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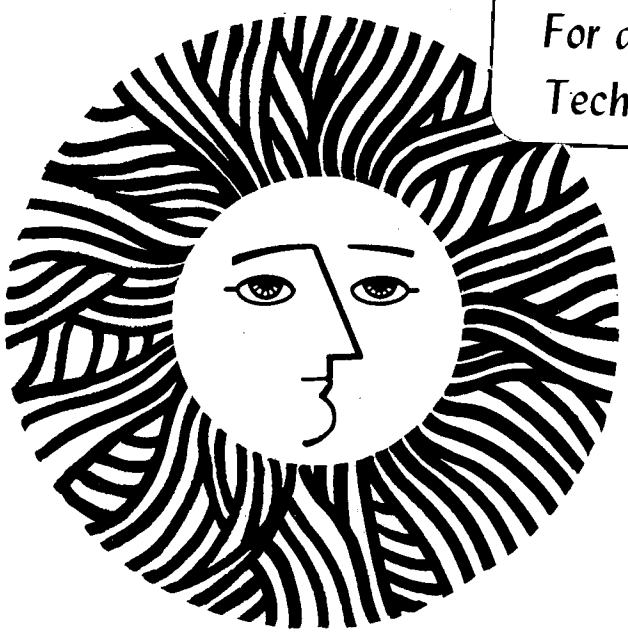
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September 1981

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This work was done with support from the U.S. Department of Energy under contract No. W-7405-ENG-48 and the Museo del Banco Central del Ecuador.

Major Sources of Ecuadorian Archaeological Obsidian and Provenience Assignments of Artifacts

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ABSTRACT

This study was made in collaboration with personnel from the Museo del Banco Central del Ecuador. Neutron activation analyses and x-ray fluorescence measurements strongly suggest that the Mullumica obsidian deposit is variable in composition with linear or nearly linear relationships between all measured elements. This behavior is very similar to that of obsidian from Borax Lake in California in the United States. Two other sources near the vol-

cano Antisana, Yanaurco Chico and Quiscatola, have identical and nearly homogeneous chemical abundances.

The two composition patterns, Mullumica and Yanaurco - Quiscatola account for nearly all (96%) of a group of 126 obsidian artifacts measured in this and a previous study. The Mullumica source is the most prominent of the two and accounts for about 75% of the artifacts. The sources are adequately distinguished by inexpensive non-destructive x-ray fluorescence measurements of Sr and Zr as well as the more definitive neutron activation analyses.

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I. Introduction

In an earlier study it was shown[1] by x-ray fluorescence (XRF) measurements and a few high-precision neutron activation analyses (NAA) that obsidian artifacts from Quito, Cotocollao, La Chimba and La Tolita island had chemical compositions which could be divided into two principal chemical groups (called Ecuador A and Ecuador B) containing most of the artifacts. Four other groups (called Mullumica, Cotocollao A, Cotocollao B and La Chimba) contained all but one of the remaining artifacts. One of the two major groups (Ecuador A) matched the

composition of obsidian from Rodeo Corrales which has been called a secondary source. Only one artifact had a composition which matched that of Mullumica, which has been called the most massive Ecuadorian obsidian source.[2] The suggestion was made, however, that the Mullumica source might be variable in composition and actually encompass some of the other chemical groups[1]. In an earlier unpublished study of 43 artifacts from El Inga, Guangala and Chobchi Cave, over 90% of the artifacts were assigned to two chemical groups[3] which were later found to be the same as Ecuador A and Ecuador B.[1] In the present work a detailed study has been made by high precision neutron activation analyses of 24 additional primary source and artifact samples in order to determine the origin of the various chemical groups previously identified[1]. The suggestion that Mullumica might be an obsidian source with variable composition has also been considered.

II Sample Sites

Primary source samples were obtained from Quiscatola, Yanaurco Chico and Ullos. Quiscatola is a mountain peak with an elevation of 4200 meters ~50 km southeast of Quito near the volcano Antisana. Quiscatola obsidian used in this work was obtained from the site called Quiscatola 2 (elevation 4120 meters) as defined by Salazar[4]. Yanaurco Chico is a mountain peak with an elevation of 4228 meters[5] about 5 km northeast from Quiscatola. Obsidian was obtained from two sites on Yanaurco Chico, Yanaurco 1 and Yanaurco 2. Ullos is a primary source in the Andean mountain range east of Quito. The obsidian samples from Ullos all contained copious inclusions, and their usefulness for

archaeological purposes is perhaps questionable.

Although Mullumica source samples were not measured in the present work, a description of the source is pertinent since Mullumica may be the source of many of the artifacts studied here. In September of 1977, E. Salazar discovered the largest known outcrop of obsidian in Ecuador. The layer is 5 km long and runs along the flanks of the glacial valley of Mullumica at approximately a 4000 meter elevation. Its thickness varies from 70 to 100 meters and gradually thins and then disappears at the extremes of the valley. The entire layer, however, is not obsidian. Obsidian generally appears in the lower part with a thickness of 15-20 meters. It is black and brown with striped configuration in its upper part. One top of this are lava flows of varying thickness with occasional mixing of obsidian flows[2].

Emil Peterson provided the descriptions of the archaeological sites and primary sources from which the obsidian samples used in the present work were obtained, and these are shown in Table I.

III. Sample preparation.

Samples for neutron activation analysis were prepared as previously described.[1] X-ray fluorescence analyses were made in a non-destructive mode which requires no sample preparation, except, occasionally, ultrasonic cleaning.

IV. Measurements

A. Neutron Activation Analyses

High precision measurements were made by the methods shown in the Appendix of the previous study.[1] Two neutron irradiations and five gamma-ray measurements were made on one sample from each group shown in Table I. The measured element abundances and estimated standard deviations are shown for each sample in Table II. Included in Table II are four of the nine previously reported[1] complete sequence NAA measurements on samples which belong to the two main chemical groups Ecuador A and Ecuador B. The data in Table II are arranged in groups with decreasing iron content. The group Ecuador B was divided into subgroups, in order to keep the standard deviation in a group roughly comparable to the precision of the measurements.

B. X-ray fluorescence

The samples were mounted in a 48 position automatic sample changer and generally analyzed by the procedure previously reported[1]. The samples is this work, however, were measured non-destructively, i.e.the artifacts were not broken and ground. The abundance measurements are not as accurate in this method as with specially prepared samples. Errors are a function of sample thickness and shape. The Compton backscatter-peak intensity varies with sample thickness and can be used to monitor the thickness. Corrections of a type previously discussed[6] can be made to reduce the errors due to this effect. Errors due to sample shape will also affect the intensity of the backscatter peak which not only monitors sample thickness but also determines the efficiency of the measurement. By taking ratios of abundances, e.g., Rb/Zr

and Sr/Zr, sample shape errors will cancel.

Measurements were made on the 107 samples shown in Table I. The samples were divided into chemical groups with previously developed criteria[1] and the groups and their distinguishing characteristics are shown in Table III. The data for three Ullos source samples are shown separately in Table III. The provenience assignments for the 99 artifacts are shown in Table IV.

Two artifacts have compositions which could be either Cotocallao A or Ullos. Neither artifact has the large number of inclusions characteristic of the three Ullos samples that were studied, so the Cotocollao A assignment is considered more likely. Neutron activation analyses on the two artifacts could make a conclusive distinction between Cotocollao A and Ullos.

V. Discussion and Conclusion

In Figures 1-3 are plotted the element abundances of the Ecuador B subgroups shown in Table I as a function of the iron content of the group. Also plotted are NAA data from the first report[1] for the Cotocallao A, Cotocollao B and Mullumica groups. When more than one sample comprises a group, the standard deviation in the mean is used as the error. With few exceptions (which may not be significant) the data are consistent with straight line dependencies for all of the elements. One of the most precisely measured elements, Na, seems to have small variations from linearity, and sample 1085 X, appears to have abundances lower than the line for many elements.

Thus a geochemical relationship between the chemical groups Mullumica, Cotocallao B, Cotocollao A and the subgroups of Ecuador B exists. This behavior is unusual for obsidian flows as they are normally homogeneous. A very similar example, however, was found in a study[7] of obsidian from near Borax Lake in the central part of California in the United States. There not only obsidian but an underlying dacite layer were found to exhibit linear relationships in all measured element abundances. The Borax Lake phenomenon was attributed to a mixing of magmas prior to or during eruption.[7]

The Mullumica linearity has so far only been detected in obsidian. Although the geochemical relationship is obvious from Figures 1-3, with only the existing chemical data it is not yet possible to distinguish with certainty between the mixing of magmas prior to or during an eruption and the differentiation of magma with periodic eruptions. It would be desirable to confirm this relationship with source samples of obsidian and also the intermixed flows of other lavas selected from a number of well-documented parts of the Mullumica deposit.

The previously reported Ecuador A chemical group[1] agrees exactly in composition with Quiscatola and Yanaurco Chico source obsidian, and the latter two sources are indistinguishable from each other. The Rodeo Corrales secondary source, which also has the same composition, is in the drainage area of these primary sources[8] and may have resulted from natural transport of obsidian.

Of 20 archaeological objects measured in this work by NAA and 30 previously measured principally by XRF,[1] thriteen match the Quiscatola-Yanaurco primary sources, 32 may be part of a variable

Mullumica source, four belong to a La Chimba chemical group and one is different in composition from any Ecuadorian or Peruvian obsidian[7] measured at the Lawrence Berkeley Laboratory. Of 76 other artifacts analyzed in this work by only non-destructive XRF, 14 match the Quiscatola-Yanaurco primary source, 60 are very likely part of a variable Mullumica source and two others may be part of the latter source.

If the strong implications of a variable Mullumica source can be verified on more source samples, nearly all Ecuadorian obsidian studied in this work arises from two sources, Quiscatola-Yanaurco and Mullumica, with the latter being more prominent. Mullumica has also been cited as the most prominent source of obsidian in in northern Ecuador in earlier work.[9]

VI. Acknowledgements

We are grateful to the personnel of the Museo del Banco Central del Ecuador and offer Emil Peterson special thanks suggesting this study, assembling the samples and arranging for the funding. We are very appreciative to Arq. Hernan Crespo Toral, Director del Museo del Banco Central del Ecuador for supplying part of the funding for this study. We thank Mr. Tek Lim, supervisor of the small Berkeley research reactor, and his staff for the irradiations used in this project. This work was done with support from the U.S. Department of Energy under contract No. W-7405-ENG-48 and the Museo del Banco Central del Ecuador.

VII. References

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3. R.L. Burger and F. Asaro unpublished data (1977).

4. Reference 2 page 50.

5. Reference 2 page 47.

6. R.L. Burger and F. Asaro, "Trace Element Analyses of Obsidian Artifacts from the Andes: New Perspectives on Pre-Hispanic Economic Interaction in Peru and Bolivia," Lawrence Berkeley Laboratory Report LBL-6343, June 1977. "Análisis de rasgo significativos en la obsidiana de los Andes Centrales," Revista del Museo Nacional, Lima, Peru, 43 1977, 281-325.

7. H.R. Bowman, F. Asaro and I. Perlman, "On the Uniformity of Composition in Obsidians and Evidence for Magmatic Mixing," Jour. Geology 34 312-327 (1973).

8. E. Salazar, Private communication to F. Asaro, 1980.

9. Reference 2 page 78.

TABLE I

Designations and descriptions of obsidian samples studied in the present work

Sample designation		No. of samples	Location	Description
Cotocollao	No. 1	4	Outside of Quito	Formative Period
	No. 2	4		
	No. 3	5		
	No. 4	5		
	No. 5	5		
	No. 6	5		
Nayon Sur	No. 2	5	In Quito	Formative Period
Ullos		3	In Andes east of Quito	Primary source
La Ponga	LP-D109	10	Quito Valley	Pre-ceramic sites
	D120			
	D135			
	D142			
	D147			
	D160			
	D163			
La Ponga	LP-A7,-D7 -D9	10		
Santa Marta		6		
Yanaurco #1		2	In Andes southeast of Quito	Primary sources
Yanaurco #2		3		
Quiscatola #2		3		
Chacachupa		5	Quito Valley	Pre-ceramic site
Quito Valey	F087	5	Quito Valley	Controlled surface survey
	170-1	3		
	082-2	6		
	127-1	3		
	130-1	2		
	058-2	3		
	104	4		
	129-1	3		
	034 B4	3		

TABLE II
Element abundances of Ecuadorian obsidian
measured by neutron activation analyses

Abundances and errors* in parts-per-million or percent (for Al, Fe, K and Na)

Sample Name	NAA Name	Sampling Site	Al(%)	Ba	Ce	Co	Cs	Dy	Eu
ECUA-67	1085 N	Ullos (primary source)	6.61±.14	1072±22	48.7±1.5	1.32±.07	7.50±.23	1.47±.07	.451±.015
ECUA-77	1085 X	Quito Valley	6.44±.14	1007±36	46.7±1.7	.61±.06	6.90±.25	1.50±.09	.417±.015
ECUA-61	1085 F	Cotocollao 2-10	6.70±.13	1055±30	49.9±1.4	.39±.06	7.23±.20	1.54±.06	.421±.012
ECUA-64	J	Cotocollao 5-24	6.81±.26	1017±32	47.1±1.5	.41±.06	7.11±.22	1.55±.07	.411±.013
ECUA-66	M	Nayon Sur 2	6.37±.11	1059±32	50.5±1.5	.48±.06	7.69±.23	1.52±.07	.432±.013
ECUA-70	Q	Santa Marta 116/5	6.46±.10	1011±32	47.5±1.5	.42±.06	7.33±.23	1.51±.08	.399±.013
ECUA-79	Z	Quito Valley 130-1	6.39±.21	1038±16	49.4±0.8	.47±.06	7.50±.11	1.43±.10	.420±.007
ECUA-31	1065 X 1033 E	La Tolita	6.60±.09	1056±19	49.1±0.6	.36±.05	7.67±.11	1.48±.06	.413±.008
	Mean*		6.55	1039	48.9	.42	7.42	1.50	.416
	RMSD*		.20	21	1.3	.05	.24	.04	.011
	Average Counting Error*		.15	27	1.2	.06	.18	.07	.011
ECUA-60	1085 E	Cotocollao 1-2	6.40±.12	1047±20	48.7±1.0	.34±.06	7.48±.14	1.50±.06	.396±.008
ECUA-63	H	Cotocollao 4-18	6.21±.18	1041±32	48.0±1.5	.34±.06	7.68±.23	1.50±.07	.379±.012
ECUA-68	O	La Ponga LP-D147	6.14±.16	1003±32	46.5±1.5	.40±.06	7.22±.23	1.39±.07	.386±.013
ECUA-78	Y	Quito Valley 127-1	6.52±.16	1016±36	46.6±1.7	.29±.06	7.48±.26	1.48±.09	.399±.015
ECUA-81	1086 F	104 Quito Valley	6.46±.11	1036±16	47.7±0.8	.31±.05	7.54±.11	1.48±.08	.395±.007
ECUA-27	1065 U 1033 G	Quito	6.35±.21	1033±19	47.2±0.6	.31±.05	8.01±.12	1.51±.06	.400±.007
	Mean*		6.35	1029	47.4	.33	7.57	1.48	.393
	RMSD*		.15	17	.8	.04	.26	.04	.008
	Average Counting Error*		.16	26	1.2	.06	.18	.07	.010
ECUA-69	1085 P	La Ponga LP-D7	6.51±.20	1043±34	45.7±1.5	.41±.06	7.72±.24	1.41±.07	.372±.013
ECUA-62	1085 G	Cotocollao 3-11	6.60±.15	896±28	32.0±1.1	.23±.05	10.88±.32	1.37±.06	.281±.009
ECUA-65	K	Cotocollao 6-29	6.47±.10	917±29	33.0±1.1	.19±.05	11.35±.33	1.42±.06	.288±.010
ECUA-71	R	Yanaurco 1 (primary source)	6.60±.12	900±35	32.5±1.4	.13±.06	11.10±.41	1.34±.08	.290±.012
ECUA-72	S	Yanaurco 2 (primary source)	--	933±32	33.0±1.2	.13±.05	11.40±.37	--	.295±.011
ECUA-73	T	Quiscatola 2 (primary source)	6.54±.17	880±14	33.0±0.7	.21±.05	11.29±.15	1.30±.08	.297±.006
ECUA-74	U	Chacachupa	6.52±.22	865±39	30.0±1.4	.14±.06	10.52±.45	1.34±.09	.268±.013
ECUA-75	V	Quito Valley F087	6.22±.10	867±33	29.9±1.2	.13±.06	10.60±.39	1.32±.08	.284±.012
ECUA-76	W	Quito Valley 170-1	6.48±.12	886±34	32.4±1.3	.18±.05	10.99±.40	1.35±.08	.279±.012
ECUA-82	1086 G	129-1 Quito Valley	6.53±.13	929±32	33.1±1.2	.22±.05	10.96±.36	1.19±.08	.295±.011
ECUA-83	H	034-B4 Quito Valley	--	895±31	32.8±1.3	.18±.06	10.92±.36	--	.298±.011
ECUA-13	1065 Y 1033 H 1061 U	Cotocollao B-6	6.67±.13	866±16	32.7±0.5	.18±.05	10.87±.14	1.27±.09	.284±.007
ECUA-5	1033 J	Cotocollao PHD	--	934±20	32.2±0.6	.17±.05	10.84±.15	1.32±.09	.302±.008
ECUA-80	1086 E	058-2 Quito Valley	6.37±.09	885±31	32.8±1.2	.79±.06	10.80±.36	1.33±.08	.291±.011
	Mean*		6.50	896	32.3	.174	10.96	1.32	.289
	RMSD*		.13	25	1.1	.036	.27	.06	.009
	Average Counting Error*		.14	29	1.1	.053	.32	.08	.010

TABLE II
Element abundances of Ecuadorian obsidian
measured by neutron activation analyses

Abundances and errors* in parts-per-million or percent (for Al, Fe, K and Na)

Sample Name	NAA Name	Sampling Site	Fe(%)	Hf	K(%)	La	Mn	Na(%)	Rb
ECUA-67	1085 N	Ullos (primary source)	.780±.022	3.59±.12	3.35±.16	30.1±1.2	371±7	2.97±.06	148±6
ECUA-77	1085 X	Quito Valley	.576±.020	2.95±.11	3.24±.25	25.2±1.2	365±7	3.10±.06	139±7
ECUA-61	1085 F	Cotocollao 2-10	.554±.015	3.14±.10	3.44±.16	28.8±1.1	364±7	3.19±.06	153±6
ECUA-64	J	Cotocollao 5-24	.550±.017	3.00±.10	3.29±.16	26.9±1.2	366±7	3.19±.06	142±6
ECUA-66	M	Nayon Sur 2	.569±.017	3.20±.10	3.53±.16	27.4±1.2	359±7	3.08±.06	159±7
ECUA-70	Q	Santa Marta 1165	.528±.017	2.88±.10	3.69±.22	24.8±1.0	352±7	3.07±.06	143±6
ECUA-79	Z	Quito Valley 130-1	.545±.008	2.94±.06	3.43±.27	2.7.5±.9	348±7	3.02±.06	145±5
ECUA-31	1065 X, 1033 E	La Tolita	.536±.008	2.97±.05	3.50±.17	28.1±.9	349±3	3.08±.03	156±6
	Mean*		.547	3.02	3.48	27.2	356	3.10	150
	RMSD*		.014	.12	.13	1.4	8	.07	7
	Average Counting Error*		.014	.08	.19	1.0	6	.06	6
ECUA-60	1085 E	Cotocollao 1-2	.498±.010	2.91±.07	3.67±.16	28.0±0.9	355±7	3.09±.06	151±5
ECUA-63	H	Cotocollao 4-18	.481±.015	2.86±.10	3.68±.18	26.3±1.0	355±7	3.04±.06	151±6
ECUA-68	O	La Ponga LP-D147	.480±.017	2.74±.10	3.18±.18	25.5±1.1	348±7	3.07±.06	152±6
ECUA-78	Y	Quito Valley 127-1	.495±.018	2.77±.11	3.14±.25	24.2±1.2	357±7	3.05±.06	144±7
ECUA-81	1086 F, 1065 U	104 Quito Valley	.493±.008	2.91±.06	3.46±.22	26.4±1.0	342±7	3.06±.06	152±5
ECUA-27	1033 G	Quito	.485±.008	2.87±.05	3.37±.16	26.0±0.8	344±3	2.98±.03	158±6
	Mean*		.489	2.84	3.42	26.1	350	3.04	151
	RMSD*		.008	.07	.23	1.2	6	.04	4
	Average Counting Error*		.012	.08	.19	1.0	6	.06	6
ECUA-69	1085 P	La Ponga LP-D7	.457±.015	2.83±.10	3.36±.16	27.1±1.2	354±7	3.00±.06	166±7
ECUA-62	1085 G	Cotocollao 3-11	.380±.012	2.66±.09	3.97±.16	17.8±0.8	342±7	2.98±.06	187±8
ECUA-65	K	Cotocollao 6-29	.415±.013	2.64±.09	3.53±.16	18.3±0.9	343±7	2.91±.06	194±8
ECUA-71	R	Yanaurco 1 (primary source)	.398±.015	2.47±.10	3.90±.22	17.5±1.0	344±7	2.99±.06	179±9
ECUA-72	S	Yanaurco 2 (primary source)	.403±.014	2.60±.10	--	16.2±0.9	--	--	190±8
ECUA-73	T	Quiscotola 2 (primary source)	.407±.006	2.66±.06	4.04±.21	16.0±0.7	334±7	2.82±.06	182±6
ECUA-74	U	Chacachupa	.384±.017	2.41±.11	3.58±.21	14.8±1.0	328±7	2.87±.06	170±9
ECUA-75	V	Quito Valley F087	.382±.014	2.46±.10	3.64±.23	16.2±0.9	335±7	2.80±.06	174±8
ECUA-76	W	Quito Valley 170-1	.387±.015	2.55±.10	3.82±.23	16.2±1.0	343±7	2.95±.06	179±8
ECUA-82	1086 G	129-1 Quito Valley	.393±.014	2.67±.10	3.45±.21	18.5±1.0	321±6	2.82±.06	179±8
ECUA-83	H	034-134 Quito Valley	.396±.014	2.59±.10	--	18.1±1.1	--	--	185±8
ECUA-13	1065 Y, 1033 H, 1061 U	Cotocollao B-6	.392±.007	2.53±.05	4.05±.27	16.2±0.7	333±3	2.88±.03	185±7
ECUA-5	1033 J	Cotocollao PHD	.375±.007	2.50±.05	4.06±.27	17.3±0.5	335±3	2.72±.03	175±6
ECUA-80	1086 E	058-2 Quito Valley	.384±.014	2.60±.10	3.83±.22	18.8±1.1	328±7	2.88±.06	183±8
	Mean*		.392	2.56	3.81	17.1	335	2.87	182
	RMSD*		.012	.09	.22	1.2	7	.08	7
	Average Counting Error*		.012	.09	.22	0.9	6	.05	8

TABLE II
Element abundances of Ecuadorian obsidians
measured by neutron activation analyses

Abundances and errors* in parts-per-million or percent (for Al, Fe, K and Na)

Sample Name	NAA Name	Sampling Site	Sb	Sc	Sm	Ta	Th	U	Yb
ECUA-67	1085 N	Ullos (primary source)	1.19±.10	2.060±.055	2.428±.066	.908±.025	19.13±.51	7.64±.21	.878±.035
ECUA-77	1085 X	Quito Valley	1.38±.12	1.482±.049	2.289±.076	.901±.030	18.47±.60	7.26±.25	.891±.038
ECUA-61	1085 F	Cotocollao 2-10	1.33±.11	1.520±.036	2.390±.059	.967±.024	19.33±.46	7.70±.20	.954±.034
ECUA-64	J	Cotocollao 5-24	1.23±.10	1.466±.040	2.326±.067	.904±.026	19.06±.53	7.39±.22	.913±.036
ECUA-66	M	Nayon Sur 2	1.30±.11	1.555±.040	2.481±.067	.969±.026	20.03±.52	7.94±.22	.973±.037
ECUA-70	Q	Santa Marta 116/5	1.34±.11	1.464±.040	2.325±.067	.922±.026	19.04±.53	7.50±.22	.882±.035
ECUA-79	Z	Quito Valley 130-1	1.42±.11	1.530±.015	2.368±.024	.983±.010	19.46±.19	7.72±.08	.918±.026
	1065 X								
ECUA-31	1033 E	La Tolita	1.58±.11	1.530±.015	2.424±.024	.966±.010	20.00±.20	7.87±.09	.881±.020
	Mean*		1.37	1.511	2.38	.952	19.49	7.69	.920
	RMSD*		.12	.037	.06	.031	.44	.21	.037
	Average Counting Error*		.11	.031	.05	.020	.40	.17	.031
ECUA-60	1085 E	Cotocollao 1-2	1.38±.10	1.480±.020	2.329±.031	.944±.012	19.43±.29	7.78±.12	.892±.028
ECUA-63	H	Cotocollao 4-18	1.24±.10	1.486±.041	2.316±.063	.943±.026	19.38±.51	7.92±.22	.893±.035
ECUA-68	O	La Ponga LP-D147	1.19±.10	1.424±.042	2.241±.066	.897±.026	18.63±.53	7.41±.22	.820±.034
ECUA-78	Y	Quito Valley 127-1	1.40±.12	1.459±.048	2.336±.077	.933±.031	19.18±.64	7.48±.25	.881±.039
ECUA-81	1086 F	104 Quito Valley	1.42±.11	1.520±.015	2.346±.023	.953±.006	19.38±.19	7.70±.09	.899±.026
	1065 U								
ECUA-27	1033 G	Quito	1.41±.11	1.534±.015	2.382±.024	.975±.006	20.03±.20	8.05±.09	.894±.020
	Mean*		1.4	1.484	2.325	.941	19.34	7.72	.880
	RMSD*		.10	.040	.047	.026	.45	.25	.030
	Average Counting Error*		.11	.030	.047	.018	.39	.16	.030
ECUA-69	1085 P	La Ponga LP-D7	1.26±.10	1.472±.043	2.310±.068	.948±.028	19.22±.58	8.00±.24	.905±.036
ECUA-62	1085 G	Cotocollao 3-11	1.73±.12	1.351±.037	1.700±.047	1.153±.031	20.36±.55	9.60±.27	.922±.036
ECUA-65	K	Cotocollao 6-29	1.67±.13	1.412±.039	1.791±.050	1.174±.032	21.24±.57	9.82±.28	.900±.036
ECUA-71	R	Yanaurco 1 (primary source)	1.84±.15	1.366±.048	1.743±.064	1.162±.041	20.81±.73	9.61±.35	.841±.040
ECUA-72	S	Yanaurco 2 (primary source)	1.72±.14	1.394±.043	1.746±.056	1.172±.036	21.13±.64	9.91±.31	.904±.038
ECUA-73	T	Quiscatola 2 (primary source)	1.94±.14	1.393±.014	1.741±.018	1.156±.012	21.07±.21	9.56±.09	.896±.026
ECUA-74	U	Chacachupa	1.71±.15	1.295±.054	1.624±.069	1.068±.044	19.73±.82	9.00±.38	.822±.044
ECUA-75	V	Quito Valley F087	1.65±.14	1.338±.047	1.655±.056	1.091±.038	19.78±.68	9.05±.32	.840±.039
ECUA-76	W	Quito Valley 170-1	1.96±.15	1.355±.048	1.681±.061	1.124±.039	20.29±.70	9.01±.32	.830±.039
ECUA-82	1086 G	129-1 Quito Valley	1.78±.14	1.367±.042	1.742±.057	1.169±.036	20.59±.63	9.74±.31	.910±.040
ECUA-83	H	034-134 Quito Valley	1.77±.14	1.361±.042	1.702±.055	1.141±.035	20.70±.63	9.58±.31	.892±.039
	1065 Y								
ECUA-13	1033 H	Cotocollao B-6	1.79±.12	1.365±.014	1.697±.018	1.134±.011	20.71±.21	9.50±.10	.881±.020
	1061 U								
ECUA-5	1033 J	Cotocollao PHD	1.78±.13	1.393±.014	1.753±.018	1.159±.012	20.74±.21	9.73±.07	.896±.022
ECUA-80	1086 E	058-2 Quito Valley	1.84±.14	1.392±.043	1.750±.057	1.159±.072	20.65±.63	9.67±.31	.857±.037
	Mean*		1.78	1.368	1.717	1.143	20.60	9.52	.876
	RMSD*		.09	.030	.046	.032	.46	.31	.034
	Average Counting Error*		.14	.028	.047	.031	.55	.26	.035

*Errors are estimates of the standard deviations (counting errors). Mean is the average abundance of an element for a given chemical group. RMSD is the root-mean-square deviation for an element in a given group. Typical counting error is the average counting error of an element in a group.

TABLE III

Distinguishing characteristics of Ecuadorian obsidian chemical groups as measured by XRF*

	Present study by non-destructive XRF				Previous study by destructive XRF[1]		
Group Assignments	No. of samples	Sr(ppm)	Sr/Zr	XRF No.	No. of samples	Sr(ppm)	Sr/Zr
Ecuador A	30	84±4	1.179±.038		9	86.0±2.5	1.126±.040
Ecuador B	58	128±11	1.339±.070		13	133±8	1.330±.055
Cotocollao A	10	163±6	1.399±.022		4	174±8	1.390±.060
Cotocollao B	1	205±3	1.446±.032		3	210±10	1.390±.035
Mullumica	3	240±10	1.413±.026		6	253±14	1.367±.028
La Chimba					4	167±9	1.752±.098
Cotocollao A or possibly Ullos							
Cot. 3-13	1	181±2	1.392±.027	8102-L			
Q.V. 082-2	1	178±3	1.367±.032	8102-·			
Ullos source samples							
	1	207±8	2.15±.13	8104-O			
	1	205±6	1.85±.10	8104-P			
	1	184±4	1.43±.04	8098-K			

* Errors are the larger of the root-mean-square deviations or the statistical errors in counting x-rays. The accuracy of the non-destructive measurements should generally be about 10%, but may be considerably worse for occasional samples.

TABLE IV

Provenience assignments of Ecuadorian archaeological obsidian

Sample and site designations		ECUA-DOR A	ECUA-DOR B	Coto-collao A	Coto-collao B	Mullu-mica	Uncer-tain or Ullos
Cotocollao	No. 1		4				
	No. 2		3	1			
	No. 3	1	3				1
	No. 4	1	4				
	No. 5	1	1	2		1	
	No. 6	2	3				
Nayon Sur	No. 2		4	1			
Chacachupa		5					
Quito Valley	F087	5					
	170-1	2	1				
	082-2	1	1	3			1
	127-1		3				
	130-1		2				
	058-2	1	1			1	
	104		4				
	129-1	1	1	1			
	034 B4	1		1		1	
La Ponga	LP-D109, D120,D135,D142 D147,D160		9		1		
	LP-A7,D7,D9		9	1			
Santa Marta		1	5				
Total numbers of artifacts		22	58	10	1	3	2

Figure Captions

Figure 1 - Plot of Ba, Na, Sc, Mn and Co versus Fe for Ecuadorian obsidian groups measured by NAA.

Figure 2 - Plot of Hf, Sm, Ce, La, Eu, Dy and Yb versus Fe for Ecuadorian obsidian groups measured by NAA.

Figure 3 - Plot of U, Th, Cs, Ta, Rb, Sb and K versus Fe for Ecuadorian obsidian groups measured by NAA.

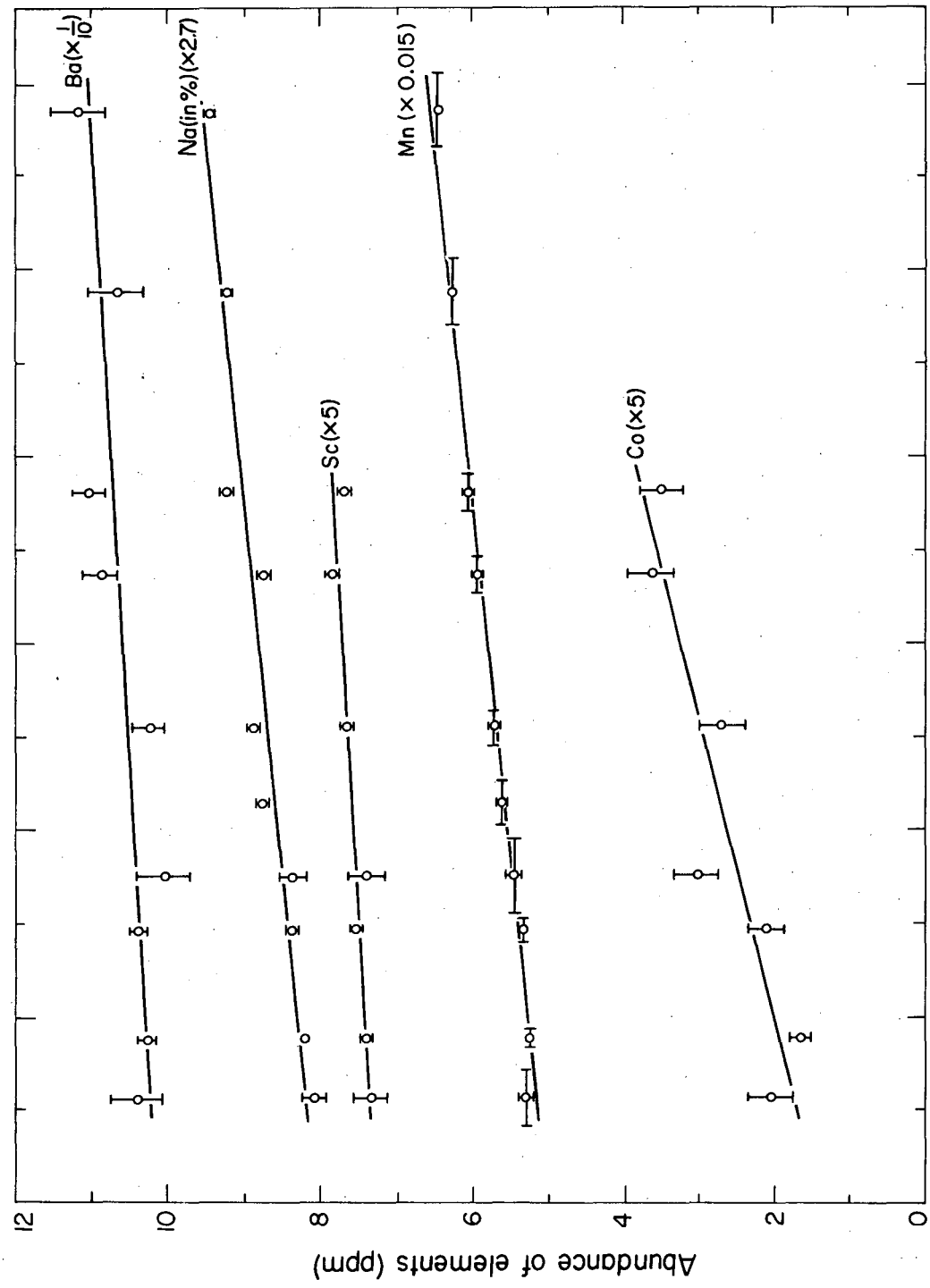

Ba(× 1/10)
Na(in %)(×2.7)
Sc(×5)
Mn (× 0.015)
Co(×5)
Abundance of elements (ppm)
Iron abundance (per cent)
0
2
4
6
8
10
12
0.4
0.5
0.6
0.7
0.8
0.9
1.0
XBL 817-1043

Fig. 1

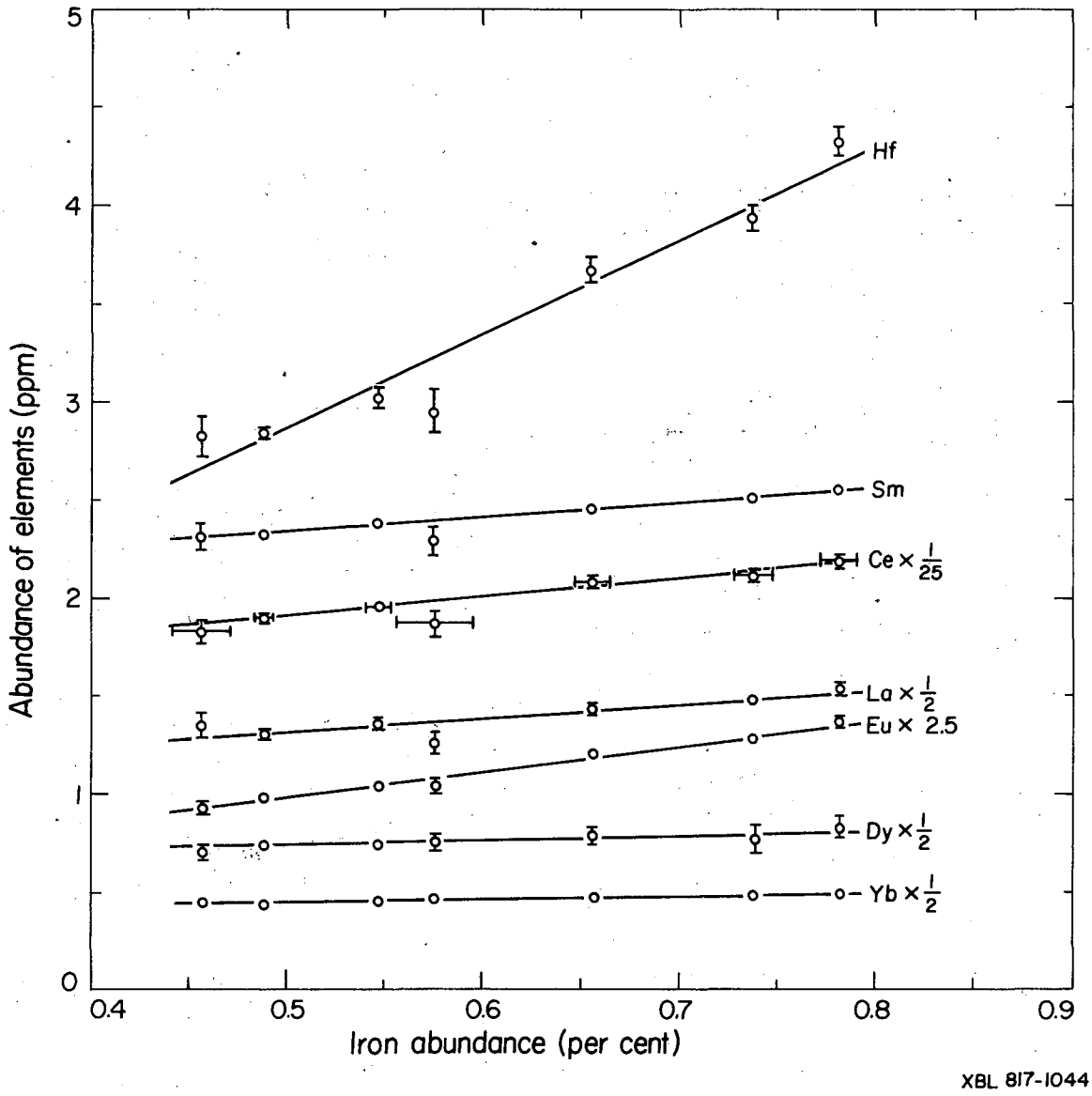

Abundance of elements (ppm)
Iron abundance (per cent)
0
1
2
3
4
5
0.4
0.5
0.6
0.7
0.8
0.9
Hf
Sm
Ce × 1/25
La × 1/2
Eu × 2.5
Dy × 1/2
Yb × 1/2
XBL 817-1044

Fig. 2

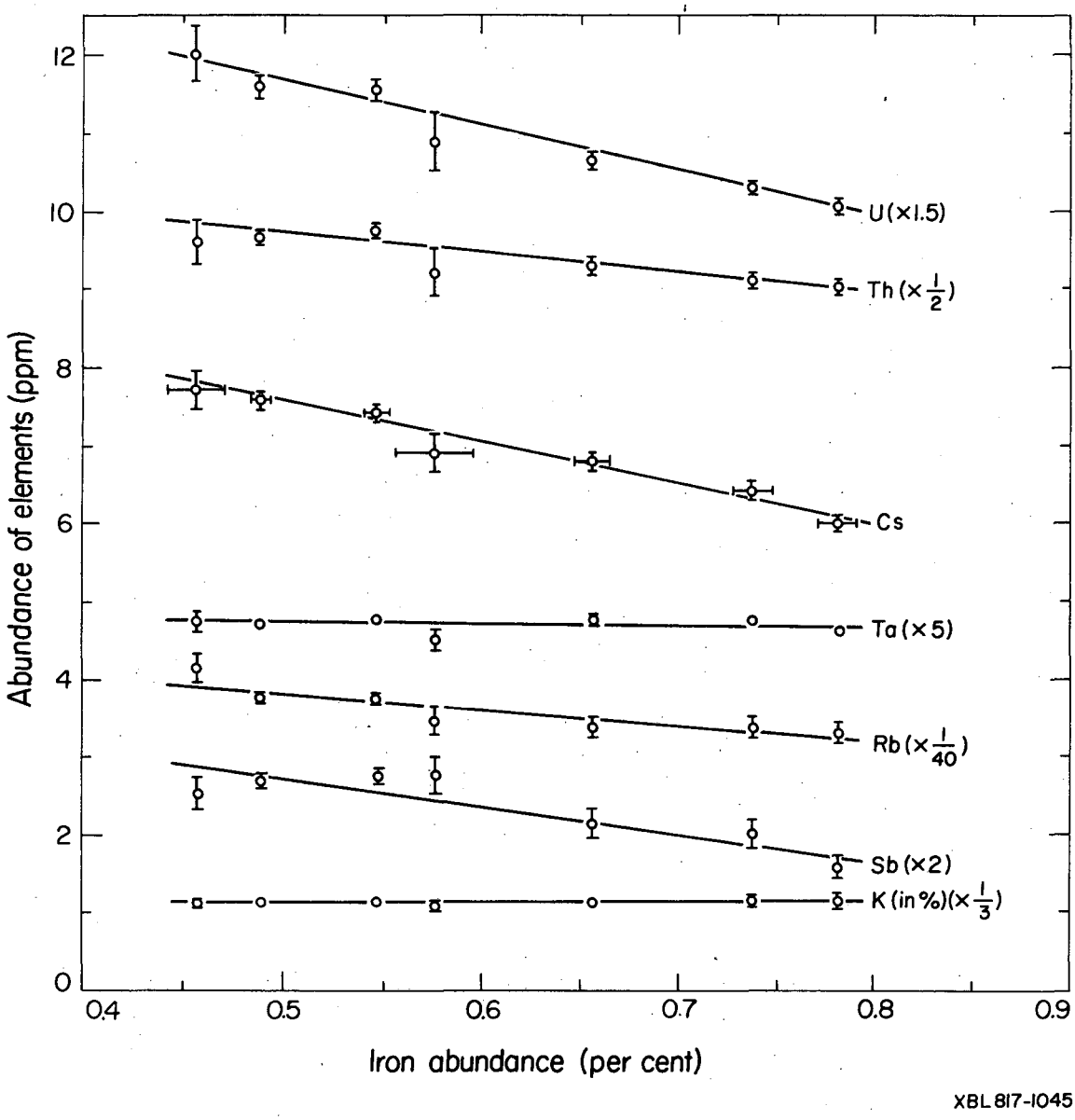

Abundance of elements (ppm)
Iron abundance (per cent)
U(×1.5)
Th(×1/2)
Cs
Ta(×5)
Rb(×1/40)
Sb(×2)
K(in %)(×1/3)
0
2
4
6
8
10
12
0.4
0.5
0.6
0.7
0.8
0.9
XBL 817-1045

Fig. 3

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