Geology of the Lo Increíble Mining District and U-Pb Age of the Early Proterozoic Yuruari Formation of the Pastora Supergroup, Guayana Shield, Venezuela

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ABSTRACT

Results of new mapping combined with geochemical and U-Pb isotopic data provide a framework for the geology, age, and origin of gold deposits in the Lo Increíble mining district of the Guayana Shield of eastern Venezuela. Gold deposits within the district are shear-zone-hosted lode deposits restricted to a major ductile transpressive shear zone that has developed a strong S-C mylonitic fabric, sigmoidal boudinage, and small-scale folds. Dextral oblique slip thrust (or reverse movement) in the shear zone has placed older tholeiitic metabasalt of the El Callao Formation over younger quartz-biotite-muscovite schist of the Yuruari Formation, both of the Early Proterozoic Pastora Supergroup. The gold deposits formed as discontinuous quartz veins parallel with the tectonic foliation within the zone.

Zircon mineral separates from the Yuruari Formation, which forms the upper unit of the Pastora Supergroup, yield a U-Pb age of 2,131±10 Ma. This is the first published U-Pb zircon date of the Pastora Supergroup in Venezuela and confirms the Early Proterozoic age for greenstone-belt rocks of the Guayana Shield.

Major- and trace-element geochemical data for quartz-normative tholeiitic pillow lavas of the Early Proterozoic El Callao Formation have affinity with modern low-potassium island arc tholeiite. Calc-alkaline basalt from the younger Early Proterozoic Caballape Formation has a composition similar to that of low-potassium calc-alkaline basalt and basaltic andesite typical of island arc sequences. We suggest that the rocks in the region formed in an immature intraoceanic island arc setting that underwent subsequent oblique dextral thrusting along a northwest-oriented axis of tectonic compression.

RESUMEN

Los resultados de la cartografía geológica reciente y datos geoquímicos isotópicos por el método U-Pb proporcionan un marco de referencia para la geología, edad y origen de los depósitos minerales en el Distrito Minero Lo Increíble en el Escudo de Guayana. Los depósitos de oro en este distrito son del tipo de veta y diseminaciones encajados en zonas de falla restringidas a extensas zonas de cizallas dúctiles con movimiento transpresivo el cual ha originado una fuerte estructura milonítica del tipo S-C, budinage sigmoidal y pequeños pliegues. Corrimientos oblicuos dextrales (o movimiento inverso) en la zona de cizalla ha puesto basaltos toleíticos (más viejos) de la Formación El Callao sobre esquistos quarzo-biotítico-muscovítico (más joven) de la Formación Yuruari. Ambas formaciones pertenecen al Supergrupo Pastora de edad Proterozoico Temprano. Los depeositos de oro se formaron en vetas discontinuas de cuarzo paralelas a la foliación tectónica de la zona.

Los análisis isotópicos en zircones separados de la Formación Yuruari, la cual forma la unidad superior del Supergrupo Pastora, arrojan una edad por el metodo U-Pb de

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2,131±10 Ma. Esta es la primera edad isotópica obtenida en zircones por el metodo U-Pb para el Supergrupo Pastora en Venezuela, la misma confirma la edad Proterozoico Temprano para rocas verdes (greenstones) en el Escudo de Guayana.

Datos geoquímicos de elementos mayores y elementos traza obtenidos de lavas toleíticas almohadilladas con cuarzo normativo de la Formación El Callao, la cual tiene una edad Proterozoica Temprana, tienen afinidad con toleitas bajas en potasio originadas en un ambiente de arco de islas. Los basaltos calco-alcalinos de la Formación Caballape (más joven) tienen una composición similar a basaltos calco-alcalinos bajos en potasio y andesitas basálticas típicas en sequencias de arcos de islas. Las rocas de la región estudiada se formaron probablemente en un arco de islas inmaduro intraoceánico el cual fue deformado por corrimiento oblicuo dextral a lo largo de un eje de compresión tectónica orientado en sentido noreste.

INTRODUCTION

The Lo Increíble mining district provides a unique opportunity to unravel the structural setting of Precambrian lode gold deposits of the Guayana Shield of Venezuela and to date the Early Proterozoic Yuruari Formation of the Pastora Supergroup (fig. 1). Although Gibbs and Olszewski (1982) dated rocks equivalent to the Pastora Supergroup in Guyana to the east, this study provides the first published U-Pb date on zircon from a sample of the Pastora Supergroup in Venezuela. The mapping described herein was a part of a joint U.S. Geological Survey–Corporación Venezolana de Guayana, Técnica Minera, C.A. (CVG–TECMIN) geologic field mapping course taught by W.C. Day in June 1989. R.M. Tosdal provided the U-Pb date on zircon from a sample of the Early Proterozoic Yuruari Formation. The remaining co-authors participated in the field course.

The Lo Increíble mining district is in the eastern part of Estado Bolívar, approximately 150 km southeast of Puerto Ordaz and 10 km northeast of the El Callao mining district. The study area is covered by a thick weathered profile and dense tropical jungle vegetation, and thus our observations were limited to linear traverses cut through the jungle and sites along roads and mines and creek bottoms.

GEOLOGY

REGIONAL STRATIGRAPHIC SETTING

Rocks of the Lo Increíble mining district are Early Proterozoic volcanic, plutonic, and sedimentary rocks generally metamorphosed to low grade (middle to upper greenschist facies) and to a lesser extent medium grade (lower amphibolite facies). Regional mapping studies by Menendez (1968, 1972, 1974) established the stratigraphic framework for the area. The oldest rocks in the study area belong to the Early Proterozoic Pastora Supergroup. Menendez recognized that the oldest part of the Pastora Supergroup is made up of the Carichapo Group, which consists of pillow lavas of the El Callao Formation and amphibole-biotite schist of the Cicapra Formation; however, rocks of the Cicapra Formation are not present in the study area. Sedimentary rocks of the Early Proterozoic Yuruari Formation, which forms the youngest unit within the Pastora Supergroup, structurally overlie the Carichapo Group (Menendez, 1968, 1972, 1974). Our mapping confirms that the contact between the two formations is faulted. Volcanogenic sedimentary rocks of the Early Proterozoic Caballape Formation overlie rocks of the Pastora Supergroup (Menendez, 1972). Rocks of the Pastora Supergroup and the Caballape Formation were regionally intruded by diabasic to gabbroic sills and (or) dikes.

GEOLOGY AND GEOCHEMISTRY OF THE LO INCREIBLE MINING DISTRICT

The northern part of the study area is underlain by rocks of the Early Proterozoic Yuruari Formation (fig. 2). Rocks of the Yuruari Formation are poorly exposed, except in mine workings near the shear zone that separates the Yuruari and the El Callao Formations in the central part of the study area. The southern part of the study area is dominated by a large gabbro sill that forms a prominent ridge. The gabbroic sill is enfolded within the Caballape Formation.

EL CALLAO FORMATION

The oldest rocks in the study area are basalts of the Early Proterozoic El Callao Formation, which forms the basal unit in the Pastora Supergroup. This formation is characterized by tholeiitic basaltic pillow lava flows (unit Xec, fig. 2) and interlayered flow breccia (unit Xecb). The shape and orientation of the pillow structures, which are well exposed along the highway in the western part of the study area (fig. 2), indicate that the unit is upward facing and youngs stratigraphically to the southeast in the study area. The formation weathers light brown and in many places is recognized only by light-brown colluvial soil and float. Although regionally the unit is of low metamorphic grade, within and immediately adjacent to the shear zone (<250 m) in the central part of the study area the El Callao Formation has been recrystallized to hornblende-biotite schist of medium metamorphic grade.

Two sheets of basaltic breccia lie within the El Callao Formation (unit Xecb, fig. 2). These sheets are each about 50 m thick and contain angular basaltic clasts as much as 15 cm in diameter in a volcaniclastic basaltic matrix. The brec-

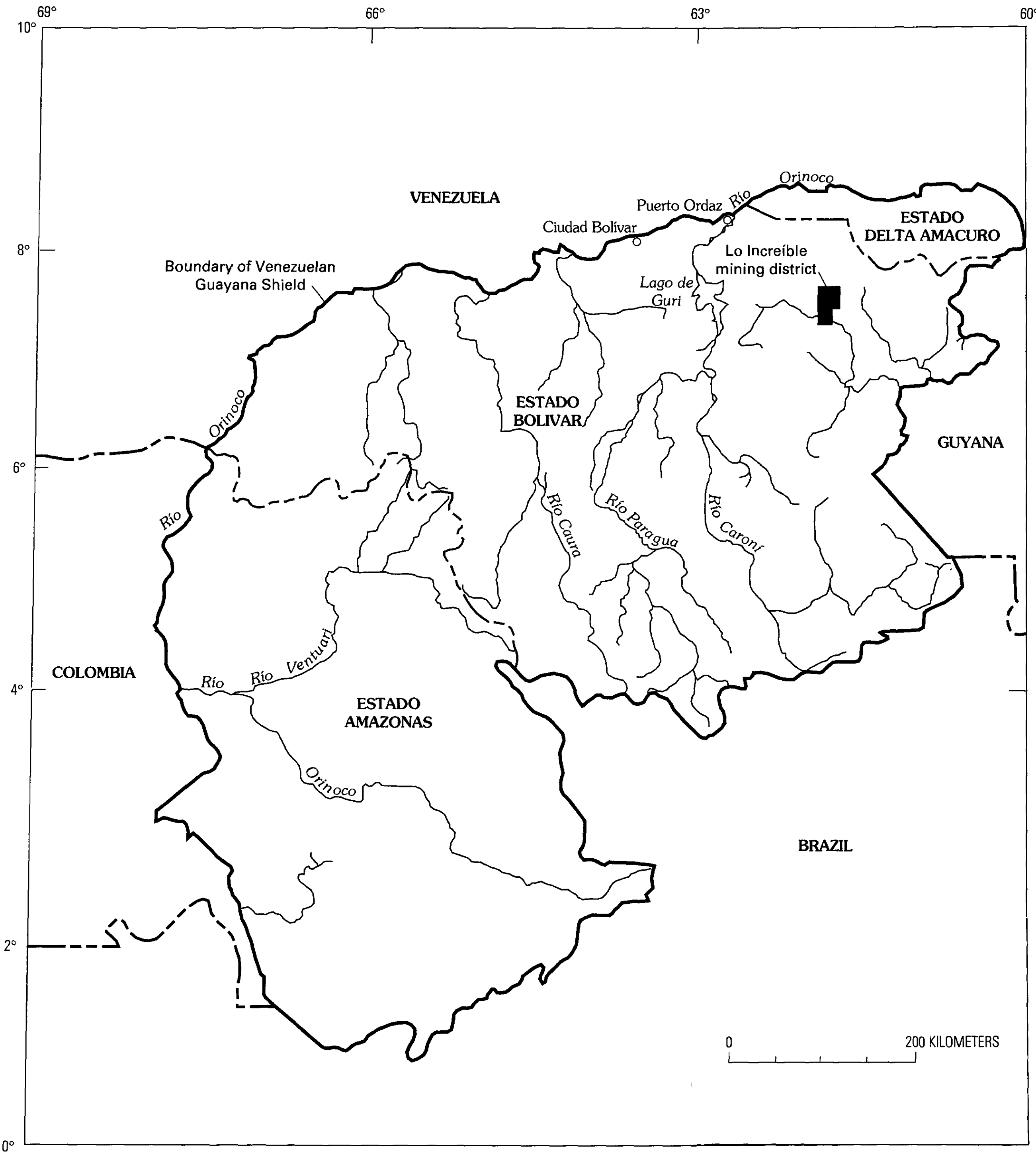


Figure 1. Location of the Lo Increíble study area, Estado Bolívar, Venezuela.

cia sheets formed as interflow breccias within the basaltic flows of the El Callao Formation.

Rocks of the El Callao Formation are metaluminous, quartz-normative, low-potassium tholeiitic basalt. Plotted on a Jensen (1976) diagram, our samples of the El Callao Formation range from high-iron to high-magnesian tholeiite (fig. 3*A*). The Mg-numbers are from about 47 to 63 (table 1), typical of tholeiitic basalt (Basaltic Volcanism Study Project, 1981, p. 132–192). The rare earth element patterns (fig. 4*A*) are relatively flat and are about 10 times chondrite in abundance. All of these characteristics are similar to modern mid-ocean ridge, low-potassium island arc, and back-arc

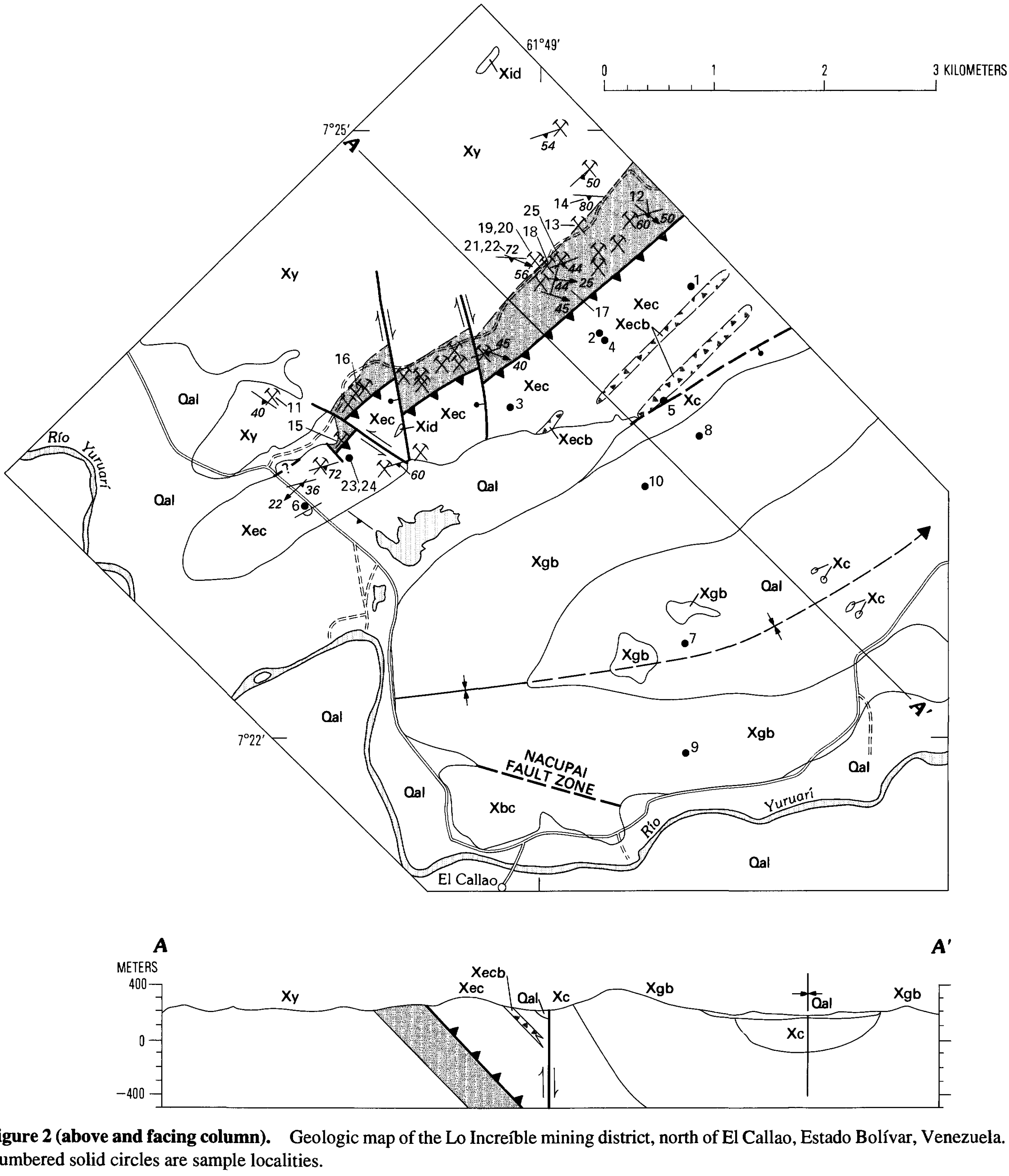


Figure 2 (above and facing column). Geologic map of the Lo Increíble mining district, north of El Callao, Estado Bolívar, Venezuela. Numbered solid circles are sample localities.

basalts (*see* Jakes and Gill, 1970, p. 19). The proportions of MnO, TiO_2, and P_2O_5 are similar to those of modern island arc tholeiite (fig. 3*B*). Rocks of the El Callao Formation contain less TiO_2 than tholeiite formed in mid-ocean ridge environments.

In order to characterize the environment of formation, the trace element geochemistry for samples of the El Callao Formation is compared with that for island arc low-potassium basalt and normal (or N-type) mid-ocean ridge basalt (MORB), which may have formed in similar tectonic

EXPLANATION

Qal	**Alluvium**
Xbc	**Tectonic breccia**
Xgb	**Gabbro**
Xid	**Diabase**
	Pastora Supergroup—Divided into:
Xc	**Caballape Formation**
Xy	**Yuruari Formation**
Xec, Xecb	**El Callao Formation of the Carichapo Group**—Includes volcanic breccia (unit Xecb)

Contact—Approximately located; dashed where inferred

Fault—Dashed where inferred; arrows show direction of movement. Bar and ball on downthrown side

Thrust fault—Sawteeth on upper plate

Shear zone

Syncline—Dashed where inferred

40 **Strike and dip of foliation**

60 **Bearing and plunge of lineation**

Pillow lava showing younging direction

Mine or prospect

Paved road

Unimproved road

Town

Lake

environments (fig. 5*A*). The data are normalized to an average composition for island arc low-potassium tholeiite formed near Benioff zones (Holm, 1985, p. 311). A sample with a trace element composition identical to that of the average island arc low-potassium tholeiite will have a ratio of unity, a sample having lower elemental abundances will plot below the unity line, and, conversely, a sample having higher abundances will plot above.

Tholeiite of the El Callao Formation is relatively depleted in the large-ion lithophile elements K, Sr, and Ce but has abundances of the high field strength elements P, Zr, Ti, Y, and Yb comparable to those of island arc low-potassium tholeiite (fig. 5*A*). The rubidium concentration of El Callao tholeiite is similar to that of island arc tholeiite. By comparison, normal mid-ocean ridge basalt (Pearce, 1982, p. 527) is also relatively depleted in large-ion lithophile elements but has higher high field strength element abundances than the El Callao Formation or island arc low-potassium tholeiite.

YURUARI FORMATION

The Yuruari Formation is a quartz-biotite-muscovite schist containing white quartz pods and veinlets that are parallel with the foliation. The unit is highly susceptible to weathering and forms low-lying topography. Outcrops are rare except near mines. The formation has a characteristic bright orange to red soil that contains residual pods of white quartz. The schist has been metamorphosed to medium grade (amphibolite facies), but ubiquitous alteration of primary biotite to chlorite indicates retrograde to low-grade (greenschist facies) metamorphism. Less weathered exposures within the shear zone show that the protolith was dacite and felsic volcaniclastic graywacke and locally interlayered basalt.

The intensely weathered nature of the Yuruari Formation limits geochemical sampling to determine the composition of the protolith. One sample of the Yuruari Formation, although weathered, is listed in table 1 (sample 11). The sample plots as calc-alkaline dacite on the Jensen diagram (fig. 3*A*) but has rhyolitic SiO_2 content (75.6 weight percent). The relatively higher SiO_2 may reflect the effects of weathering in which other constituents are leached. The rare earth element data also suggest similar leaching effects. Assuming that the composition of the protolith was generally similar to typical shale or graywacke (Menendez, 1972), approximately an order of magnitude loss has occurred in the abundance of the light rare earth elements (fig. 4*B*).

CABALLAPE FORMATION

The Caballape Formation consists of calc-alkaline andesite, dacite, and rhyolite tuff and felsic volcaniclastic sedimentary rocks that have been metamorphosed to low grade (greenschist facies). The formation is poorly exposed in the study area; outcrops are in the creek bed adjacent to the high-angle normal fault north of the gabbroic sill and at isolated locations in the core of the east-plunging syncline in the central and southern parts of the study area (fig. 2).

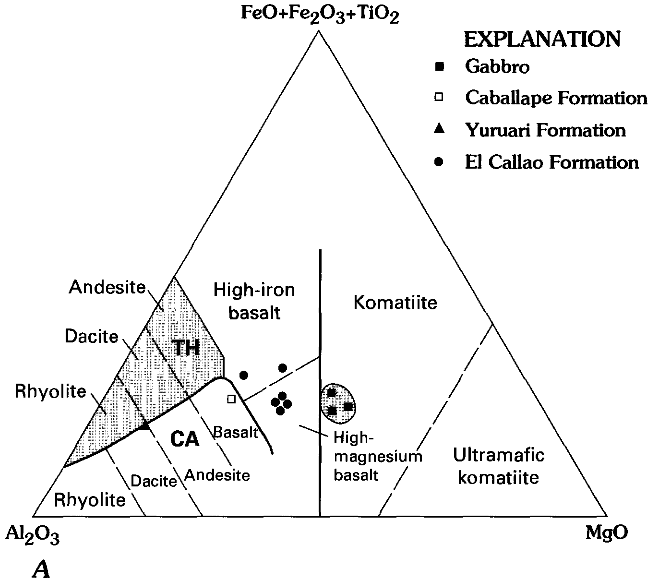
One sample from the core of the syncline in the study area is low-potassium calc-alkaline basalt (sample 7, table 1, fig. 3*A*). In the Anacoco area, approximately 100 km southeast of this study area, the Caballape Formation ranges in composition from calc-alkaline basalt through dacite (Day and others, 1989). In both the Anacoco and Lo Increíble areas, the major-, minor-, and trace-element content of the unit is similar to that of calc-alkaline low-potassium basalt and basaltic andesite typical of island arc sequences (figs. 3*B*, 4*C*).

GABBRO

A large gabbroic body (unit Xgb, fig. 2) was intruded as a sill and then infolded with the Caballape Formation to form an eastward-plunging syncline in the central and southern part of the study area (fig. 2). Fresh surfaces are dark green to black. The texture of the gabbro grades from fine-grained diabasic margins inward to a medium- to coarse-grained interior. The gabbro has undergone regional greenschist facies metamorphism. It is relatively resistant to weathering and forms outcrops along the prominent ridge in the southern part of the study area.

The gabbro is younger than supracrustal rocks of the Pastora Supergroup. Several smaller diabasic sills (or dikes) are present within the El Callao and Yuruari Formations (unit Xid, fig. 2). The relative ages of the main gabbro and the diabase sills are not established; however, the units are considered coeval.

The gabbro is quartz normative, metaluminous, and tholeiitic in composition (samples 8–10, table 1). The Mg-numbers are relatively high (less evolved), ranging from approximately 65 to 69 (table 1). The gabbro is distinctly different from the El Callao Formation in that it has higher Mg-numbers and greater abundances of the light rare earth (figs. 4*A*, 4*D*) and large-ion lithophile (fig. 5*B*) elements. Although the major element contents of the gabbro are similar to komatiitic compositions (fig. 3*A*), the light rare earth element contents and higher MnO abundances (fig. 3*B*) show that the gabbro has affinities with calc-alkaline basaltic magmas. The calc-alkaline affinity of the trace elements may imply that the gabbro evolved during the same calc-alkaline magmatic episode as the Caballape Formation, which it intrudes.



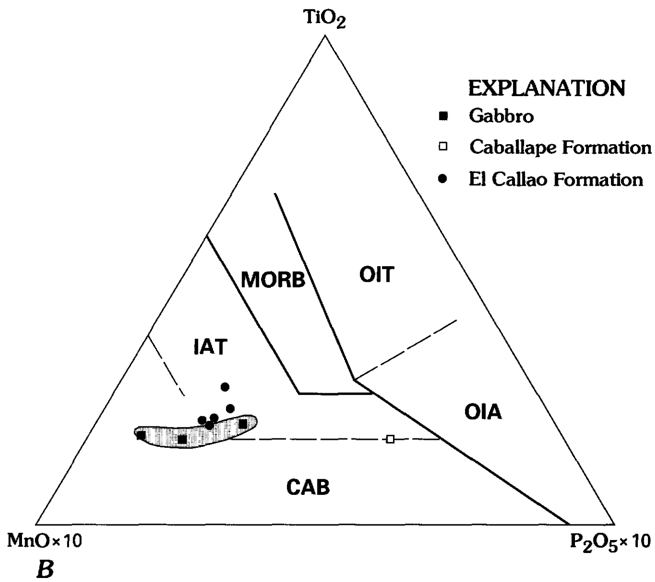


Figure 3. Ternary plots showing chemical characteristics of samples from the Lo Increíble mining district, Estado Bolívar, Venezuela. *A*, Jensen diagram. Modified from Jensen (1976). *B*, $MnO/TiO_2/P_2O_5$ discriminant diagram for basalt and basaltic andesite. Fields: CAB, island arc calc-alkaline basalt; IAT, island arc tholeiite; MORB, mid-ocean ridge and marginal basin basalt; OIT, ocean island tholeiite; OIA, ocean island basalt (Mullen, 1983).

U-PB ZIRCON AGE OF THE EARLY PROTEROZOIC YURUARI FORMATION

Zircon extracted from a metadacite tuff within the Yuruari Formation (sample location 25, fig. 2) provides a reliable radiometric date for the formation and, therefore, for the upper part of the Pastora Supergroup. Although the Yuruari Formation is highly weathered, reliable age data can be extracted from zircon in units that have undergone extreme tropical weathering (Gibbs and Olszewski, 1982).

Five zircon fractions analyzed from the sample metadacite tuff of the Yuruari Formation have discordant $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ ages (table 2). All the fractions define a chord on a concordia diagram (mean square weighted deviation=0.3) (Ludwig, 1983) with an upper intercept of 2,131±10 Ma and a lower intercept that is essentially present-day (fig. 6). This pattern of discordance in the ages indicates that lead was lost from zircon during a subsequent event (Silver and Deutsch, 1963). The upper concordia intercept age of 2,131±10 Ma is interpreted to indicate an Early Proterozoic crystallization age for the dacitic tuff. This interpretation is confirmed by the good agreement between the $^{207}Pb/^{206}Pb$ ages of the individual zircon fractions and the upper intercept age on the concordia diagram. The lower

Table 1. Major- and trace-element abundances for rocks of the Lo Increíble mining district, Estado Bolívar, Venezuela.

[Locations of samples shown by sample numbers in figure 2. All field numbers are prefixed by WDV. Major-element oxides in weight percent; trace elements in parts per million]

Rock type	Basalt	Basalt	Basalt	Basalt	Basalt	Basalt	Andesite	Gabbro	Gabbro	Gabbro	Schist
Formation	El Callao	El Callao	El Callao	El Callao	El Callao	El Callao	Caballape				Yuruari
Sample No.	1	2	3	4	5	6	7	8	9	10	11
Field No.	89–019	89–030	89–055	89–031	89–034	89–068	89–073	89–037	89–071	89–051	89–063
Major elements											
SiO_2	47.60	48.50	49.00	49.90	49.40	50.00	55.60	49.30	49.40	50.10	75.60
Al_2O_3	15.60	14.60	14.40	14.10	13.50	14.20	14.80	11.60	12.30	11.30	11.80
Fe_2O_3t	13.90	11.50	11.40	10.50	14.90	10.60	10.00	12.20	11.00	11.40	4.76
MgO	5.58	8.52	8.16	7.93	7.23	7.60	4.99	10.10	10.80	11.30	1.26
CaO	13.00	12.50	11.90	12.70	8.63	12.70	7.08	11.60	12.30	12.30	0.02
Na_2O	0.85	1.38	2.03	2.31	2.09	2.26	2.98	1.69	1.11	1.00	0.76
K_2O	0.04	0.04	0.04	0.03	0.04	0.06	0.38	0.50	0.17	0.17	0.50
TiO_2	0.89	0.66	0.67	0.63	1.01	0.64	0.78	0.74	0.49	0.54	0.52
P_2O_5	0.06	0.06	0.06	0.06	0.09	0.06	0.23	0.09	<0.05	0.05	<0.05
MnO	0.17	0.19	0.19	0.18	0.23	0.17	0.13	0.19	0.19	0.20	<0.02
CO_2	<0.01	<0.01	0.01	0.09	0.13	0.02	<0.01	0.09	0.01	0.01	0.01
LOI 900°C	2.70	2.45	2.16	1.78	2.86	1.77	2.76	2.20	2.50	2.35	1.67
Total	100.39	100.40	100.01	100.12	99.98	100.06	99.73	100.21	100.26	100.71	96.89
Mg-number[1]	51.00	65.76	64.98	66.19	55.71	65.02	56.40	68.21	71.79	71.99	40.69
Trace elements											
Nb	<10	<10	<10	<10	<10	<10	<10	13	<10	11	<10
Rb	7	<2	7	<2	6	<2	17	11	5	7	12
Sr	443	165	108	82	105	65	522	165	139	134	158
Zr	46	38	45	39	60	42	130	73	44	51	91
Y	19	10	18	11	28	17	18	17	12	14	12
Ba	11	9	10	8	11	18	201	199	86	104	229
Cu	61	120	108	111	117	82	2	71	142	150	40
Ni	178	141	110	117	91	118	105	184	156	149	44
Zn	87	76	79	68	107	78	60	83	68	64	80
Cr	297	439	431	384	45	400	264	307	100	112	88
La	3.6	2.0	2.2	1.7	2.7	1.7	28.0	12.0	4.8	6.6	2.5
Ce	8.0	5.1	5.7	4.9	7.3	4.6	53.0	25.0	10.0	15.0	4.4
Pr	1.2	0.8	0.9	0.7	1.1	0.7	6.2	2.8	1.3	1.8	0.5
Nd	6.7	4.3	5.0	4.3	6.5	4.2	27.0	14.0	5.8	8.1	2.1
Sm	2.20	1.40	1.50	1.20	2.10	1.40	4.90	3.30	1.70	2.20	0.88
Eu	0.93	0.60	0.67	0.60	0.91	0.54	1.40	1.00	0.56	0.69	0.37
Gd	2.6	1.8	2.0	1.7	2.4	1.5	4.2	3.2	1.7	2.4	1.1
Tb	0.73	0.31	0.36	0.34	0.51	0.30	0.64	0.59	0.32	0.41	0.25
Dy	4.5	2.5	2.9	2.5	3.8	2.4	3.4	3.6	1.8	2.4	2.0
Ho	0.87	0.52	0.54	0.59	0.80	0.52	0.62	0.69	0.41	0.54	0.42
Er	2.6	1.5	1.6	1.5	2.4	1.4	1.7	2.2	1.1	1.4	1.4
Tm	0.42	0.26	0.25	0.21	0.38	0.22	0.24	0.30	0.14	0.26	0.18
Yb	2.9	1.4	1.6	1.6	2.2	1.4	1.6	1.8	0.9	1.1	1.1

[1]Mg-number=100×Mg/(Mg+Fe^{2+}), where Fe^{2+}=0.85× (Fe_2O_3t/79.85×0.8995)

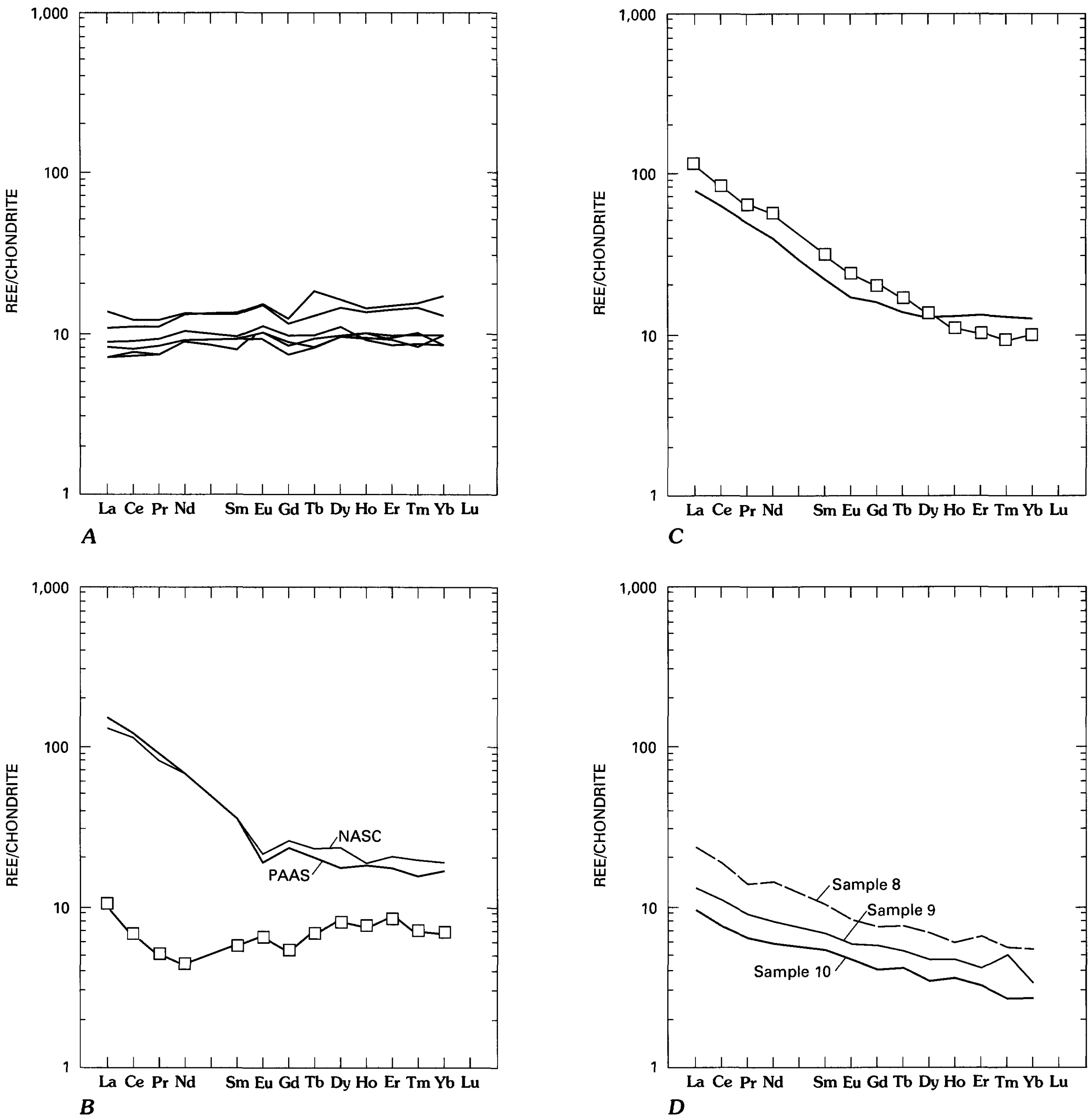


Figure 4. Chondrite-normalized rare earth element (REE) diagrams for rocks of the Lo Increíble mining district, Estado Bolívar, Venezuela. *A*, El Callao Formation. *B*, Weathered sample of the Early Proterozoic Yuruari Formation (open squares). Typical post-Archean Australia shale (PAAS; heavy line) and North America Shale Composite (NASC; light line) (Taylor and McLennan, 1985) are shown for comparison. *C*, Meta-andesite sample from the Caballape Formation (open squares). Typical calc-alkaline island arc andesite (Gill, 1981) (heavy line) is shown for comparison. *D*, Samples from a gabbroic sill that intrudes the Caballape Formation.

intercept age is interpreted to indicate that the time of lead loss was recent. The lower intercept (70±50 Ma) (fig. 6) probably reflects lead loss due to surficial weathering during the Cretaceous to Paleogene, similar to the lead loss described by Gibbs and Olszewski (1982) for rocks equivaenslent to the Pastora Supergroup in Guyana. The geomorphological development of the Venezuelan Guayana Shield and the effects of weathering on shield rocks in the Mesozoic and Tertiary are discussed by Briceño and Schubert (1990) and by references contained therein.

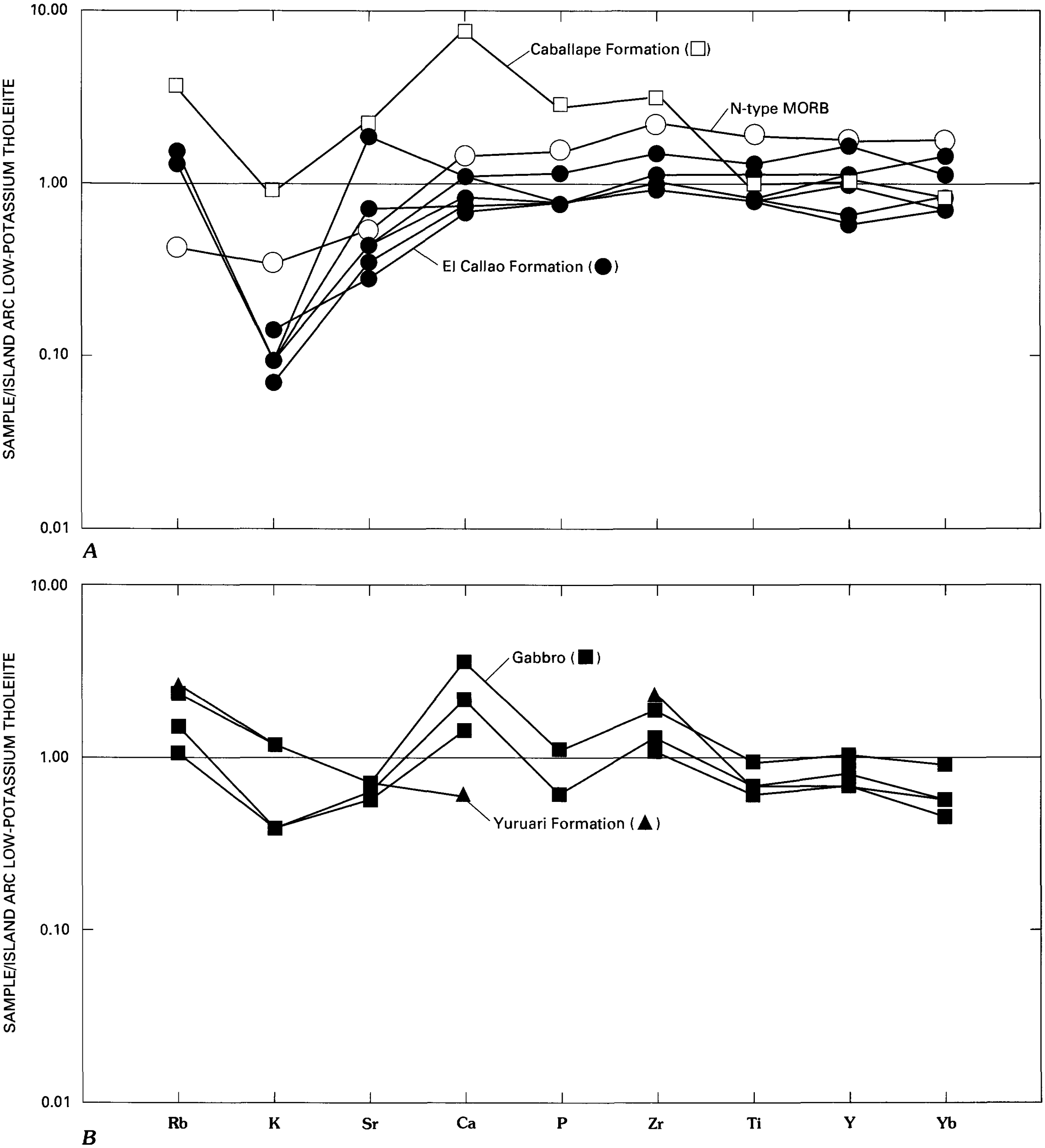


Figure 5. Spider diagrams for rocks of the Lo Increíble mining district, Estado Bolívar, Venezuela. Normalized to island arc low-potassium tholeiite (Holm, 1985, p. 311). *A*, El Callao (circles) and Caballape Formations (squares). Normal mid-ocean ridge basalt (N-type MORB) (Pearce, 1982, p. 527) is also shown (diamonds). *B*, Yuruari Formation (triangles) and gabbro unit (squares) that intrudes the Caballape Formation.

Neither prograde medium-grade metamorphism within the shear zone nor subsequent retrograde (greenschist facies) metamorphism during the Trans-Amazonian orogeny (about 2.15–2.0 Ga) affected the U-Pb isotopic systematics in zircon from the sample of the Yuruari Formation. Lead loss during any younger event is enhanced by radiation damage to the zircon lattice that accumulates through geologic time. The low uranium content (100–220 ppm ^{238}U) of the zircon from the felsic tuff effectively precluded any extensive radiation damage to the zircon lattice due to the decay of

Table 2. U-Pb geochronologic data (zircon) for dacite (WDV–89–12) from the Yuruari Formation of the Pastora Supergroup, Lo Increíble area, Venezuela.

[Location of sample shown as sample location 25 in figure 2. Asterisk (*) following element symbol denotes radiogenic Pb. Sample dissolution and ion exchange chemistry modified from Krogh (1973) and Mattinson (1987). Fraction: N, nonmagnetic; M, magnetic; amperes/side slope on a Franz Isodynamic separator; C, coarse-grained split; F, fine-grained split. Observed ratios corrected for 0.125 per unit mass fractionation, based on replicate analyses of NBS 981. Uncertainties in the measured $^{208}Pb/^{206}Pb$ and $^{207}Pb/^{206}Pb$ ratios are less than 0.1 percent and uncertainties in the measured $^{206}Pb/^{204}Pb$ ratios are between 0.5 and 2 percent at the 2 sigma level(σ). Isotopic data measured on a Finigan-Mat MAT 262 multiple collector mass spectrometer at the U.S. Geological Survey, Menlo Park, Calif. Atomic ratios calculated using the following constants: $^{238}U/^{235}U$=137.88; ^{235}U=0.98485×10^{-9}yr^{-1}; ^{238}U=0.155125×10^{-9}yr^{-1}. Observed ratios are corrected for common Pb ratios: 208:207:206:204 Pb of 34.6:15.1:14.9:1 using average crustal growth model of Stacey and Kramers (1975). All errors are reported to two sigma (σ); error analysis follows Mattinson (1987)]

Fraction (mg)	Weight (ppm)	$^{206}Pb^*$ (ppm)	^{238}U	Observed ratios $^{206}Pb/^{204}Pb$	$^{207}Pb/^{206}Pb$	$^{208}Pb/^{206}Pb$	Atomic ratios $^{206}Pb^*/^{238}U$	$^{207}Pb^*/^{235}U$	$^{207}Pb^*/^{206}Pb^*$	Age and error (Ma) $^{206}Pb^*/^{238}U$	$^{207}Pb^*/^{235}U$	$^{207}Pb^*/^{206}Pb^*$
NC(1.8/0.5)	2.9	55.1	210.4	7634	0.13352	0.1878	0.302552	5.49805	0.131797	1,704±2	1,900±2	2,122±4
NC(1.8/0.5)	2.3	25.6	99.7	6494	0.13369	0.1914	0.297271	5.39664	0.131665	1,678±2	1,884±2	2,120±4
NF(1.8/0.5)	2.8	39.1	159.4	6289	0.13370	0.1953	0.283556	5.14547	0.131609	1,609±2	1,844±2	2,120±4
MF(1.8/0.5)	3.6	39.4	166.3	3788	0.13479	0.1996	0.273863	4.95854	0.131317	1,560±2	1,811±2	2,116±4
MF(1.8/1)	2.3	39.1	171.7	3484	0.13504	0.2023	0.263158	4.76547	0.131176	1,508±2	1,779±2	2,115±4

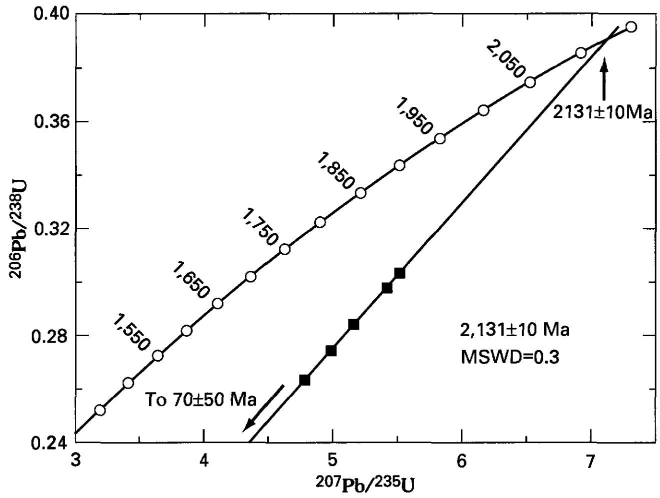


Figure 6. U-Pb concordia diagram showing U-Pb isotopic data for zircon from a metadacite tuff in the Yuruari Formation of the Pastora Supergroup, Lo Increíble mining district, Estado Bolívar, Venezuela. Solid diamonds represent data points; analytical errors at the two-sigma (2σ) confidence level on each analysis are smaller than the square and are not shown. Solid chord is regression line through all five zircon fractions.

uranium and thorium in the period between the crystallization age of the tuff and its subsequent metamorphism and tectonic burial during the Trans-Amazonian orogeny.

STRUCTURAL SETTING OF GOLD DEPOSITS

STRUCTURAL OBSERVATIONS

The shear zone that separates the Yuruari and El Callao Formations in the study area is a northeast-striking zone of intense ductile deformation. Although rocks of the Yuruari Formation are dominant within the shear zone, locally rocks of the El Callao Formation are incorporated and have been recrystallized to amphibolite schist. The orientation of the shear zone is presumably parallel to the generally southeast dip of the tectonic foliation within the zone. Such an orientation indicates that the El Callao Formation south of the shear zone structurally overlies the Yuruari Formation to the north. Therefore, assuming the stratigraphy outlined by Menendez (1972), the shear zone has a component of thrusting, placing the older El Callao Formation over the younger Yuruari Formation.

Rocks within the shear zone are highly foliated and are locally deformed into small-scale folds of S and Z symmetry; the latter is the dominant geometry. An S-C mylonitic fabric is well developed within the shear zone. Two foliations characterize the S-C mylonitic fabric. One foliation (C surface) forms the dominant foliation and is the plane of strongly localized ductile shearing (*see* Lister and Snoke, 1984). The other foliation (S surface) is developed oblique to

Table 3. Gold and trace element abundances for samples associated with gold deposits of the Lo Increíble mining district, Estado Bolívar, Venezuela.

[In parts per million. Location of samples shown by sample number in figure 2. All field numbers are prefixed by WDV]

Rock type	Schist	Quartz vein	Quartz vein	Quartz vein	Quartz vein	Schist host	Quartz vein	Schist host	Quartz vein	Schist host	Quartz vein	Schist host	Quartz vein
Sample No.	12	13	14	15	16	17	18	19	20	21	22	23	24
Field No.	89–016	89–013	89–014	89–061	89–053	89–009	89–008	89–46A	89–46B	89–47A	89–47B	89–60A	89–60B
Au	<0.002	0.004	0.200	0.008	2.100	0.030	7.000	<0.002	<0.002	0.150	4.450	0.022	18.000
As	<10	<10	<10	50	60	30	50	20	<10	70	60	150	280
Co	2	12	16	45	3	17	13	4	3	18	5	48	123
V	23	6	34	170	52	101	59	239	47	111	17	262	145
Rb	10	<2	12	42	4	44	18	8	3	68	<2	74	40
Sr	526	37	153	114	109	360	151	184	109	153	20	45	27
Zr	162	12	67	34	16	112	94	57	22	215	20	53	43
Y	6	3	9	10	4	3	9	11	7	31	4	34	15
Ba	12	165	295	92	16	670	314	203	9	704	51	139	117
Ce	34	100	21	9	<2	46	47	<2	2	65	8	16	12
La	32	2	<2	5	<2	35	9	8	<2	26	13	23	11
Cu	10	3	9	47	15	31	41	45	10	115	15	111	189
Ni	48	<5	22	100	31	36	29	94	74	45	7	151	111
Zn	92	12	36	57	82	38	55	28	48	112	31	178	117
Cr	95	<20	<20	343	140	67	50	392	114	75	<20	486	37

the C surface and is characterized by elongation and flattening of mineral grains. Locally, the foliations are boudinaged parallel with the principal plane of ductile shearing (C surface).

The intersection of the S and C surfaces forms an acute angle to the northeast, indicating a dextral sense of shear. In addition, sygmoidal-shaped boudins, as well as the predominance of small-scale folds having Z symmetry, confirm the dextral sense of lateral shear. These kinematic indicators, combined with the older-over-younger relation of the El Callao and Yuruari Formations (assuming the stratigraphy outlined by Menendez, 1972), indicate that the shear zone is a right-oblique slip-thrust (or reverse) fault zone. Therefore, rocks of the study area underwent a dextral oblique compression, or dextral transpression, along a northwest-oriented tectonic axis of maximum compression.

GOLD DEPOSITS

Gold deposits in the Lo Increíble mining district are low-sulfide shear-zone-hosted lode gold (or mesothermal) type. Native gold is within discontinuous quartz veins that are 0.5–20 cm wide and as long as 100 m. The quartz veins pinch and swell within planes of shear foliation within the host schist and are both subparallel with and discordant to the tectonic foliation. The host schist is a tectonic melange of biotite-sericite schist of the Yuruari Formation and biotite-amphibole schist of recrystallized El Callao Formation. Therefore, the host samples listed in table 3 could have been derived originally from either formation, but were tectonically juxtaposed within the shear zone.

Two generations of quartz characterize the gold-bearing veins. An early dark-gray pyrite-bearing tourmaline-rich quartz is cut by later, white bull quartz veins. Alteration minerals associated with the gold deposits include tourmaline, sericite, chlorite, pyrite, quartz, and carbonate minerals.

Analyses of grab samples from quartz veins in surface deposits are listed in table 3. Because weathering within the shear zone was intense, these analyses do not represent original protolith compositions. Sample 12, from a 5–10-m-deep prospect pit, is an unmineralized sample of schist. It is a weathered fine-grained mafic volcanic tuff that contains fine-grained feldspar phenocrysts and has a superimposed tectonic foliation. The protolith was probably fine-grained mafic tuff within the Yuruari Formation. Samples 13–16 are composite samples from several gold deposits in the district. Samples 17–22 are paired samples of host biotite-sericite schist and corresponding quartz-vein material (sample 17 with sample 18, 19 with 20, and 21 with 22). Protolith for the host biotite-sericite schist of the paired samples was probably volcaniclastic sedimentary rock of the Yuruari Formation.

In general, gold concentrations in these samples are as high as 18 ppm. Samples that have higher gold values also have elevated arsenic contents. The quartz veins are relatively enriched in gold, but they are depleted in most of the other elements analyzed.

The overall nature, mode of occurrence, and origin of the gold deposits are similar to those described by Berger and Bliss (1986) for low-sulfide gold-quartz veins and by Colvine (1989) for shear-zone-hosted lode-gold deposits in the Canadian Shield. The gold deposits are restricted to the quartz veins in or adjacent to the shear zone separating the Yuruari and El Callao Formations. Formation of alteration minerals in the host rock during deformation within the shear zone is indicated by the parallel foliation within the secondary micaceous minerals and the unmineralized host schist. Therefore, gold deposition accompanied deformation and alteration within the shear zone.

Historical grade and tonnage information for the gold deposits of the Lo Increíble mining district is limited. Data for mines within the district (Locher, 1974) show that the district has produced at least 1,300 kg of gold at a grade of about 12 grams per metric ton (53.3 metric tons at 10.6 grams per metric tons for the Experiencia mine, 3.3 metric tons at 6.2 grams per metric ton for the Garrapata mine, 45.3 metric tons at 14.7 grams per metric ton for the Increíble mine, and 1.7 metric tons at 11.4 grams per metric ton for the Talisman mine). The limited production data are a result of the ad hoc mining within the district in dominantly hand dug surface trenches and primitive underground workings. Gold has been recovered primarily from mercury amalgamation of hand-cobbed quartz-vein material, and a quantitative assessment of the gold potential of the district would be speculative at best. The assay values reported in table 2 indicate, however, that high-grade veins are present in the district. High potential at a high degree of certainty is present for undiscovered shear-zone-hosted lode-gold deposits within and along the extension of the shear zone. Further exploration of the shear zone, especially to the east of the study area, should result in the discovery of additional gold deposits.

CONCLUSIONS

The paleotectonic environment of the Lo Increíble mining district of Estado Bolívar, Venezuela, and, by extension, the entire Pastora Supergroup, can be deciphered by integrating geologic and geochemical data from all of the units in the area. Major-, minor-, and trace element data for the El Callao Formation show an affinity of these rocks with modern low-potassium island arc tholeiite. Metagraywacke of the Yuruari Formation may have formed along a convergent plate margin. Calc-alkaline basalt from the younger Early Proterozoic Caballape Formation is similar in composition to low-potassium calc-alkaline basalt and basaltic andesite typical of island arc sequences.

We suggest that the rocks in the Pastora Supergroup formed in an immature intraoceanic island arc setting that underwent subsequent oblique dextral thrusting along a northwest-oriented axis of tectonic compression. Similar relationships are observed in the Early Proterozoic Birimian greenstone belts of West Africa (Sylvester and Attoh, 1992), which Sidder and Mendoza (1991, this volume) correlate with rocks of the Pastora Supergroup of Venezuela.

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