GEOLOGY, GEOCHEMISTRY, AND MINERAL RESOURCES OF THE UPPER CAURA RIVER AREA, BOLIVAR STATE, VENEZUELA

by

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ABSTRACT

Several types of felsic to intermediate composition volcanic rocks, intermediate to mafic dike rocks, and a small body of gabbro were identified during recent geologic mapping in the upper Caura River basin near the confluence of the Guaña River with the Merevari River. Outcrops are abundant along and in the river, and exposures are commonly greater than 100 m^2. The volcanic rocks include rhyolitic to andesitic, porphyritic crystal-rich and crystal-lithic-bearing tuffs. These rocks do not exhibit evidence of regional metamorphism; however, hydrothermal alteration (generally propylitization and silicification) and sulfide mineralization (<1 to about 10 modal % pyrite and traces of chalcopyrite) have occurred in varying intensities. Andesitic to basaltic dikes, some up to 8 m thick, cut the felsic volcanic rocks. These dikes are commonly altered and sulfide-bearing. A small area (about 100 m long) along the Merevari River contains large boulders of slightly altered medium-grained equigranular gabbro.

Chemical analyses confirm the felsic to intermediate composition of the volcanic rocks collected from the Caura River area. Silica concentrations vary from about 59 to 78 wt percent SiO_2. The tuffs contain relatively low concentrations of total Fe (about 1.34 to 6.13 wt percent), Cu (<80 ppm), Pb (<30 to 42 ppm), and Zn (<25 to 144 ppm), and moderate to high concentrations of Ba (an average of about 975 ppm, 71 to 1874 ppm), La (30 to 86 ppm), Ce (58 to 130 ppm), Nd (34 to 64 ppm), and Zr (154 to 353 ppm). In contrast, the dikes and the gabbro contain about 43 to 54 wt percent SiO_2, and relatively high concentrations of total Fe (11.80 to 19.14 wt %), Cu (142 to 245 ppm), Pb (30 to 87 ppm), and Zn (136 to 243 ppm), and low to moderate concentrations of Ba (53 to 977 ppm), La (10 to 26 ppm), Ce (27 to 59 ppm), Nd (16 to 39 ppm), and Zr (91 to 192 ppm).

The tuffaceous rocks are calc-alkalic in composition. Their field, petrographic, and chemical characteristics indicate that they are correlative with the Early Proterozoic Caicara Formation in Venezuela and the Surumu Formation in Brazil. Some of the andesitic dike rocks may be comagmatic with the tuffs. In addition, some dikes may be related to the Middle Proterozoic or Mesozoic diabase dikes that are present throughout the Guayana Shield.

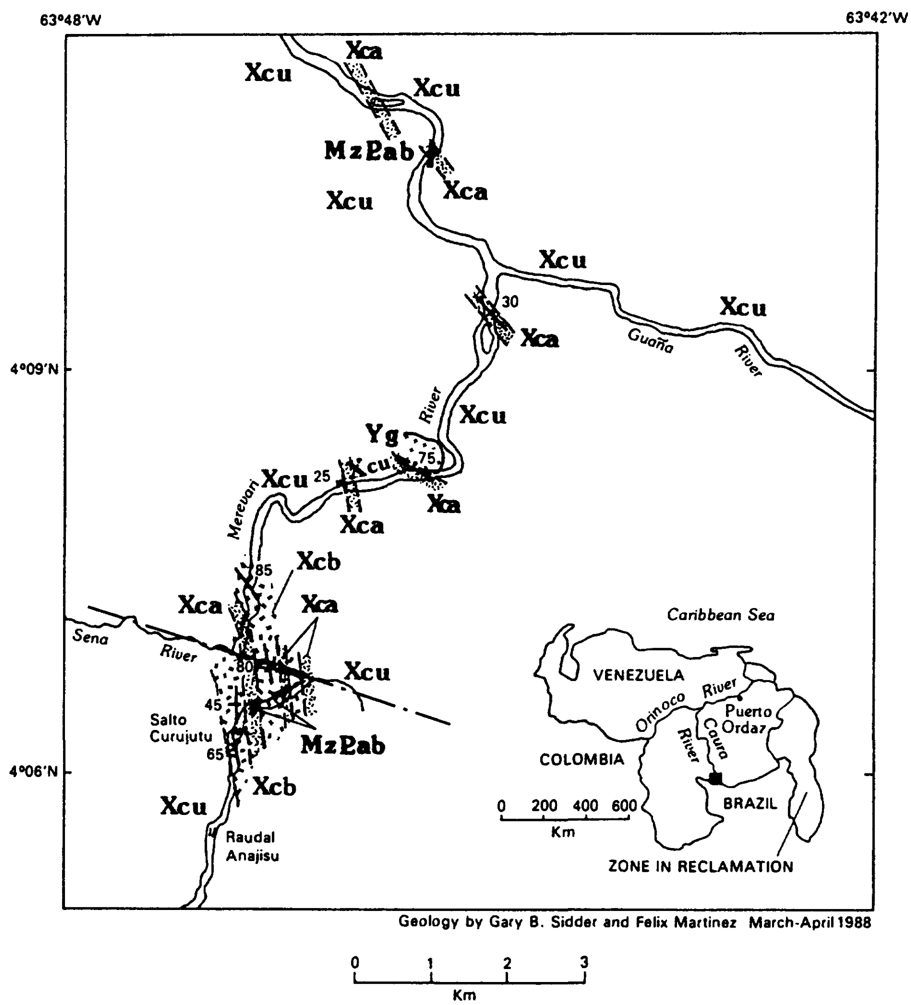
Some samples contain anomalous values of metals that imply the existence of possible mineral exploration targets. For example, a quartz-sulfide vein that cuts the felsic volcanic rocks near their contact with an andesitic dike contains 0.026 ppm Au, 3 ppm Ag, 1000 ppm Bi, 20 ppm Mo, and 70 ppm Pb. Another sample of silicified rhyolitic rocks contains

0.7 ppm Ag. A sample of andesitic dike material contains anomalous values of Cu (334 ppm), As (153 ppm), and Mo (7 ppm). A mineral deposit model for epithermal precious metal veins best represents the occurrences in the upper Caura River area.

INTRODUCTION

The Corporacion Venezolana de Guayana-Compania Tecnica Minera, C.A. (CVG-TECMIN), is conducting reconnaissance geologic mapping as part of its inventory project of the natural resources of the Guayana region of Venezuela. The U.S. Geological Survey has been assisting CVG-TECMIN since 1987 as part of a five-year Memorandum of Understanding that calls for an assessment of and exploration for new mineral deposits in the Precambrian Guiana Shield of Venezuela. The area discussed in this paper is centered near the confluence of the Guaña River with the Merevari (or upper Caura) River between latitudes 4°06' and 4°10' North and longitudes 63°43' and 63°47' West (Figure 1). The total area covers about 125 km^2. A much larger area has been mapped downriver along the Caura River during this project, but results of that mapping will be discussed in other reports. Field work for this study was conducted during March and April, 1988; mapping throughout the Caura River basin was conducted during 1987 to 1989.

The study area lies within a hilly terrain with local relief of 50 to 150 m. The hills are covered by dense virgin jungle except in places where the local indigenous population has cleared fields to grow bananas and papaya. Access to the upper Caura River area is limited to either helicopter or small fixed-wing airplane. A landing strip and housing facilities at an Electrificación del Caroní, C.A. (EDELCA), camp at the confluence of the Guaña River with the Merevari River served as the base for our work. Work was conducted primarily by boat along the rivers and less commonly by foot along traverses in the jungle. Outcrops in and along the Guaña River are generally small (<50 m^2) and scattered, but readily accessible because the river has a calm flow with few areas of white-water. Outcrops along the Merevari River are abundant and range in size from about 10 m^2 to more than 300 m^2. However, several outcrops in the Merevari River were difficult to map because the river contains numerous rapids, and it was not possible to disembark safely. The southern limit of the area of study is demarcated by waterfalls of about 4 m in height at Salto Curujutu.



EXPLANATION

	MzPab	Dikes of andesite to basalt (Mesozoic?, or Middle Proterozoic?, and Proterozoic)
	Yg	Equicrystalline gabbro (Middle Proterozoic)
	Xca	Caicara Formation, crystal +/– lithic-rich tuffs, rhyolite to dacite (Early Proterozoic)
	Xcb	Caicara Formation, crystal-poor tuffs, rhyolite to dacite (Early Proterozoic)
	Xcu	Caicara Formation, undivided, crystal-poor to crystal +/– lithic-rich tuffs, rhyolite to andesite (Early Proterozoic)
		Side-looking airborne radar (SLAR) lineament
85		Strike and dip of beds
		Inferred contact between units

Figure 1. Location map and geologic sketch map of the upper Caura River area.

REGIONAL GEOLOGY

The Venezuelan Guiana Shield consists of five lithotectonic provinces. These include: 1) the Archean Imataca Complex; 2) the Early Proterozoic greenstone-granite terranes; 3) the Early Proterozoic Cuchivero Group; 4) the Early to Middle Proterozoic Roraima Group; and 5) the Middle Proterozoic granite of the Parguazan Province (Gibbs and Barron, 1983; Teixeira and others, 1989; Sidder, 1990). The upper Caura River area lies within the Cuchivero Group province.

The Imataca Complex, which occupies the northern portion of the Venezuelan Guiana Shield, is composed of metasedimentary and meta-igneous rocks of amphibolite to granulite facies. These rocks consist predominantly of quartzo-feldspathic paragneiss and felsic to mafic granulite and orthogneiss, with minor charnockite, banded iron-formation, manganiferous metasedimentary rocks, dolomitic marble, and anorthosite (Dougan, 1977; Gibbs and Wirth, 1986). The protolith for the paragneissic rocks has been dated at 3700 to 3400 Ma. The Early Archean rocks of the Imataca Complex were deformed, intruded, and regionally metamorphosed during the Late Archean (about 2800 Ma) and were subjected to upper amphibolite to granulite facies metamorphism at about 2000 Ma during the Trans-Amazonian orogeny (Montgomery, 1979; Onstott and others, 1989).

Early Proterozoic greenstone-granite terranes, about 2250 to 2100 Ma, crop out in the central and eastern parts of the Venezuelan Guiana Shield. These terranes consist of metamorphosed submarine sequences of mafic-ultramafic intrusions, mafic and possibly ultramafic to felsic volcanic flow rocks and tuffs, and volcaniclastic, turbiditic, and chemical sedimentary rocks that have been intruded by granitic plutons and domes (Menendez, 1972; Gibbs, 1987). The contact between the greenstone-granite terrane and the Imataca Complex is a series of thrust faults with a transcurrent component of displacement (Onstott and others, 1989). Named stratigraphic units of the Venezuelan greenstone belts include the older Pastora Supergroup and the younger Botanamo Group. Granites of the Supamo Complex have intruded these metasedimentary and metavolcanic rocks (Menendez, 1972; Gibbs and Olszewski, 1982).

Early to Middle Proterozoic rocks of the Cuchivero, Roraima, and Parguaza Provinces were emplaced in and deposited on the older greenstone-granite terranes. These supracrustal rocks crop out in the southern, central, and western parts of the Guiana Shield in Venezuela. They include thick sequences of felsic to intermediate subaerial volcanic rocks and their associated plutonic rocks of the Cuchivero Group, continental fluvial sandstones and conglomerates with lesser siltstone, shale, chert, and interlayered felsic volcanic rocks of the Roraima Group, and anorogenic rapakivi granite of the Parguazan Province. The Cuchivero Group consists of volcanic rocks of the older Caicara Formation and the younger granites of Guaniamito, San Pedro, and Santa Rosalia (Mendoza and others, 1975). Ages in the Cuchivero Group range from about 1875 to 1700 Ma. The Roraima Group is about 1800 to 1500 Ma in age and consists predominantly of quartzite, quartz sandstone, and quartz-pebble conglomerate (Ghosh, 1985). The Roraima Group is intruded by Middle Proterozoic continental tholeiitic dikes, sills, sheets, and irregular bodies of the Avanavero Suite (Gibbs, 1986). The granites of the Parguazan Province were emplaced in the westernmost part of the shield about 1545 Ma (Gaudette and others, 1978).

Previous work along the Caura River has suggested that rocks in our area of study are part of the Cuchivero Group (Tepedino, 1985). Rocks mapped in this study include felsic to intermediate tuffs, mafic to intermediate dikes, and a gabbroic pluton. The volcanic rocks are probably correlative with the Caicara Formation of the Cuchivero Group. However, the more mafic rocks are possibly associated with the Avanavero Suite or with Mesozoic diabases that occur throughout the Guiana Shield.

LOCAL GEOLOGY

The major rock type in the upper Caura River study area is felsic to intermediate composition volcanic rocks. These include crystal(-lithic)-rich and crystal-poor tuffs (Figure 1). These rocks are not metamorphosed, but they do exhibit varying intensities of hydrothermal alteration. The tuffs are cut by intermediate to mafic dikes, some of which are intensely hydrothermally altered and have an alteration halo in the tuff wall rocks, and are intruded by medium-grained equicrystalline gabbro.

All of the rocks were mapped in exposures along and in the rivers or creeks. Traverses into the jungle did not locate any outcrops, and pieces of rock in float were rarely seen. Contacts between units of tuff are indistinct or not exposed. Hence, the thickness of individual units can only be inferred from limited structural data measured in the field. The overall thickness of the sequence of tuffs in the upper Caura River area is at least 1,000 m. Contacts between dikes and tuff are sharp. The dikes are 10 m or more in thickness, and they are generally sinuous and anastomosing in form. The gabbroic rocks crop out as large boulders in float along the bank of the Merevari River. They apparently are derived from a hill immediately to the north of the exposures in the river.

Description of Rock Units

The tuffaceous rocks comprise a sequence of crystal-poor and crystal(-lithic)-rich units. The thickness of beds of crystal(-lithic)-rich tuffs is generally less than 70 m, whereas the crystal-poor tuffs are commonly greater than 70 m thick. In outcrop, the crystal-poor rocks are pale red to grayish red-purple to medium light gray in color, and in thin section they are colorless to light orangish brown due to stains of iron oxide. These rocks typically contain about 5 to 9 volume percent of phenocrysts. The phenocrysts commonly occur as broken, corroded, or embayed crystal fragments. Phenocrysts of potassium feldspar (sanidine or anorthoclase) to 4.5 mm in length are more abundant and larger than those of quartz. The groundmass is devitrified and recrystallized to potassium feldspar, quartz, and uncommonly plagioclase. Shards are not evident in thin section. However, faint bands of stretched amygdules and recrystallized groundmass several millimeters to 1 cm in thickness are commonly apparent. Opaque minerals of Fe-Ti oxide(s) comprise less than 1 modal percent of these tuffs. Field and petrographic evidence of metamorphism is not present in these samples; however, minor alteration, such as partial replacement of feldspar by fine-grained white mica or muscovite and thin veinlets of quartz or epidote$\pm$chlorite, implies deuteric or hydrothermal activity.

Crystal- and crystal-lithic-rich tuffs are more varied and apparently form thinner beds in the upper Caura River area than the crystal-poor tuffs. The color of these rocks varies with the intensity of hydrothermal alteration. Relatively unaltered rocks are light brownish gray to medium gray in color, whereas altered rocks are light greenish gray to greenish black and dark grayish red. These tuffs contain 20 to 35 modal percent phenocrysts and lithic fragments. Phenocrysts of sanidine or anorthoclase predominate, with only minor amounts of quartz (to about 8%) or plagioclase (to about 5%). One sample contains mostly phenocrysts of plagioclase (20%). Biotite was observed in one sample as a phenocryst phase, but phenocrysts of other mafic minerals were not observed in any samples. The potassium feldspar phenocrysts (to 6 mm) are commonly corroded and altered to white mica. Plagioclase is also commonly altered to white mica and epidote. Quartz is typically unaltered, rounded, and embayed. The abundance of lithic fragments varies from less than 1 to about 8 modal percent. These lithic fragments are locally derived based on their similar texture and composition to those of the host tuffs. The fine-grained groundmass is recrystallized to potassium feldspar, quartz, and less commonly plagioclase, and uncommonly displays faint bands or flow lines around phenocrysts. As in the crystal-poor rocks, these tuffs are not metamorphosed. However, those rocks in proximity to dikes and veins are moderately to strongly altered. Secondary minerals include epidote, chlorite, green or brown biotite, and opaque minerals such as pyrite and magnetite.

A third group of tuffs recognized in thin section analyses but not distinguished sufficiently in the field to be mapped separately is intermediate in phenocryst content to the two former groups. The color of these rocks varies from light brownish gray, greenish gray, grayish red, and pale red in relatively unaltered rocks to dark greenish gray and greenish black in more altered samples. These rocks contain about 15 modal percent phenocrysts and lithic fragments. Phenocrysts of plagioclase are commonly subequal or greater in abundance than those of potassium feldspar, and quartz ranges in abundance from less than 1 to about 4 percent. Lithic fragments are present in amounts of less than 1 to about 7 modal percent, and they are similar texturally and compositionally to the host rocks. The occurrence and form of the phenocrysts is similar to those in the other rock types. The groundmass is recrystallized to fine to medium grained potassium feldspar and quartz. Secondary replacement and vein minerals include epidote, clinozoisite, chlorite, muscovite, fine-grained white mica, albite, greenish blue biotite, magnetite, and pyrite. Amygdules of silica, recrystallized to polycrystalline quartz, are present in some samples, and have been flattened or stretched to appear as bands.

Dike rocks in the upper Caura River area are moderately to strongly altered. The dikes are dark greenish gray, dark grayish green, to greenish black in hand sample and thin section. In some samples, the original igneous textures are completely destroyed. Textures recognized in other samples indicate that the dikes have a fine-grained chilled margin composed of small plagioclase microphenocrysts about 0.4 mm in length within a microcrystalline groundmass. Plagioclase is moderately to intensely altered to white mica and epidote. The groundmass is altered to epidote, chlorite, amphibole, magnetite, and pyrite. This fine-grained margin is usually only 5 cm wide in a dike to 10 m wide. The interior of these dikes contains two sizes of plagioclase phenocrysts: one to greater than 7 mm in length and another to about 0.5 mm. The coarser phenocrysts form glomerocrysts that have a characteristic chicken-track texture. Rocks in the interior of the dikes are also strongly altered. Plagioclase is replaced by white mica and epidote, and the groundmass is intensely altered and replaced by blue-green amphibole (actinolitic hornblende?) and fibrous green amphibole (actinolite), epidote, chlorite, and blue-green biotite. Multiple veinlets of epidote and epidote+chlorite cut the dikes. Their anastomosing, horsetail-like form and cross-cutting relationships indicate that the veins were emplaced during more than one event or during multiple pulses of the same event.

One sample of dike rocks north of the Guaña River is much less altered than those described above from south of the Guaña River. This sample has a diabasic to subophitic texture with medium-grained plagioclase laths and interstitial fine- to medium-grained clinopyroxene. The plagioclase has been totally replaced by white mica and chlorite, whereas the clinopyroxene is relatively fresh. Biotite is present in trace to minor amounts in these dike rocks.

The gabbro is a moderately altered, dark greenish gray, medium-grained equicrystalline rock. It contains plagioclase, clinopyroxene, amphibole, sphene, apatite, and Fe-Ti oxide minerals. The amphibole may in part be a product of primary magmatic crystallization based on its interstitial habit, but it is also secondary where it replaces clinopyroxene. In such cases, the pyroxene appears as a relict core within amphibole. White mica, epidote, chlorite, actinolite, and opaque minerals (both Fe-Ti oxides and pyrite) are other secondary minerals. Thin (about 1 mm wide) veinlets of epidote cut the gabbro.

Structure

Primary igneous textures such as flow bands or flattened pumice fragments are not readily apparent in rocks of the upper Caura River area. Joints, dikes, veins, and faults are numerous and do provide some information about the structural orientations in the area. In the southern part of the study area, bands defined by stretched amygdules or faint alignment of phenocrysts strike northerly (about N5°W) and dip 45° to 65° toward the west. Farther north near the confluence of the Guaña River with the Merevari River, tuff units strike more to the northwest and west-northwest (N15°W to N70°W) and dip to the northeast. It is not known if an anticlinorium exists, or if the changes in dip are local. It might be noted that the Merevari River flows generally northward from south of Salto Curujutu to the confluence of the Guaña River with the Merevari River, and north of the confluence it flows to the north-northwest and northwest. In other words, the river appears to flow generally along the strike of the tuff units.

Joints are strongly developed throughout the volcanic rocks in the region. At least two sets and commonly three or four sets can be measured from a single outcrop. Joints strike predominantly about N15-35°E and dip nearly vertical. Other sets include one that strikes N30-60°W and dips steeply both to the northeast and the southwest, another that strikes N60-80°E, inclined vertically or steeply to the northwest or southeast, and a less well-defined set that strikes westerly.

Veins and veinlets (0.5 m to <2 mm) of quartz or epidote fill joints and fractures in the upper Caura River area. Vein density is greater than $15/m^2$ in some areas, and the veins form a stockwork. Both dextral and sinistral shear displacement of veins and fractures through phenocrysts.have been measured in the field and in petrographic examinations.

Dikes were mapped in several isolated areas in the upper Caura River area. Where present, they form an anastomosing network that cuts the tuffaceous volcanic rocks. Some dikes are 10 m wide or more, and apophyses finger into the wall rocks along joints and fractures. The thicker dikes have a chilled margin. The contact between dikes and their wall rocks is commonly sinuous and irregular. Dikes sampled at two localities about 0.5 km north of Salto Curujutu appear to strike dominantly N55-65°E, with thin apophyses (to 20 cm) branching from this main trend. Perhaps coincidentally, the river in this area flows along this same course.

Lineaments identified from side-looking airborne radar (SLAR) images trend through the upper Caura River area with a strike of about N60-80°W. Interestingly, one strong lineament (fault or shear zone?; see Figure 1) cuts the area where offset of veins and dikes has been measured and where hydrothermal alteration is most intense. The river also changes direction from about N60°E to about N70°W, apparently to follow this lineament. The Merevari River continues its northerly flow about 1 km downstream; however, the Sena River flows into the Merevari River at this point, and the Sena River flows about N70°W, also apparently along the trend of the lineament. Although a lineament along the Guaña River is not clearly recognized on the SLAR image, it should be noted that the river flows along a course of N70°W. It is possible that the Guaña River also flows along a lineament that is en echelon to that to the south along the Merevari-Sena River trend.

GEOCHEMISTRY

Representative samples of rock units were collected from outcrops in the field. Those chosen for geochemical analyses were commonly 2 to 8 kg in size. These samples were cut in half, and one part was crushed and ground to -100 mesh powder, whereas the other half was trimmed for thin section. 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). Fe_2O_3 and FeO were calculated according to the method recommended by Middlemost (1989). Standard ratios of Fe_2O_3/FeO are defined by this method based upon in which field a sample plots on a total alkali-silica diagram. The volatile elements H_2O, CO_2, F, and Cl were not analyzed separately, but the reported loss on ignition (LOI) at 925°C is a measure of their total bulk concentration. The trace elements Cu, Zn, Ga, Rb, Sr, Y, Zr, Nb, Ba, La, Ce, and Nd were analyzed by energy-dispersive X-ray fluorescence and followed the procedure outlined by Johnson and King (1987). Some of the samples have also been analyzed for 35 elements by semi-quantitative direct-current arc emission spectrography and for gold by graphite furnace atomic absorption spectroscopy.

Analytical Results

The tuffaceous rocks are dominantly calc-alkaline in composition and range from rhyolite to dacite and andesite (Table 1, Figure 2). Although these rocks have different textural characteristics and phenocryst abundances, they seem to form a coherent pattern on a Peacock diagram, and (Na_2O + K_2O) equals CaO between about 55 and 60 wt percent SiO_2 (Figure 3), which is within the calc-alkaline field defined as equivalence between 56 and 61 wt percent SiO_2. The calc-alkaline trend is also seen on the ternary AFM diagram (Figure 4). All of the rocks contain normative quartz, are moderately peraluminous, and most of the samples are corundum-normative.

Consistent variations within the data indicate that the volcanic rocks in the upper Caura River area are related genetically, even though the abundance of the oxides in these volcanic rocks may have been altered by hydrothermal alteration and tropical weathering. A Harker diagram (Figure 5) of the abundance of the major element oxides versus silica content shows trends of decreasing Fe_2O_3t, MgO, TiO_2, MnO, Al_2O_3, P_2O_5, and CaO, and increasing K_2O with increasing SiO_2. These are consistent with a modal decrease of mafic minerals as the rocks evolved from andesite to rhyolite.

Trace element concentrations in the tuff units also have systematic variations with evolution of the volcanic rocks. For example, the lithophile elements Zr and Rb increase with increasing SiO_2 content (Figure 6), and Y, Nb, La, and Ce increase slightly. In contrast, the abundance of Zn decreases. Ba displays an interesting distribution. In general, the concentration of Ba increases with increasing silica to 73 wt percent SiO_2. However, the abundance of Ba is significantly lower in volcanic rock samples with greater than 73 wt percent SiO_2. This decrease is seen in all

Table 1. Major and trace element abundances for the upper Caura River area. Rock names from Jensen diagram (Figure 2). NA, not analyzed. J. Taggart, A. Bartel, D. Siems, and E. Du Bray, analysts.

Major oxides, in weight percent

	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Dacite	Rhyolite
SAMPLE	88167	88131	88128	88168	88126	88125	88152	88171
SiO2	77.7	77.5	77.1	76.7	76.3	75.2	74.8	74.8
Al2O3	11.5	11.4	12.1	12.5	12.0	13.0	11.8	12.7
Fe2O3t	1.41	2.30	1.17	0.51	1.53	1.39	3.16	2.57
MgO	<0.10	0.24	<0.10	0.11	0.11	0.11	0.91	0.24
CaO	0.14	2.26	0.07	0.12	0.12	0.17	0.44	0.34
Na2O	3.07	3.40	3.44	3.28	3.24	4.10	4.68	3.56
K2O	4.98	1.78	5.03	5.22	5.10	4.72	0.92	4.73
TiO2	0.20	0.20	0.19	0.17	0.16	0.17	0.49	0.15
P2O5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	<0.05
MnO	<0.02	0.04	<0.02	<0.02	0.08	0.04	0.02	0.04
LOI	0.11	0.42	0.21	0.47	0.55	0.42	1.95	0.11
TOTAL	99.11	99.54	99.31	99.08	99.19	99.32	99.28	99.24
Fe2O3c	0.44	0.71	0.36	0.16	0.47	0.43	0.98	0.80
FeOc	0.88	1.43	0.73	0.32	0.95	0.86	1.96	1.59

Trace elements, in parts per million

Cu	<39	78	<39	NA	NA	NA	78	<39
Zn	<25	50	50				50	50
Ga	16	20	25				28	16
As	<35	<35	<35				70	<35
Rb	152	35	156				58	140
Sr	49	169	35				127	128
Y	34	28	39				18	28
Zr	230	207	238				229	162
Nb	17	15	19				14	14
Mo	<3	7	6				7	<3
W	<55	<55	<55				<55	110
Pb	30	30	30				30	34
Bi	<13	26	<13				26	26
Th	<9	<9	<9				18	<9
U	<14	<14	<14				<14	<14
Ba	289	811	543				334	789
La	40	33	35				35	37
Ce	81	58	59				74	72
Nd	43	38	42				40	39

Table 1. Major and trace element abundances for the upper Caura River area.
Rock names from Jensen diagram (Figure 2). NA, not analyzed.
J. Taggart, A. Bartel, D. Siems, and E. Du Bray, analysts.

Major oxides, in weight percent

	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Rhyolite	Dacite	Rhyolite
SAMPLE	88167	88131	88128	88168	88126	88125	88152	88171
SiO2	77.7	77.5	77.1	76.7	76.3	75.2	74.8	74.8
Al2O3	11.5	11.4	12.1	12.5	12.0	13.0	11.8	12.7
Fe2O3t	1.41	2.30	1.17	0.51	1.53	1.39	3.16	2.57
MgO	<0.10	0.24	<0.10	0.11	0.11	0.11	0.91	0.24
CaO	0.14	2.26	0.07	0.12	0.12	0.17	0.44	0.34
Na2O	3.07	3.40	3.44	3.28	3.24	4.10	4.68	3.56
K2O	4.98	1.78	5.03	5.22	5.10	4.72	0.92	4.73
TiO2	0.20	0.20	0.19	0.17	0.16	0.17	0.49	0.15
P2O5	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	<0.05
MnO	<0.02	0.04	<0.02	<0.02	0.08	0.04	0.02	0.04
LOI	0.11	0.42	0.21	0.47	0.55	0.42	1.95	0.11
TOTAL	99.11	99.54	99.31	99.08	99.19	99.32	99.28	99.24
Fe2O3c	0.44	0.71	0.36	0.16	0.47	0.43	0.98	0.80
FeOc	0.88	1.43	0.73	0.32	0.95	0.86	1.96	1.59

Trace elements, in parts per million

	88167	88131	88128	88168	88126	88125	88152	88171
Cu	<39	78	<39	NA	NA	NA	78	<39
Zn	<25	50	50				50	50
Ga	16	20	25				28	16
As	<35	<35	<35				70	<35
Rb	152	35	156				58	140
Sr	49	169	35				127	128
Y	34	28	39				18	28
Zr	230	207	238				229	162
Nb	17	15	19				14	14
Mo	<3	7	6				7	<3
W	<55	<55	<55				<55	110
Pb	30	30	30				30	34
Bi	<13	26	<13				26	26
Th	<9	<9	<9				18	<9
U	<14	<14	<14				<14	<14
Ba	289	811	543				334	789
La	40	33	35				35	37
Ce	81	58	59				74	72
Nd	43	38	42				40	39

Table 1 (continued).

Major oxides, in weight percent

	Dacite	Dacite	Dacite	Andesite	Dacite	Rhyolite	Dacite	Dacite
SAMPLE	88133	88137	88147	88141	88173	88164	88151	88153
SiO2	67.0	66.2	65.2	64.7	64.1	62.7	60.8	59.8
Al2O3	14.9	14.9	15.6	14.8	18.6	16.8	18.8	18.2
Fe2O3t	4.79	5.25	5.28	6.19	3.51	6.00	5.42	5.44
MgO	1.22	1.28	1.34	1.75	0.59	1.43	1.80	2.55
CaO	2.99	2.37	3.51	3.50	0.19	3.23	0.91	0.99
Na2O	3.86	4.25	3.72	4.27	2.18	4.68	9.36	6.44
K2O	3.83	4.02	3.84	3.38	6.05	1.54	0.07	4.32
TiO2	0.52	0.56	0.44	0.56	0.71	0.86	0.72	0.72
P2O5	0.16	0.17	0.16	0.18	0.16	0.41	0.19	0.26
MnO	0.09	0.10	0.10	0.10	0.06	0.11	0.10	0.08
LOI	0.25	0.56	0.36	0.13	3.17	1.66	1.20	1.09
TOTAL	99.61	99.66	99.55	99.56	99.32	99.42	99.37	99.89
Fe2O3c	1.27	1.63	1.64	1.92	1.09	1.59	1.68	1.69
FeOc	3.17	3.26	3.28	3.84	2.18	3.97	3.36	3.38

Trace elements, in parts per million

Cu	78	89	119	78	NA	78	<39	78
Zn	139	144	51	53		93	122	139
Ga	23	19	28	21		30	21	18
As	70	87	<35	70		70	70	<35
Rb	114	81	112	89		81	2	107
Sr	335	283	505	339		505	166	82
Y	32	20	20	26		23	35	27
Zr	202	205	191	194		188	283	243
Nb	12	15	10	8		13	18	13
Mo	6	<3	<3	6		6	6	6
W	110	<55	110	110		<55	<55	<55
Pb	30	49	30	30		35	30	30
Bi	26	<13	27	26		26	26	26
Th	18	<9	18	18		<9	<9	18
U	<14	<14	<14	<14		<14	<14	<14
Ba	1131	1267	1249	1099		1015	71	909
La	40	31	42	36		34	64	86
Ce	83	65	78	72		82	130	128
Nd	38	34	42	39		40	64	63

Table 1 (continued).

Major oxides, in weight percent

	Andesite	Andesite	Gabbro	Andesite	Andesite	Andesite	Basalt	Basalt
SAMPLE	88166	88135	88155	88174	88130	88129	88139	88165
SiO2	59.1	53.6	52.4	50.5	49.1	48.9	47.4	43.8
Al2O3	16.7	15.6	16.2	16.9	15.9	15.8	15.2	16.8
Fe2O3t	7.04	11.80	10.50	11.40	14.70	13.60	14.10	14.60
MgO	2.01	3.41	5.24	3.56	3.28	2.32	6.95	6.07
CaO	5.64	6.29	7.31	8.54	8.82	12.20	8.99	6.42
Na2O	4.22	3.88	3.87	2.98	3.34	3.91	3.18	1.67
K2O	2.42	1.94	1.15	1.27	1.81	0.21	1.19	4.49
TiO2	0.84	1.54	1.01	1.08	1.98	1.91	1.33	2.04
P2O5	0.35	0.32	0.42	0.38	0.39	0.37	0.20	0.43
MnO	0.12	0.27	0.21	0.18	0.23	0.20	0.22	0.23
LOI	1.09	0.90	1.78	2.82	0.66	0.62	1.15	3.39
TOTAL	99.53	99.55	100.09	99.61	100.21	100.04	99.91	99.94
Fe2O3c	1.86	2.83	2.23	2.42	3.12	2.07	2.15	3.10
FeOc	4.66	8.07	7.44	8.08	10.42	10.37	10.75	10.34

Trace elements, in parts per million

Cu	78	245	142	177	170	334	157	192
Zn	103	243	202	136	177	158	171	191
Ga	24	42	26	32	36	57	41	42
As	89	103	104	86	111	153	107	84
Rb	82	83	47	23	84	10	61	267
Sr	741	433	714	688	417	701	501	433
Y	27	34	22	18	34	32	23	25
Zr	154	192	134	110	173	177	91	130
Nb	11	8	<3	7	8	11	6	18
Mo	<3	10	<3	<3	6	7	<3	<3
W	<55	<55	110	110	175	110	116	110
Pb	37	60	34	37	40	87	52	30
Bi	<13	26	34	31	34	47	31	35
Th	<9	<9	18	<9	<9	<9	<9	<9
U	<14	<14	<14	<14	28	<14	<14	<14
Ba	955	483	726	806	977	53	586	1543
La	30	25	21	16	26	21	10	24
Ce	67	56	51	46	59	52	27	53
Nd	39	25	35	27	39	28	16	31

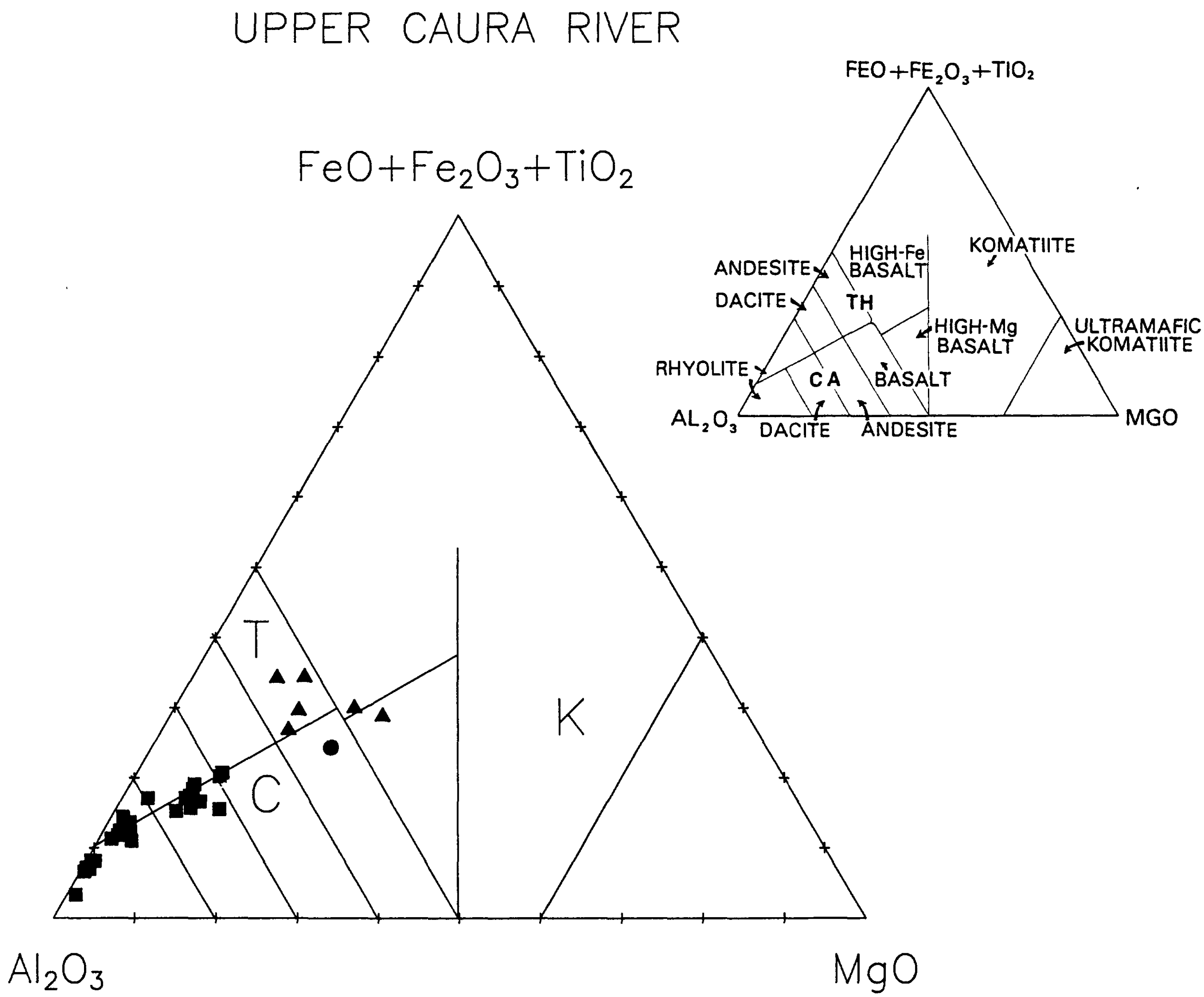


Figure 2. Jensen cation plot (Jensen, 1976) showing the distribution of rocks from the upper Caura River area relative to the cation proportions of Al_2O_3, ($FeO + Fe_2O_3 + TiO_2$), and MgO (anhydrous). Tholeiitic, calc-alkaline, and komatiitic trends pass through or near the letters Th and T, Ca and C, and K, respectively. Closed squares, tuffs; closed triangles, dikes; closed circle, gabbro.

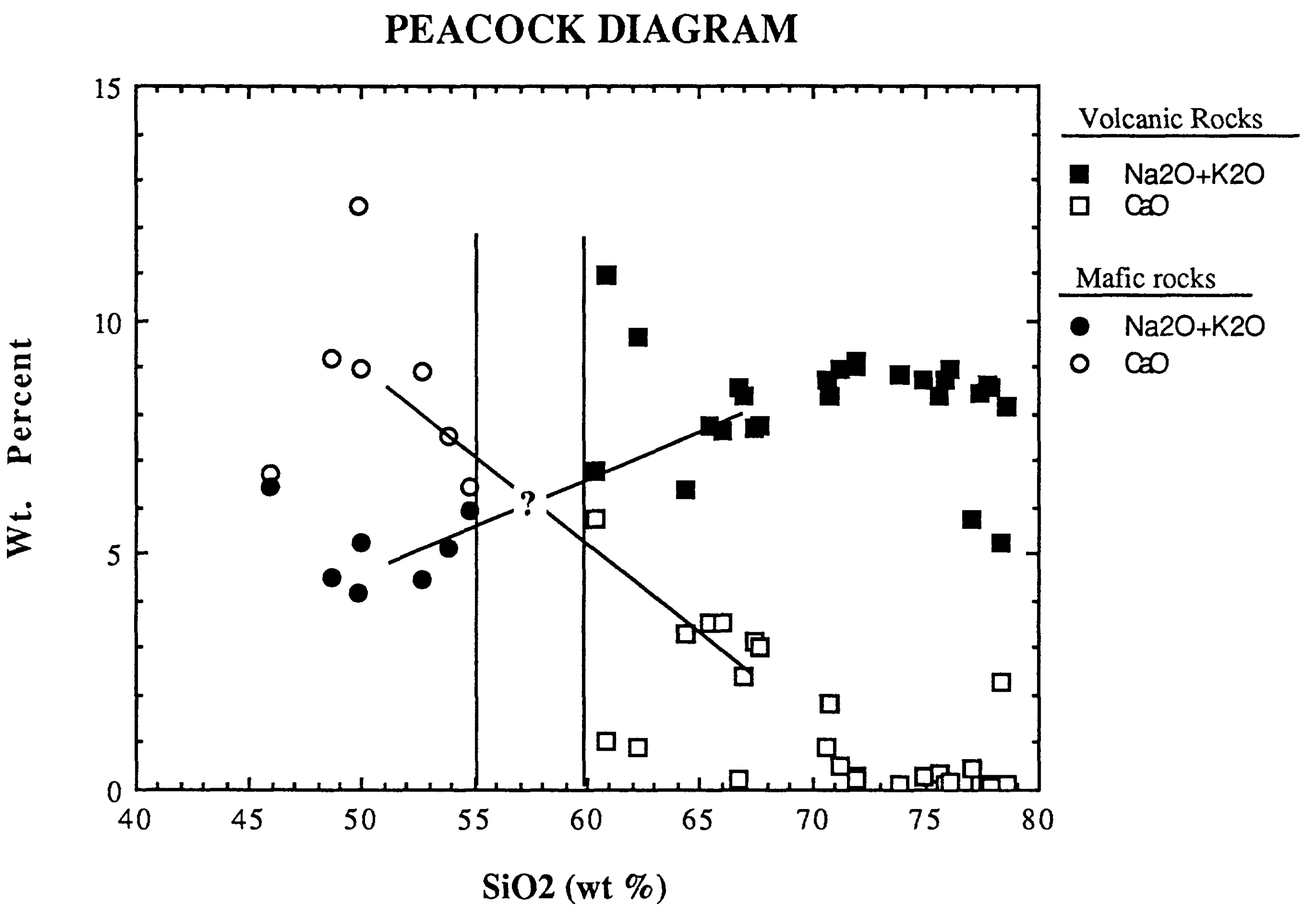


Figure 3. Peacock diagram (Na2O + K2O and CaO vs. SiO2) showing the distribution of rocks from the upper Caura River area. Proportions calculated anhydrous.

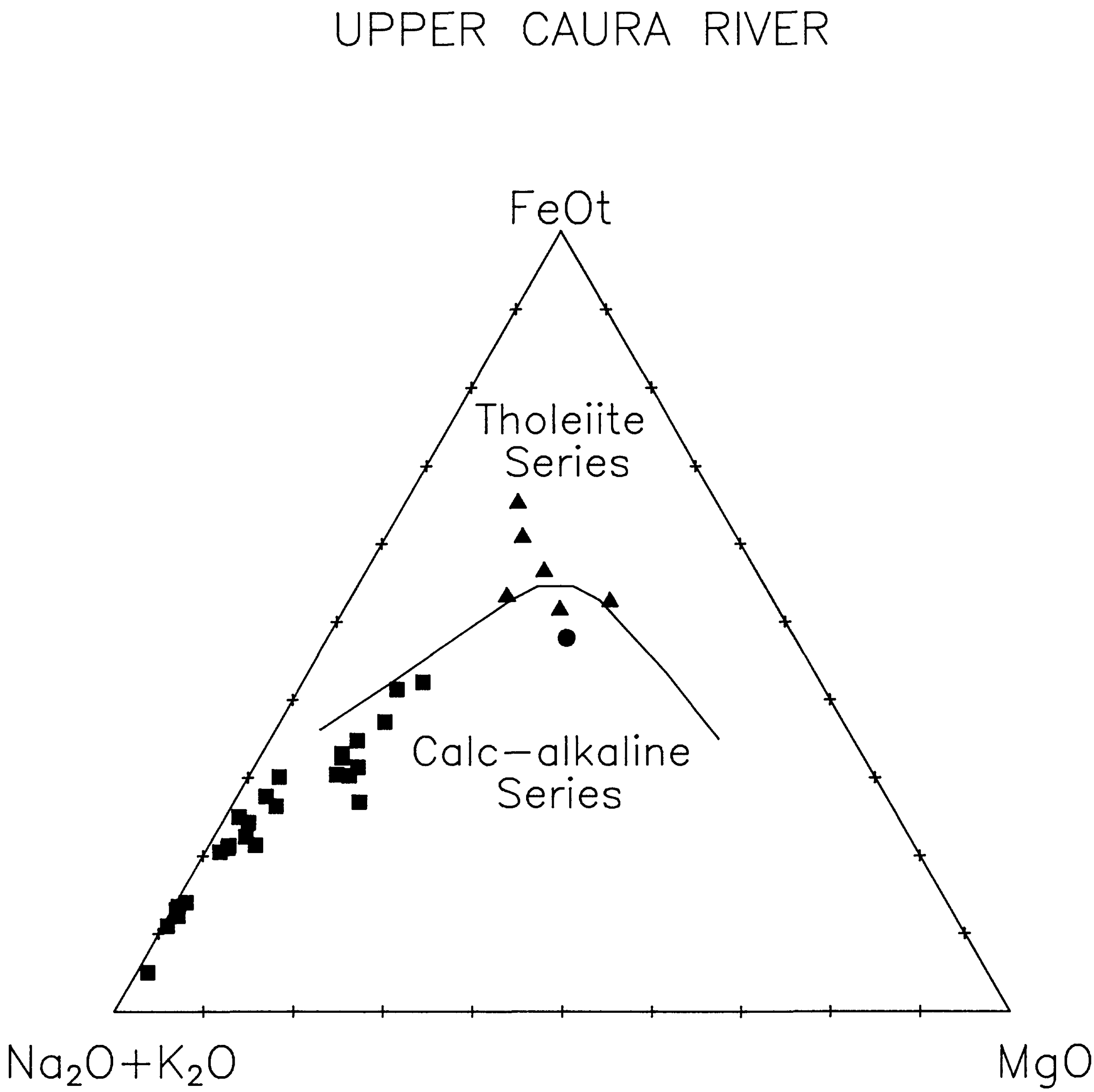


Figure 4. Ternary AFM (Na_2O + K_2O-FeOt-MgO) showing the distribution of rocks from the upper Caura River area. Proportions calculated anhydrous. Dividing line between tholeiitic and calc-alkaline series from Irvine and Baragar (1971). Symbols as in Figure 2.

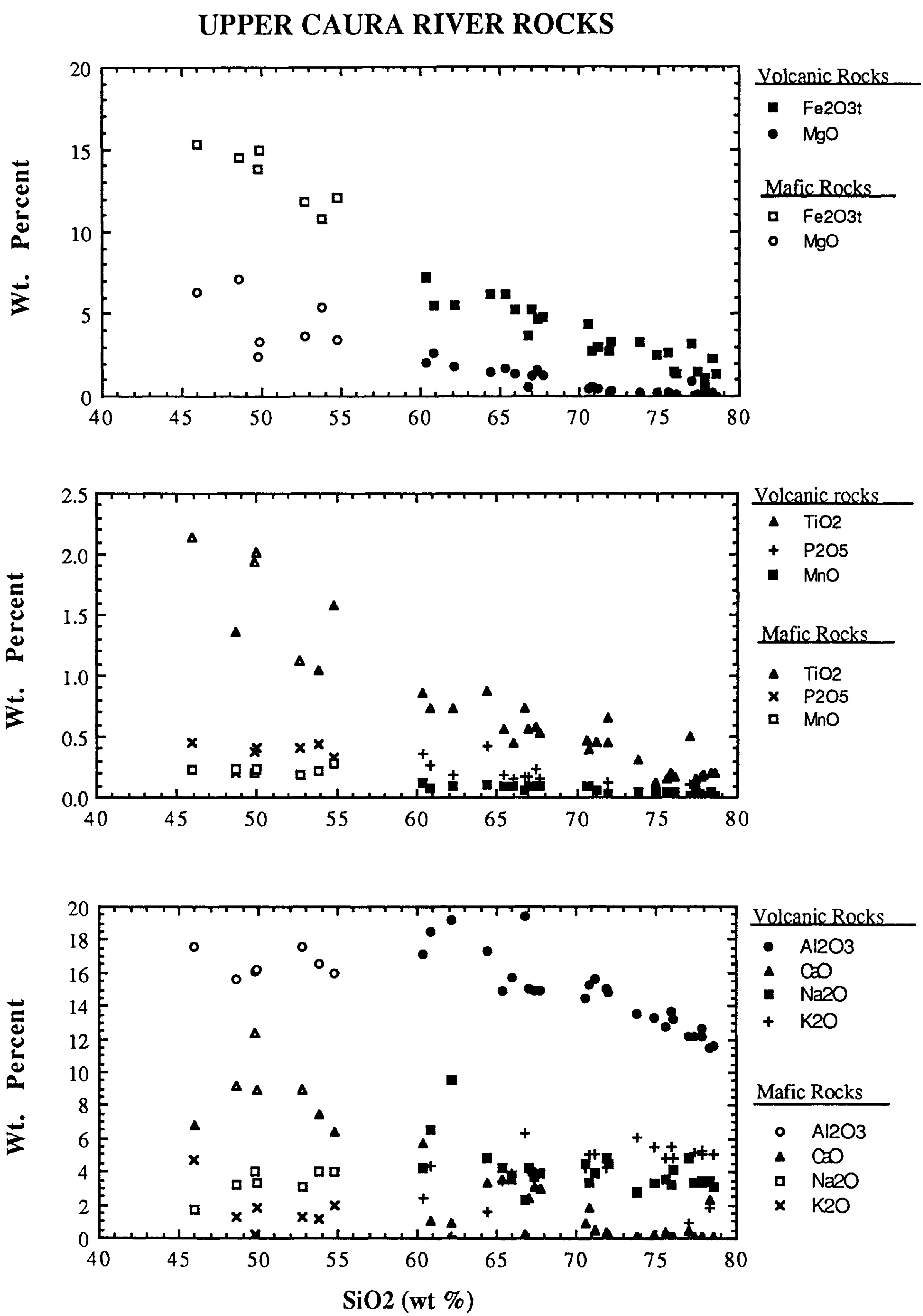


Figure 5. Major element Harker variation diagram (anhydrous) for rocks from the upper Caura River area.

UPPER CAURA RIVER ROCKS

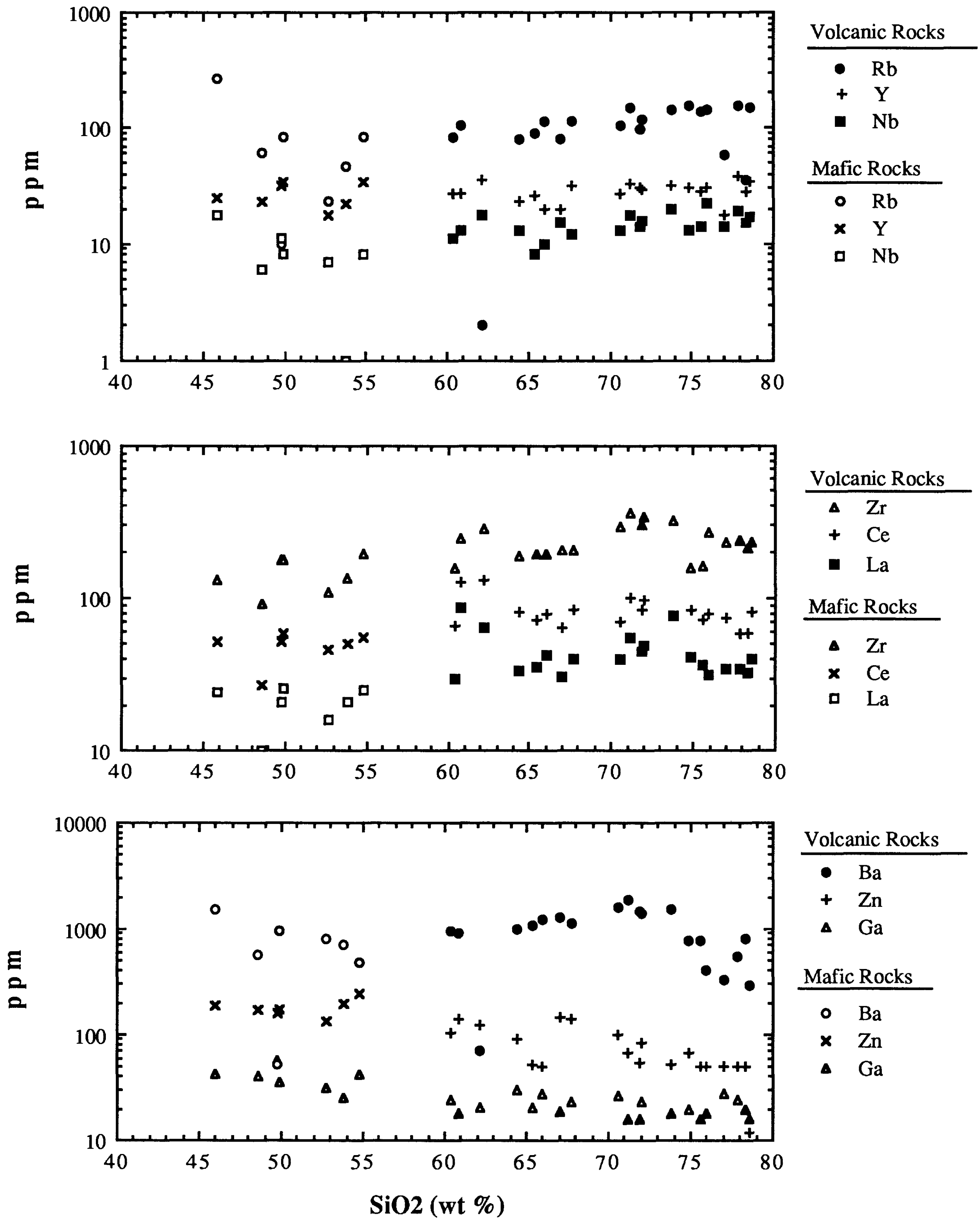


Figure 6. Trace element Harker variation diagram for rocks of the upper Caura River area.

three types of tuffs. When the data are inspected more closely, it is recognized that this decrease in Ba content coincides with a decrease in the modal abundance of potassium feldspar phenocrysts and the concentration of K_2O. This suggests that Ba is predominantly partitioned into potassium feldspar, and that this decrease is not a result of alteration. The apparent downturn in Zr, Ce, and La at silica concentrations greater than about 70 wt percent SiO_2 may indicate that zircon became a liquidus phase at this point in the crystallization sequence and depleted the magma in these elements.

The silica content of the dikes in the upper Caura River area indicates that they range in composition from basalt to basaltic andesite, with the abundance of silica varying from about 54 to 44 wt percent SiO_2. However, these rocks are classified as andesites with a tholeiitic affinity and basalts on the Jensen cation plot (Figure 2). A sufficient number of samples of these intermediate to mafic rocks was not analyzed chemically to interpret rigorously patterns in distribution of their major element oxide and trace element abundances. Moreover, the moderate to intense deuteric and hydrothermal alteration has probably altered the primary composition of these igneous rocks. In general, the dike rocks contain high concentrations of total iron (about 10.5 to 14.7 wt % Fe_2O_3t), relatively high abundances of CaO (about 6.3 to 12.2 wt %), TiO_2 (1.3 to 2.0 wt %), MnO (0.20 to 0.27 wt %), Cu (157 to 334 ppm), and Zn (158 to 243), and low amounts of high-field strength and light rare earth elements Zr (91 to 192 ppm), La (10 to 26 ppm), Ce (27 to 59 ppm), and Nd (16 to 39 ppm). As will be discussed below, the concentrations of some of the metals such as Cu and Zn may be considered geochemically anomalous.

Teggin and others (1985) compared the composition of Proterozoic and Mesozoic diabases and distinguished them on the basis of differences in the abundance of total iron, TiO_2, volatiles (as measured by the loss on ignition), Cu, and V. The samples of dikes from the upper Caura River area plot both out of and within the fields of both types of diabases for several elements used to distinguish the two age groups. The one relatively fresh dike sample collected from north of the Guaña River is similar to these diabases in texture, composition, and appearance in the field. It falls in the field of iron-rich basalt on the Jensen cation plot (Figure 2). However, textural characteristics such as glomerocrysts of plagioclase in the other dikes of the upper Caura River are not typical of diabase dikes seen in other parts of the Venezuelan Guiana Shield. The form and occurrence of these dikes also is unlike other diabase dikes seen in the western part of the shield. It is possible that these mafic dikes are not related to the diabasic intrusions, but rather are derivatives of a less differentiated, cogenetic body that intruded penecontemporaneously with, or perhaps even was the source magma of the more felsic rocks. It could be argued that a continuum exists, and that a trend from andesite with a tholeiitic affinity to calc-alkalic andesite, dacite, and rhyolite is maintained, from the mafic rocks to the felsic rocks (Figure 2), albeit with a slight compositional gap between 55 and 60 wt percent SiO_2 (Figure 3). This gap could be the result of a cessation in the eruptive history or to the alteration noted in the mafic rocks. For example, replacement of clinopyroxene (augite) by amphibole (actinolite or actinolitic hornblende) could diminish the concentration of silica in the rocks.

The one sample of gabbro from the upper Caura River area is similar chemically to rocks of the Middle Proterozoic Avanavero Suite. However, it is not possible to verify this correlation with the Avanavero Suite on the basis of only one sample. The gabbro plots in the field of calc-alkalic basalt on the Jensen diagram (Figure 2).

ECONOMIC GEOLOGY

The alteration, vein occurrences, and geochemical anomalies found in the upper Caura River area have some similarities to epithermal precious metal deposits and possibly a porphyry-type system. Alteration of the felsic tuffs and a higher density of veins are localized near areas of dike intrusion. Epidote is ubiquitous in the alteration assemblage, and chlorite, greenish blue biotite, less commonly green amphibole, and opaque minerals such as pyrite and magnetite are also present. It is difficult to identify a zonation; however, it does appear that biotite is more abundant closer to the contact with a dike or vein. Also, the wall rocks to epidote veinlets are noticeably colored pink by potassium feldspar. This may indicate that a narrow zone (<1 to about 5? m) of potassic alteration (biotite + kspar) surrounded by more widespread (to 10 m or more) propylitic alteration (epidote + chlorite) envelopes the dikes and veins. Some rocks are bleached or heavily iron-stained (iron oxide after sulfide) and contain clay alteration. However, this type of alteration is not widespread. Whereas in the field, some rocks appeared to be altered by silicification or silica flooding, this was not substantiated completely in petrographic examinations. Quartz veins and veinlets do cut some rocks, but replacement of phenocrysts and groundmass by quartz or other silica minerals is minor.

Geochemical anomalies are present in both the quartz veins and altered dikes as well as in altered tuffaceous wall rocks. For example, disseminations and pockets of pyrite and possibly chalcopyrite are found in a sample of an anastomosing network of quartz veins to 3 cm in width that cuts the rhyolitic rocks near an altered dike 10 m in width. A sample from this vein contains 3 ppm Ag[3], 0.026 ppm Au[4], 1000 ppm Bi[3], and 20 ppm Mo[3]. Samples of altered dike from the immediate area contain as much as 3 ppm Ag[3], 153 ppm As[5], 334 ppm Cu[5], 175 ppm W[5], and 7 ppm Mo[5]. Altered crystal-rich tuff in proximity to this vein contains as much as 144 ppm Zn[5], 89 ppm Cu[5], 49 ppm Pb[5], 87 ppm As[5], and 110 ppm W[5].

Although epithermal deposits are not common in the Proterozoic, the main explanation offered for their absence in Precambrian rocks is that they were removed by erosion, if they formed at all (Hutchinson, 1987). However, it is known that sedimentary rocks of the Roraima Group were deposited soon after the deposition of the volcanic rock pile of the Cuchivero Group, and large tepuis (high flat-topped mesas) with rocks of the Roraima Group are visible on the SLAR imagery immediately to the east of the upper Caura River area. It is possible that epithermal-type mineralization may have been preserved in these Early Proterozoic rocks by the cover of sedimentary rocks associated with the Roraima Group. Moreover, porphyritic granitic plutons that intrude the volcanic rocks have been mapped to the northwest of this study area (Martinez, unpublished data). Additional, more detailed geologic mapping, analyses of stream sediments and panned concentrates from streams that drain the area in addition to analyses of rocks, and geophysical studies such as magnetometry and very low frequency electromagnetics (VLF-EM) are warranted based on the reconnaissance data presented in this study.

REGIONAL CORRELATION

Rios (1972) identified the Cuchivero igneous association as Precambrian extrusive and intrusive silicic rocks that have a characteristic north-northwest structural grain. The oldest unit of this sequence was named the Caicara Formation, and it consists of porphyritic, massive to slightly foliated recrystallized rhyolitic, rhyodacitic, and dacitic ignimbrites. Rios (1972) recognized that these rocks were probably folded and thermally metamorphosed in restricted zones in proximity to intrusions. It is significant to note that Rios (1972) identified a "foliación", or foliation, visible in some rocks as flow bands. He did not recognize any regional metamorphic effects. However, subsequent authors have referred

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[3] Emission spectrograph analysis
[4] Graphite-furnace atomic absorption analysis with hydrobromic acid digestion
[5] Energy-dispersive X-ray fluorescence analysis

to the Caicara Formation as a sequence of metavolcanic rocks (Tepedino, 1985), and others have called the rocks metavolcanic, but noted that the rocks had suffered contact metamorphism (or "thermal-regional metamorphism") only due to intrusions of the granitic batholith of the Cuchivero Group (Mendoza, 1977). As noted in this paper, the volcanic rocks in the upper Caura River area are not metamorphosed, but they are hydrothermally altered near faults, dikes, and veins. The textural and compositional characteristics of the Caicara Formation as described in this study allow the correlation of the volcanic rocks of the upper Caura River area with those to the north and northwest in the Guiana Shield described by Rios (1972) and Mendoza (1977).

Montalvao (1975) and Montalvao and others (1975) described Early Proterozoic (about 1800 Ma) silicic volcanic rocks in northern Brazil that include rhyodacitic, dacitic, and lesser rhyolitic and andesitic tuffs, breccias, and ignimbrites that are intruded by silicic plutonic rocks. These volcanic rocks of the Surumu Formation of the Uatuma Group exhibit their original igneous textures and are not metamorphosed. The volcanic rocks are devitrified and hydrothermally altered in proximity to fault zones. The descriptions of these volcanic rocks indicate that the Surumu Formation in Brazil is correlative with the Caicara Formation in Venezuela.

Plots of major oxide data for the Caicara and Surumu Formations further strengthen the correlation of these units and emphasize their calc-alkalic trend. Diagrams of the abundance of major oxides versus silica for rocks analyzed by Montalvao and others (1975), Mendoza (1977), and this study show continuous patterns of decreasing total iron (as Fe_2O_3t), MgO, TiO_2, Al_2O_3, P_2O_5, and CaO, and increasing K_2O when plotted versus increasing SiO_2 (Figure 7). Moreover, the concentration of CaO equals that of $Na_2O + K_2O$ at about 57 wt percent SiO_2 on a Peacock diagram (Figure 8). It appears from these data that the composition of rocks in the upper Caura River area spans the range of felsic to intermediate as identified in the Caicara and Surumu Formations in other parts of the Guiana Shield (Montalvao and others, 1975; Mendoza, 1977).

SUMMARY AND CONCLUSIONS

Rocks of the upper Caura River area lie within the Cuchivero Group of the Venezuelan Guiana Shield. The predominant rock type, felsic to intermediate tuffs, is correlative with rocks of the Caicara Formation in Venezuela and the Surumu Formation in Brazil. Rocks in the upper Caura River area include crystal(-lithic)-rich tuffs, crystal-poor tuffs, and an intermediate group of crystal-lithic tuffs that are calc-alkalic in

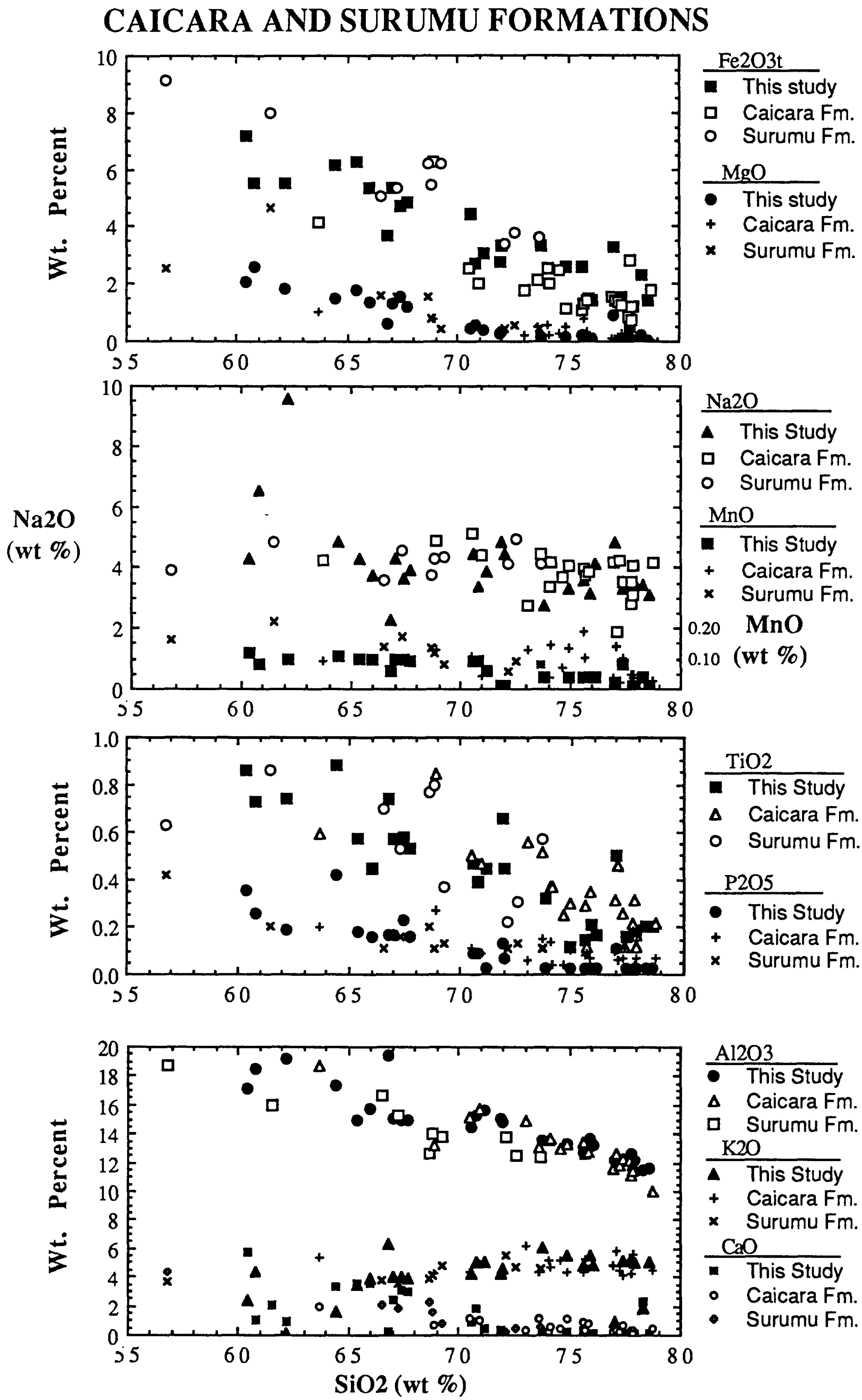

Figure 7. Major element Harker variation diagram comparing rocks of the upper Caura River area with those from the Caicara Formation (Mendoza, 1977) and the Surumu Formation (Montalvao and others, 1975).

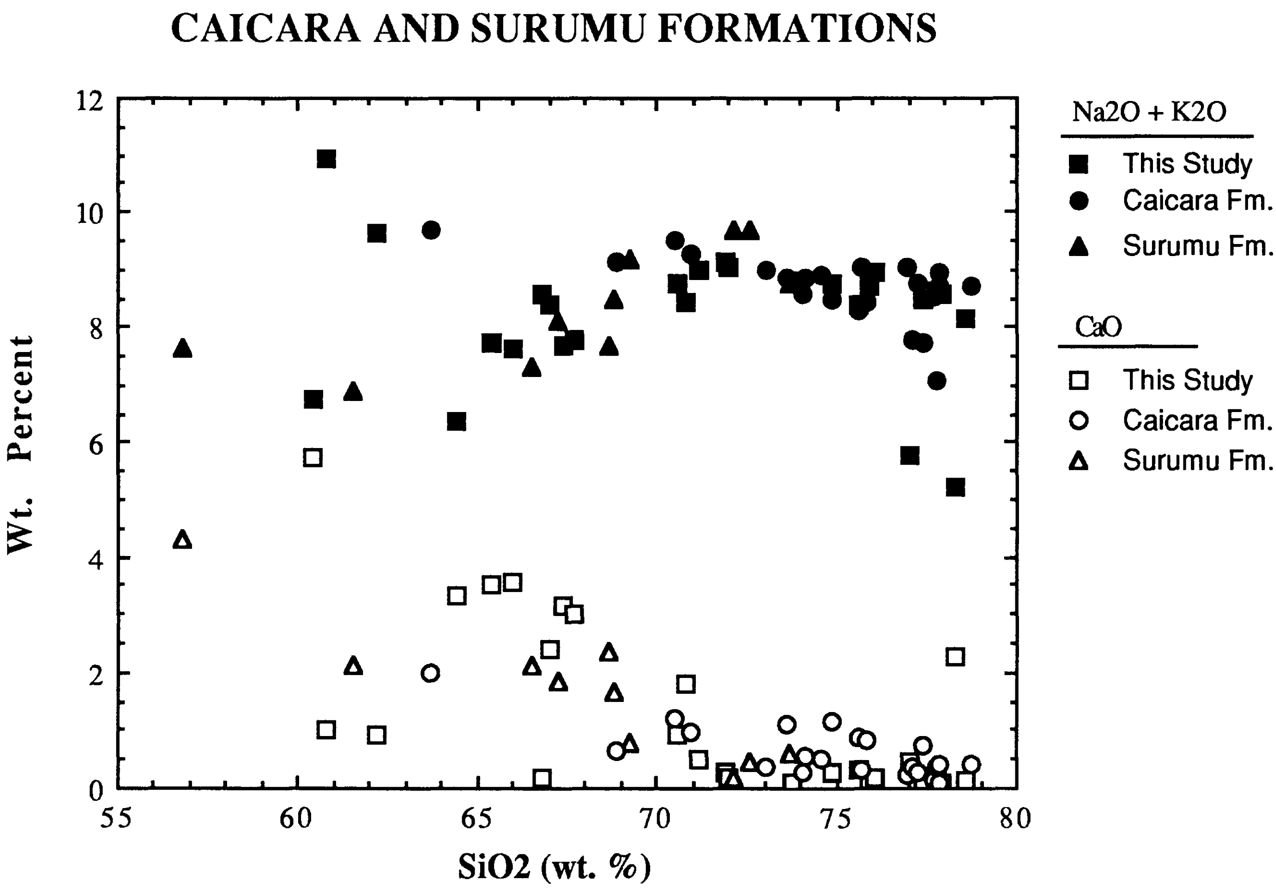

Figure 8. Peacock diagram comparing the distribution of rocks from the upper Caura River area with those from the Caicara Formation (Mendoza, 1977) and the Surumu Formation (Montalvao and others, 1975).

composition. These volcanic rocks are cut by andesitic and basaltic dikes and a gabbroic body. Some of the dikes may be related to Middle Proterozoic or Mesozoic dikes that are present throughout the shield, and others may be comagmatic with the tuffs. Coarse, blocky fragmental volcanic rocks such as breccias were not observed in the study area. This suggests that the tuffs were deposited as outflow facies on the flank(s) of a volcanic complex rather than in the central vent portion. Structures such as lineaments (large-scale faults?) and the strike of tuff units and dikes appear to control the direction of flow of the rivers in the area. These rocks do not exhibit field or petrographic evidence of regional metamorphism. However, they are altered hydrothermally and contain anomalous values of some metals such as Zn, Cu, and As in proximity to intermediate to mafic dikes and quartz veins. The alteration, occurrence of stockwork veins, and geochemically anomalous concentrations of Ag, Bi, As, Cu, Zn, W, and Mo are similar to epithermal vein precious metal deposits. Additional detailed geologic mapping, geochemical sampling, and geophysical surveying are warranted for exploration of new precious metal mineral deposits.

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