volcanogenic material.

The structural history of the Anacoco Sur II area is poorly understood as the lack of sufficient bedrock exposures does not allow rigorous structural analysis. However, float samples do allow speculation as to the degree of deformation of the area. All of the greenstone rock types are only weakly foliated and no mesoscopic folds were seen. This indicates a low degree of deformation associated with regional folding. No topographic lineaments, quartz-carbonate veins, nor schist-rich zones that commonly indicate the presence of major shear zones were observed. The greenschist facies metamorphism is typical of Precambrian greenstone belts worldwide and is not thought to represent alteration commonly associated with base-metal-bearing massive sulfide or shear-zone hosted gold deposits.

The ferruginous siltstone (limolita) rests with angular discordance on the greenstone rocks. The absence of greenschist facies metamorphic minerals and superimposed regional tectonic fabric indicates a major hiatus between the siltstone and greenstone units. The unit is not part of the underlying Lower Proterozoic rock sequence, but, instead consists of platformal sediments deposited before or at the same time as the Roraima Group during the Middle Proterozoic.

The geochemical data indicate that the major element content of the volcanic rocks was disturbed either during regional greenschist metamorphism and (or) subsequent chemical weathering. However, both the less mobile major (for example MgO, Al_2O_3, TiO_2, and P_2O_5) and trace elements (for example Zr, Y, and Ce) vary systematically throughout the continuous compositional range from basalt to andesite and dacite. This systematic variation suggests that the igneous rocks in the Anacoco Sur II area represent a cogenetic magmatic series and that they may be related by simple crystal fractionation of a common calc-alkaline basaltic parental liquid.

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