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EVALUATION OF STREAM SEDIMENTS
IN AREAS OF KNOWN MINERALIZATION,
SAN JOSE AND TALAMANCA QUADRANGLES,
COSTA RICA: AN ORIENTATION SURVEY

by

Alejandro J. Arauz

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A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Geology).

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ABSTRACT

Costa Rica's compressional island arc-type tectonic setting and considerable geologic diversity hold great promise for future discovery of economic metallic deposits. As part of U.S. government cooperation with Central America and the Caribbean nations, a reconnaissance-scale geochemical mineral resource potential assessment is being conducted in Costa Rica by Los Alamos National Laboratory. The study reported here constitutes an orientation investigation of stream sediment sampling techniques to establish optimum survey specifications for the regional geochemical survey coverage of the country.

The study was conducted in two separate areas of known mineralization which represent distinctive tropical environments and different metallogenic provinces within Costa Rica: (1) the Esparza Area, which contains the Santa Clara Gold Mine, the largest in the country, and (2) the San Isidro Area, which contains a major copper prospect.

In each area ten sample sites were selected at an average sample density of 1 sample per 8 km². At each sample site wet sieved triplicate minus 40, minus 80, and minus 100 mesh fractions of sediment were collected. Also, triple bulk samples were collected and these were

subsequently dry sieved into the same three sieve fractions. Chemical analysis for a total of 51 elements was undertaken at Los Alamos using instrumental neutron activation and x-ray fluorescence techniques. Additional atomic absorption analysis for a limited number of elements was carried out at a commercial laboratory. Statistical treatment of the data included evaluation of basic statistics, paired T-test results and correlation analysis. Statistical results were interpreted through a study of dispersion pattern plots of element content versus drainage area.

Results indicate: (1) combined instrumental neutron activation and atomic absorption analytical procedures provide adequately sensitive and precise analytical data, (2) the minus 80 mesh fraction of stream sediment material is the optimum sieve fraction to be used in routine surveys, (3) considering technical and logistical criteria, wet sieving in the field is the recommended sample preparation approach, (4) an average sample density of 1 sample per 25 km² is suitable for reconnaissance surveys, and (5) Au, Ag, As, Sb, K, Rb, and Cs data best reflect gold mineralization in the Esparza Area, whereas Cu, Pb, Ag, and Au data best characterize copper mineralization in the San Isidro Area. These results provide survey specifications appropriate for detection of the mineralization

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types investigated in this study. These specifications may subsequently be modified upon completion of similar orientation surveys around other types of potentially economic mineral deposits known to exist in Costa Rica.

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- III Statistics

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INTRODUCTION

The Costa Rican economy is predominantly agricultural. The national economy is vulnerable to international market price fluctuations of the three major export crops: coffee, bananas, and sugar. The mining industry in Costa Rica is very limited and has only been a small scale industry throughout its history. During 1960-1975, the Organizacion de los Estados Americanos (OEA) reported that the contribution of mining to the Gross National Product did not reach one percent (OEA, 1978). Mining production for that period was largely restricted to non-metallic resources intended to satisfy local demand for limestone, clay, sand, and stone. Limitations of the mining industry are mainly due to the lack of a mining tradition, the absence of methodic mineral exploration programs, and the inefficiency of past governmental policies promoting mineral development (Ulloa, 1982).

For the last decade, governmental interest in the mining industry as a method for diversification of the economy has grown considerably. A direct result of this new attitude has been the establishment of a new mining law that was published in 1982. This new mining code

"updates the legislation on the subject that had been in force for 29 years and was already obsolete" (Ministerio de Industria, Energia y Minas, 1982b)

Support for mining activity is also reflected in renewed efforts within the field of mineral exploration. As part of U.S. government cooperation with Central America and the Caribbean nations, a reconnaissance-scale geochemical survey is being conducted in Costa Rica by Los Alamos National Laboratory, funded by the United States Agency for International Development (AID). The survey is part of a multi-institutional project in which Los Alamos, the U.S. Geological Survey (USGS), the University of Costa Rica (UCR), and the Costa Rican Government, through the Ministry of Industry, Energy and Mines (MIEM), will provide a comprehensive integrated approach to identifying mineral resources and areas containing potential mineralization.

OBJECTIVES

"The objective of an orientation survey is to determine the optimum field, analytical and interpretative parameters which can distinguish an anomaly from the background" (Levinson, 1980)

The main objective of this study is to develop geochemical techniques for the Los Alamos reconnaissance-scale geochemical survey that will establish the optimum

drainage survey specifications to detect known and inferred types of mineralization in the country. This will be done by evaluating stream sediment samples collected in two mineralized areas. The sampling and analytical procedures that can give the most cost-effective geochemical information for the Costa Rican tropical surficial environment will be identified.

Because the exploration method developed here is simple and inexpensive, governmental institutions in Costa Rica and many small mining companies will be able to use similar procedures.

SCOPE OF STUDY

Costa Rica is located in a compressional, island arc-type tectonic setting (Figure 1). The Middle American trench, which corresponds to the boundary between the oceanic Cocos plate to the west and the near continental Caribbean plate to the east, lies just tens of kilometers away from the Pacific coast of this country. Although small in areal extent, Costa Rica contains varied geology, from ophiolitic complexes to intermediate terrestrial volcanics intruded by felsic plutons.

The tectonic setting and geologic diversity hold great promise for discovery of economic metallic deposits (Table 1). Castillo (1980) suggests Costa Rica has

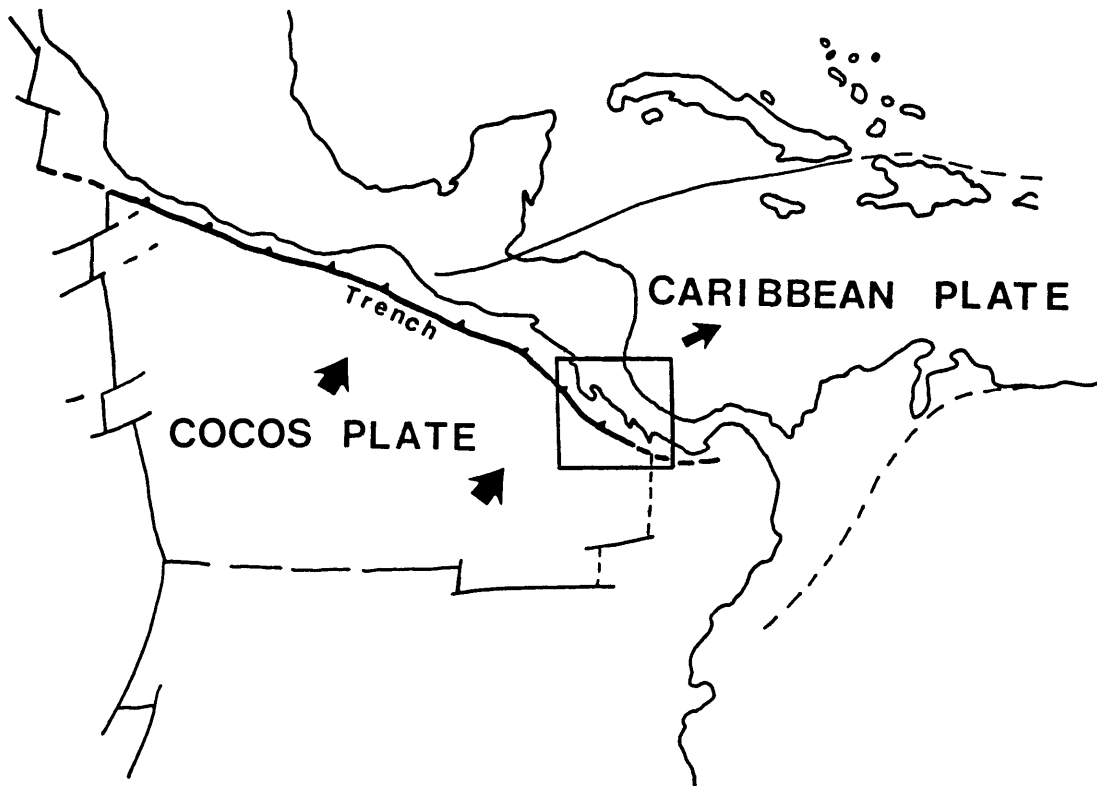


Figure 1. Regional tectonic setting of Costa Rica (after Mora 1981).

TABLE 1. Major metallogenic provinces of Costa Rica
(after Castillo, 1980)

<u>Metallogenic Province</u>	<u>Tectonic Setting</u>	<u>Elements</u>
Santa Elena Peninsula	Arc-trench gap	Cr,Ni,Pt
Osa and Nicoya Peninsula	Arc-trench gap	Mn,Fe,Cu,Zn
Talamanca Range	Inner arc	Cu,Fe,Pb,Zn
Tilaran and Aguacate Ranges	Inner arc	Au,Pb,Zn,Cu, Sb
Guanacaste and Central ranges	Inner arc	S
Atlantic and Pacific lowlands	Back-arc basins Arc-trench gap	Au(placer), Al,Fe

potential for undiscovered gold-silver deposits, lead-zinc epithermal deposits, as well as massive sulfides, podiform chromite and manganese ores.

Gold still is and always has been the most important metallic commodity sought in Costa Rica. The Santa Clara open pit gold mine, ranked as a world class deposit by Mining Magazine (1983), serves as a type example of the possible gold mineralization.

After consideration of the geology, physiography and climate of Costa Rica, two areas were selected for the orientation survey, with the specific purpose of detecting trace element signatures of two different metallogenic provinces in slightly different geochemical environments. The Esparza Area (Figure 2) is located within the Costa Rican Gold Belt and provides an area representative of typical gold mineralization. The San Isidro Area lies within the northern extension of the South American Porphyry Copper Metallogenic Province and represents terrain with potential for copper mineralization. Gold and copper are the two commodities with the best potential for development in today's mineral economy.

Specific problems addressed in this research are:

1. definition of an optimum field sampling procedure in terms of sample type, number of subsamples per sample site, and collecting method;

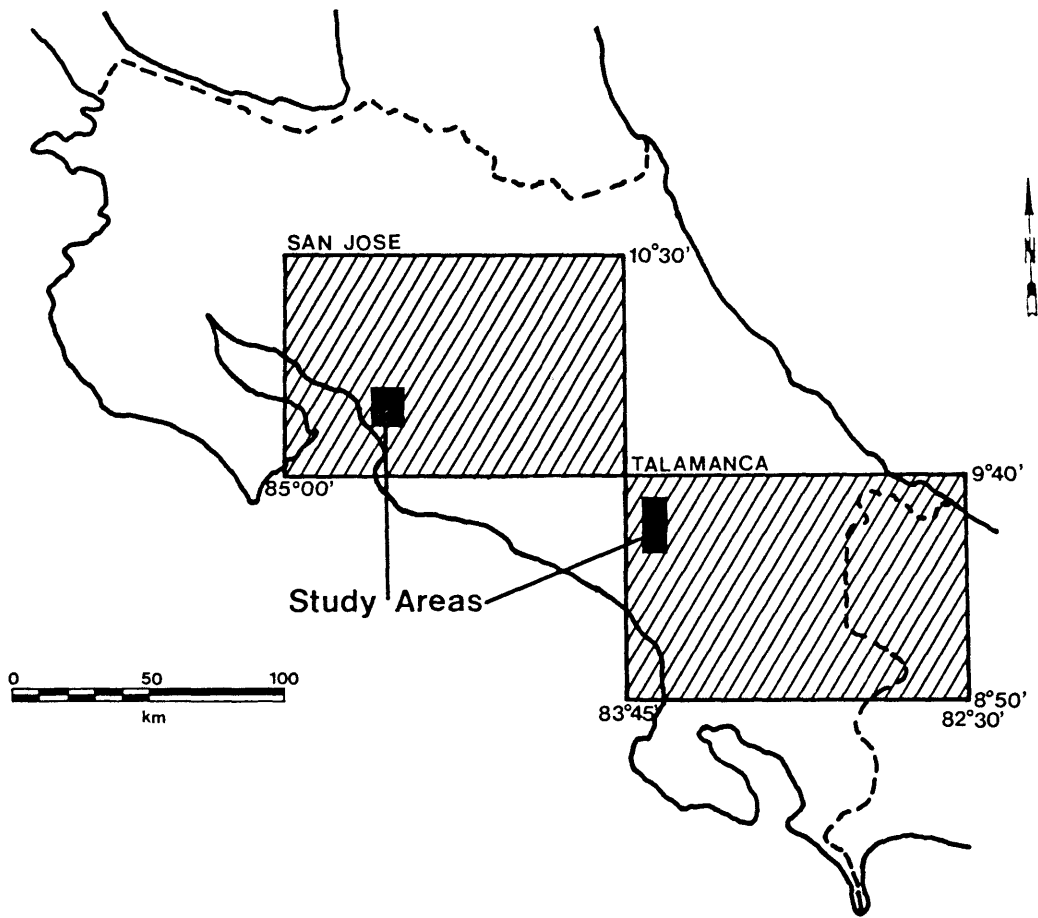


Figure 2. Location of study areas. Stippled areas show location of 1:200,000 scale quadrangles.

2. recommendation of optimum field and/or laboratory sample preparation procedures;

3. determination of optimum sample density based upon secondary dispersion patterns in the areas of known mineralization;

4. evaluation of geochemical data for 51 elements and recommendation of a limited suite of trace elements which adequately reflects the known and inferred bedrock geology and the mineral deposits for the two study areas.

PREVIOUS WORK

Laming and Gibbs (1982) provide an extensive compilation of the different exploration techniques, including geochemistry, applicable in tropical forest areas.

The utility of stream sediment surveys in reconnaissance scale exploration programs for ore deposits is documented by Meyer et al (1979). The effectiveness of wet sieving of stream sediments in the field is demonstrated by Bolviken et al (1976) as a helpful tool in reducing the volume (and consequently the weight) of samples containing little fine sediment. This technique is particularly valuable in very remote areas where samples have to be carried long distances.

Several studies have been conducted in Costa Rican geochemistry and mineral potential, mainly by UCR professors and graduate students. In the specific field of geochemistry, the most relevant studies are listed below.

Castillo (1974) reports on a United Nations funded reconnaissance scale stream sediment survey of the Nicoya and Santa Elena peninsulas. An average sampling density of 1 sample per 15 km² is employed. Atomic absorption (AA) analysis for Cu, Ni, Co, Mn, Fe and Zn reveal several anomalies. One correlates with a massive sulfide deposit.

Paredes (1976) presents results of a local stream sediment survey in a small portion (170 km²) of the San Jose 1:200,000 scale quadrangle. Data from AA analysis of Cu, Ni, Zn, Co, Mn, and Fe delineate several known base metal epithermal veins and native copper rich outcrops.

Castillo (1978 a, b) gives environmental geochemistry data for the Nicoya Peninsula and the Aguas Zarcas 1:50,000 scale topographic sheet.

Marin (1983, 1985) reports geochemical investigations on the Liberia 1:200,000 scale quadrangle utilizing AA data for Cu, Ni, Co, Zn, Mn, Fe, Ag and Pb in soils, rocks and stream sediments.

Castro (1985) contributes to gold exploration geochemistry methodology in Costa Rica through follow up stream sediment investigations, at a density of 3 samples per km², in areas of known and inferred mineralization. Results define several potential areas of gold mineralization which are presently undergoing detailed investigation.

For the last ten years, several international agencies and various American and multinational corporations have conducted exploration programs in Costa Rica, focusing primarily on porphyry copper deposit potential of the Talamanca Range of southern Costa Rica. Major aspects of these exploration programs are summarized by OEA (1978). Unfortunately, most of these surveys are limited in extent and poorly documented. In addition, specific results are largely unavailable.

ORGANIZATION

This thesis is divided into six major sections. The first part is the Introduction, in which the objectives are outlined.

The second section provides the necessary background on geographic, physiographic, and geologic aspects for

both Costa Rica in general and the study areas specifically. A brief introduction to the economic geology of Costa Rica is also given.

The third part addresses the specific problem of geochemical exploration in the Costa Rican tropical secondary environment. Here the approach for addressing the geochemical problem is defined.

The fourth section includes the survey data and a discussion of results. In this section, optimal sampling geochemical techniques for stream sediments in Costa Rica are discussed.

The final sections state a summary of this research and provide recommendations for future studies.

DESCRIPTION OF STUDY AREA

GEOGRAPHY

"In Central America's most peaceful nation, geography is the only extreme" (K. Britt, National Geographic Senior Staff, 1981)

Costa Rica is located on the central portion of the Central American Isthmus, at latitude and longitude of 10°N and 85°W, respectively. The country can be divided into three main physiographic provinces: (1) the mountain ranges; (2) the plateaus and intermountain valleys; and (3) the coastal plains (Figure 3). "None of these systems above-mentioned can be considered as independently controlled by specific geologic conditions or events, but mostly, as a reflex of several geologic influences in time and space" (Castillo, 1984).

The country which comprises 50,900 km² (19,883 square miles) is bisected by mountain ranges of diverse origins. From northwest to southeast, the three main cordilleras are the Guanacaste Range, the Central Range and the Talamanca Range. The first two ranges are volcanically active, whereas the third is volcanically inactive. The Central and Talamanca ranges enclose a large central plateau where San Jose, the capital city of the country, is located.

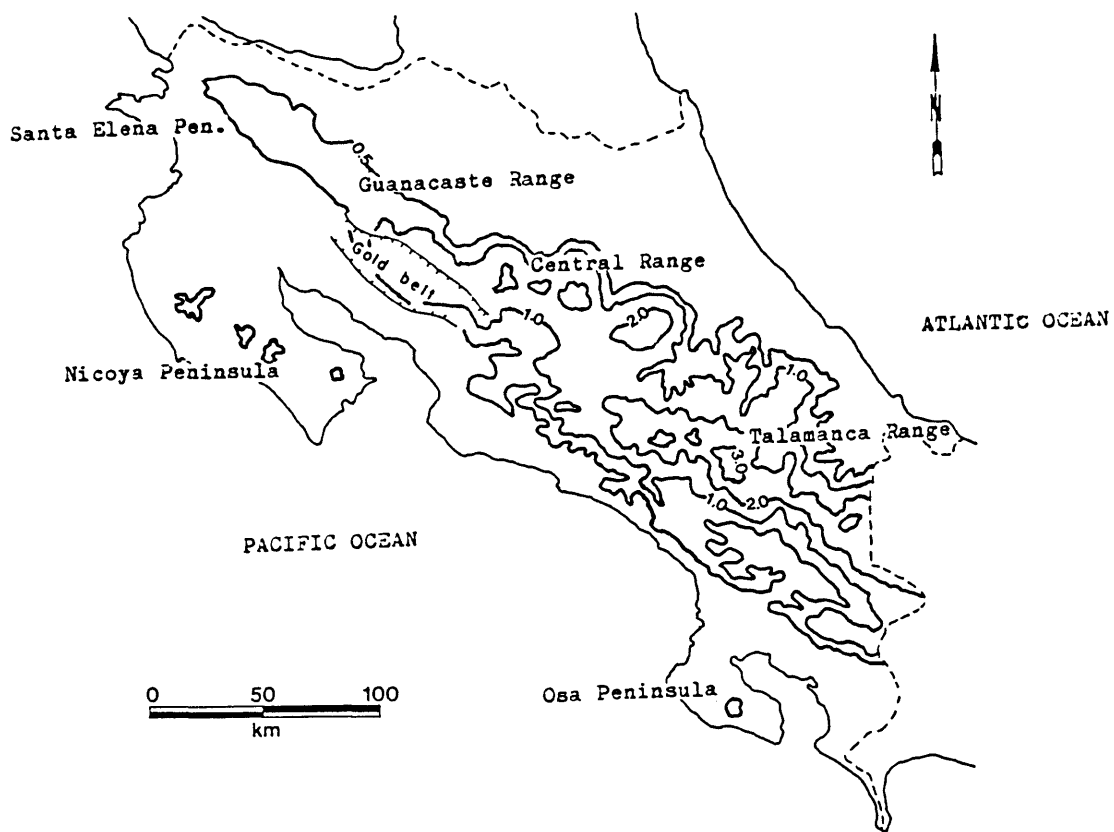


Figure 3. Physiographic map of Costa Rica. Altitudes in kilometers.

The highest peaks reach above 3,000 meters (10,000 feet) some 80 kms or less away from either coast (for example, Chirripo Peak in the Talamanca Range, 3,820 meters).

Although the climate can be considered as equatorial (Coen, 1983), there are multiple variations in climatic factors due mainly to the abrupt changes in altitude within the country. The Caribbean and Pacific lowlands experience year round temperatures of 38°C (100°F) while in the higher altitudes of the central highlands a year-round temperature of 21°C (70°F) is normal. Above timberline (approx. 3,350 meters) temperatures of 0°C (32°F) or less can be recorded in certain periods of the year. Excluding some areas of the Nicoya Peninsula in northwestern Costa Rica, mean rainfall for the country is between 2 meters (80 inches) and 6 meters (240 inches) a year, as shown in Figure 4. Annual precipitation in some areas of the Atlantic coast may exceed 10 meters (394 inches).

Dense diverse tropical vegetation is characteristic of this region. Plants are extremely numerous in species and can grow in unusual abundance and sizes, especially in areas covered by virgin tropical rain forest. Here trees can average heights of 45 to 55 meters (150-180 feet), with some trees reaching up to 90 meters (300 feet).

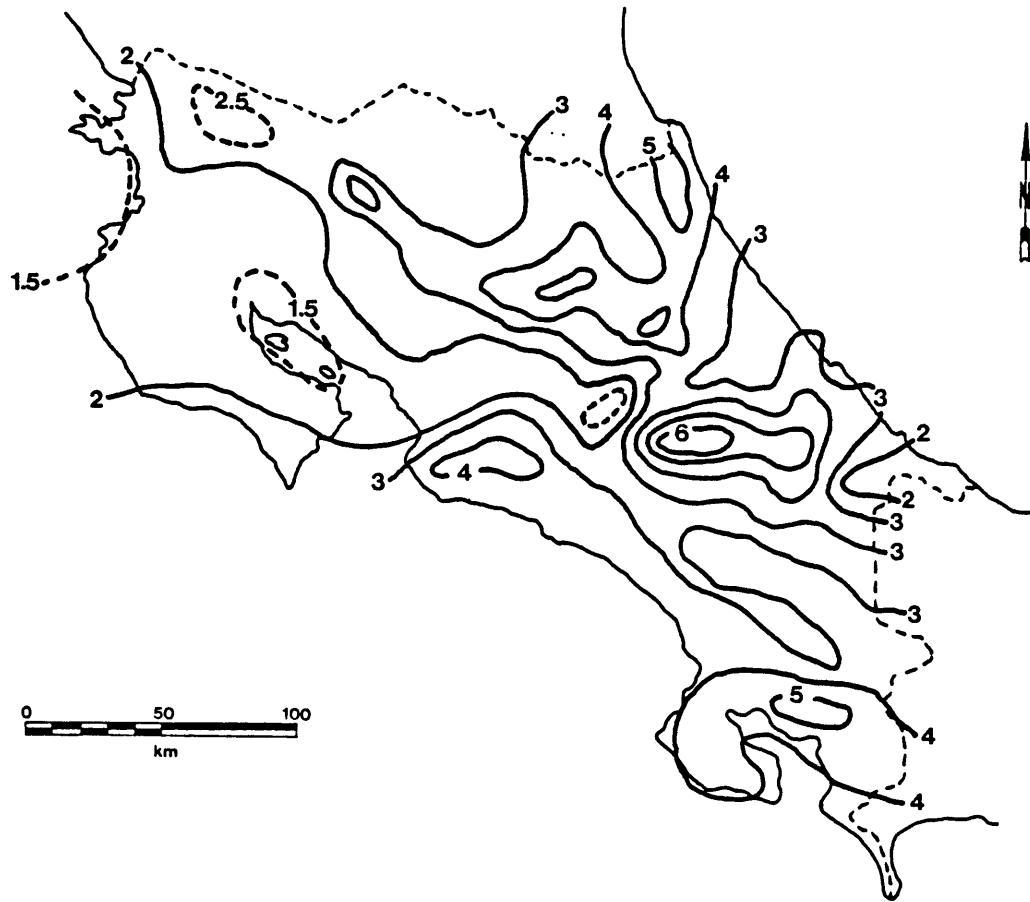


Figure 4. Mean annual precipitation; in meters (from Coen, 1983).

Although the country has a well developed net of primary and secondary roads, dense vegetation, steep topography, and heavy rains can make access to some areas difficult, if not impossible. Nevertheless, access to the specific study areas was relatively easy. Both areas are traversed by main paved roads (Figure 5), however, some sample locations involved two or three hour hikes.

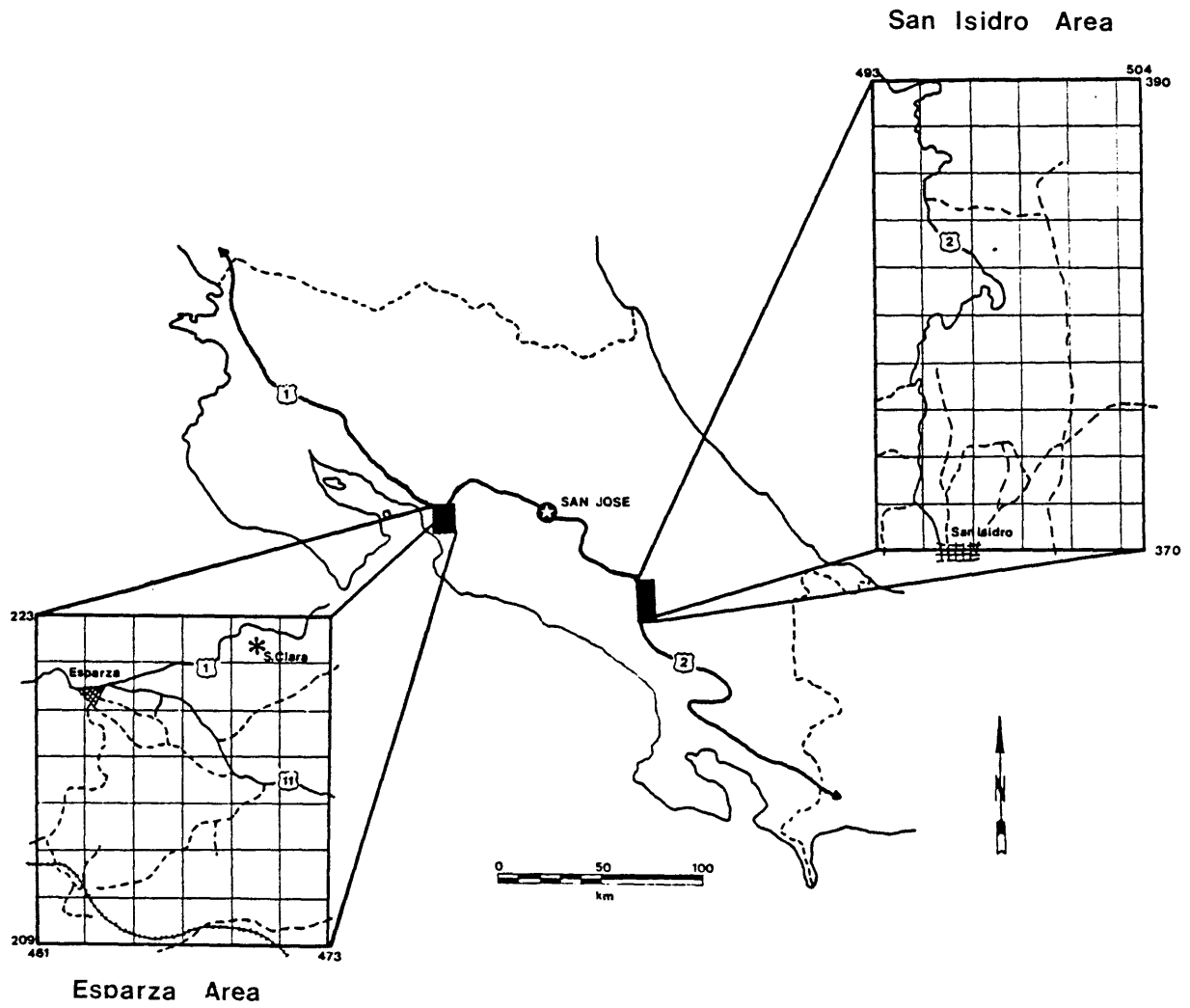


Figure 5. Access to study areas.

REGIONAL TECTONICS

Introduction

Interest in the geology and mineral deposits of Costa Rica started centuries ago, even before the Spanish conquerors, perhaps back in the time of the ancestral American cultures. The Indians of these lands were authentic artists in the field of casting gold and sculpturing rocks and semi-precious stones. The first formal studies in the field of exploration geology took place in the middle of the 18th century, with investigations by Wagner, Frantsius and Seebach (Castillo, 1984). The American, William Gabb, in 1873, was the first scientist to work methodically in the Talamanca Range and the first to recognize its importance as a metallogenic province. Castillo (1984) reviews, in detail, the historical development of geology and mineral deposit studies in Costa Rica.

The first geologic map of Costa Rica (scale 1:700,000) was published in 1968 by the Direccion de Geologia, Minas y Petroleo (DGMP) an institution that acts as the Bureau of Mines of the country. A simplified regional geological map of Costa Rica is shown in Figure 6. In 1970, a Metallogenic Map, scale 1:2,000,000, was published. In 1971 the DGMP published a mineral resources map, scale 1:750,000, showing the location of the main metallic deposits.

Geologic Characteristics

Costa Rica is part of a subduction related intra-oceanic arc. The Cocos Plate is presently descending under the Caribbean Plate in the Middle American Trench (Figure 1). Kujpers (1980) and Mora (1981), following the Dickinson (1975) classification for arc-trench systems, subdivided Costa Rica into three main tectonic regions (Figure 7), each region identified by a characteristic physiography, geology and lithology. These regions, the arc-trench gap, the inner (magmatic) arc, and the back-arc basins areas, are seen in Figure 8a and 8b. Each region is described separately below.

Arc-trench gap: The arc-trench gap is characterized by series of aligned peninsulas (outer arc) and gulfs (fore-arc basins). Geologically, the outer arc area consists of rocks of the ophiolitic suite and associated pelagic sediments. This area contains the oldest rocks recognized in Costa Rica (85 ma). Lithologies in the outer arc include basic volcanics (pillow basalts), basic and ultrabasic plutonic rocks (gabbros, diabases and peridotites), and pelagic sediments. Strong tectonic modification and incipient zeolite facies metamorphism are characteristic

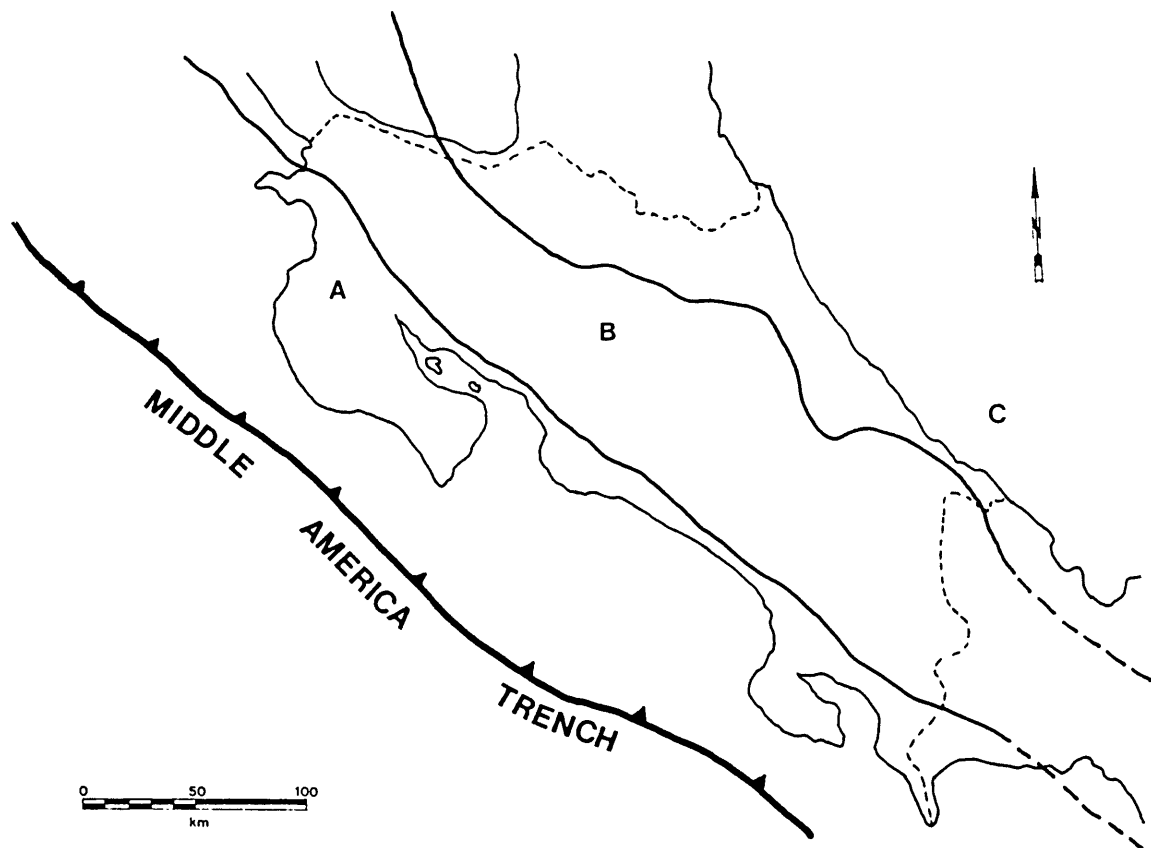


Figure 7. Main tectonic regions of Costa Rica; A) Arc-trench gap; B) Inner (magmatic) arc; C) Back-arc basins (after Mora, 1981).

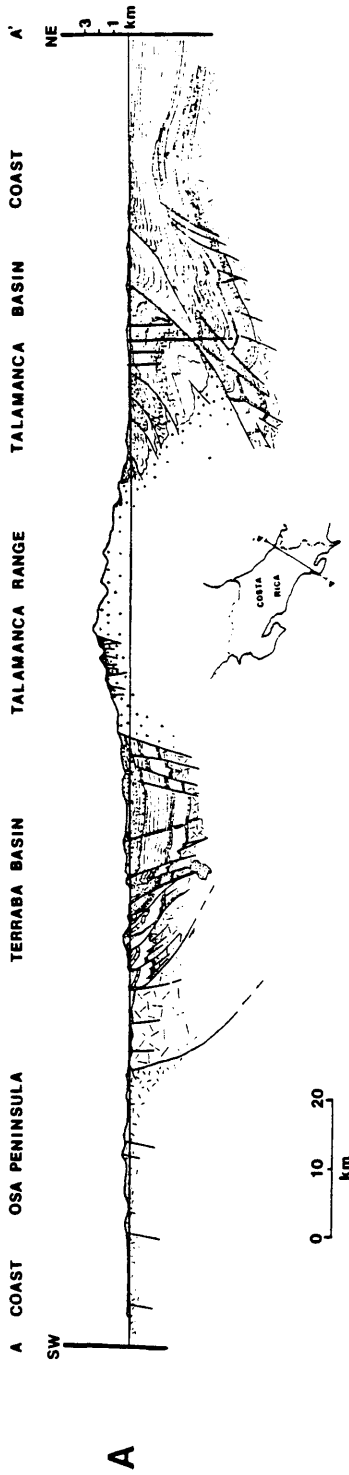


Figure 8a. Geologic cross-section of Costa Rica (from Rivier, 1985).

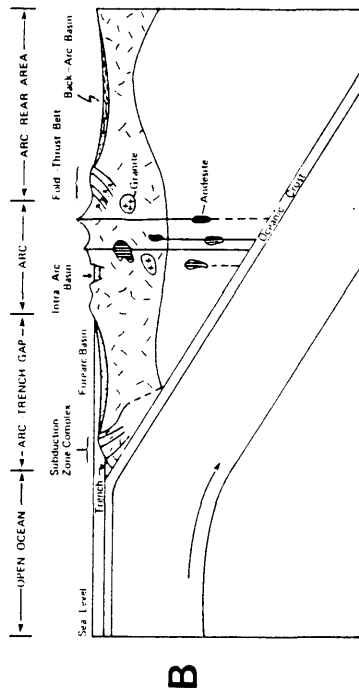


Figure 8b. Diagrammatic cross-section of an arc system (from Condie, 1983).

of this area. Rapid shallow water sedimentation is taking place today in the forearc basins, represented by the Nicoya and Dulce gulfs (Mora, 1981).

Inner arc: The inner arc includes both the magmatic arc and intra-arc basins. The magmatic arc, defined by various volcanic-plutonic mountain ranges (Figure 3), is characterized by the products of Tertiary and Quaternary calc-alkaline magmatism, although intrusive rocks of alkaline nature have been recognized in southern Costa Rica and northern Panama (Mora, 1981).

The intra-arc basins are intermountain depressions of diverse origin that are typically filled by Tertiary to Quaternary regressive sedimentary sequences. These sequences grade from shallow oceanic sediments to continental fluvial and alluvial deposits, with local littoral carbonates. All these Tertiary and Quaternary sedimentary rocks contain high proportions of pyroclastic material, clear evidence of the influence of arc vulcanism.

Back arc-basins: The back-arc basins are morphologically characterized by large plains on the Atlantic slope of Costa Rica. These basins are filled with Tertiary to Quaternary marine sediments of variable depth. Thrust faulting and low amplitude folding are tectonic

characteristics of this area. The sedimentary monotony of these deposits is interrupted by the presence of alkaline volcanic cones and lava flows.

"The geotectonic and magmatic evolution of the Central America Orogen is rather complex since subduction related compressive phases are accompanied and followed by incipient and active rift zones and volcano-tectonic segmentation. This complexity is also referred to in the magmatic history of the Costa Rican region which exhibits a very peculiar association of calc-alkaline and alkaline rocks." (Cigolini et al, 1981).

ECONOMIC GEOLOGY

Mining History

In 1502 Christopher Columbus gave the name "Costa Rica" to the region (which means Rich Coast in English) because the discoverers encountered Indians heavily ornamented with gold. The Spanish conquerors later entered the country, but never found the source of the metal. Only after Costa Rica's independence from Spain were the first ore bodies discovered, and this was shortly followed by a mining boom between 1821 and 1843. Ulloa (1979) estimates that 24000 ounces of gold and 8000 ounces of silver were produced during this period. In 1885 a second gold district was discovered and exploited for almost 30

years by an American company called Abangares Gold Fields of Costa Rica. Ulloa (1979) estimates 40000 ounces of gold and 24000 ounces of silver were extracted and exported from 1900 to 1925. The world economic crisis of the thirties caused a decline in mining activity and by 1940 systematic exploration of mineral deposits ceased (Ulloa, 1982).

A third brief mining period began in 1953 when a new mining law replaced the old Mining Ordinance that was enacted in 1830. "The third period of activity within the country, which was generated in 1953 by the establishment of the current law, was stopped after a few years of work due to: the lack of consistent and systematic mineral exploration, lack of capital investment in the mineralized zones, and deficiencies found in the incentives created by the mining law" (Ulloa, 1982).

At present, only a few gold mines and placer operations are in production. Most notable is the Santa Clara open pit mine, ranked as a world class gold deposit (Mining Magazine, 1983).

Perhaps the new mining law, enacted in 1982, and renovated efforts in mineral exploration will result in a recovery of mining activity in the years to come.

"However, only time and market conditions will decide the course that from now on the gold mining industry will take in Costa Rica" (Castillo, 1984).

Mineral Deposits

The geologic diversity of Costa Rica holds promise for the discovery of numerous types of economic mineral deposits. Known mineralization in the country can be assigned to two distinctive geologic environments: the continental and the oceanic (Castillo, 1980).

The continental deposits are those formed within the magmatic arc and in associated intra-arc basins. These deposits are directly or indirectly related to late Tertiary intrusions of calc-alkaline nature crosscutting Early to Late Tertiary volcanics and sediments. Producing Au districts are characteristic of this metallogenic province as are small, subeconomic Pb-Zn deposits. Major copper deposits in Panama (for example, Cerro Petaquilla and Cerro Colorado) occur in geologic terrains that extend northward into the southern part of Costa Rica, strongly suggesting the existence of a favorable porphyry copper environment.

In some regions of Costa Rica, where the climate is hot and very humid, surficial processes of metal accumulation are very important. This is the case for extensive

areas of laterite and bauxite formation, the products of residual concentration; and the cause of the magnetite-rich black beaches and gold placers which are the result of mechanical concentration.

Small deposits of the oceanic association are found in the ophiolitic volcanic-sedimentary sequences within the outer arc. Field evidence, mainly in the Santa Elena and Nicoya peninsulas, suggests the potential for podiform chromite deposits, massive sulfides of the Cyprus-type and manganese deposits. Phosphate in Nicaragua is associated with Cretaceous rock sequences and may exist in Costa Rica (Cunningham et al, 1984).

LOCAL GEOLOGY

Introduction

The orientation survey was conducted in two separate areas with the purpose of detecting trace element signatures for different metallogenic provinces in two separate and distinctive tropical environments within Costa Rica. Geographic and geologic aspects of each area will be discussed separately in this section.

Esparza Area

Geographic Aspects

The Esparza Area is located in the San Jose 1:200,000 scale topographic quadrangle, 2 km southeast of the small town of Esparza (Figure 9). The study area comprises 168 km² and is crossed by the Turbina, Paires, Jesus Maria, and Machuca rivers. The Santa Clara Gold Mine is found in the northeast corner and sample point locations are shown in Figure 9.

The surrounding region is used for farming and cattle raising, and only in a few areas along the steep canyons of major rivers is the natural forest vegetation still preserved. The predominant climate here is warm and dry (less than 2 meters of rain/year), with well defined rainy and dry seasons.

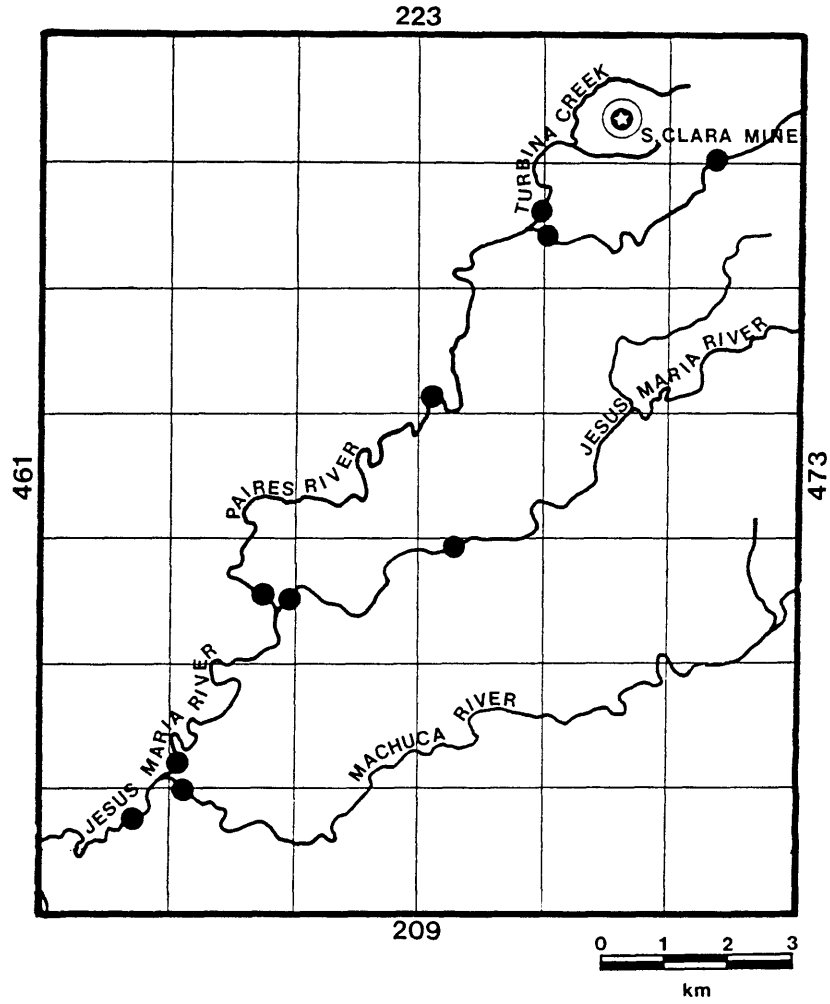


Figure 9. Location of sample sites, Esparza Area.

Bedrock Geology

The Esparza Area, as shown in Figure 10, is covered by five Tertiary to Quaternary lithologic units and their erosive products (Madrigo 1970). Regardless of their depositional environment, the five units show a strong influence from the magmatic arc. Only one unit (Tva) hosts known mineralization. Each of the outcropping units in the Esparza Area are briefly described.

Punta Carballo Formation Tm(c): The Punta Carballo Formation is a regressive sedimentary sequence of Miocene age, with a marked influence of active Tertiary volcanism. Lower stratigraphic levels are characterized by shallow water deposition of fine-grained, poorly stratified, gray sandstones rich in mollusc shells. The shallow water sandstones grade up to beach sandstones and later to red sandstones and conglomerates of fluvial and terrestrial depositional environments.

Aguacate Group Tva: The Aguacate Group includes three igneous formations defined and described by Kussmaul and Sprechmann (1984) as: a) the Miramar Andesite Formation, a lithostratigraphic unit characterized by hydrothermally altered andesites and interbedded tuffs; b) the La Union Breccia Formation, represented by green, very coarse volcanic breccias, with fragments up to 1 meter at the base, but smaller at upper levels, and a total

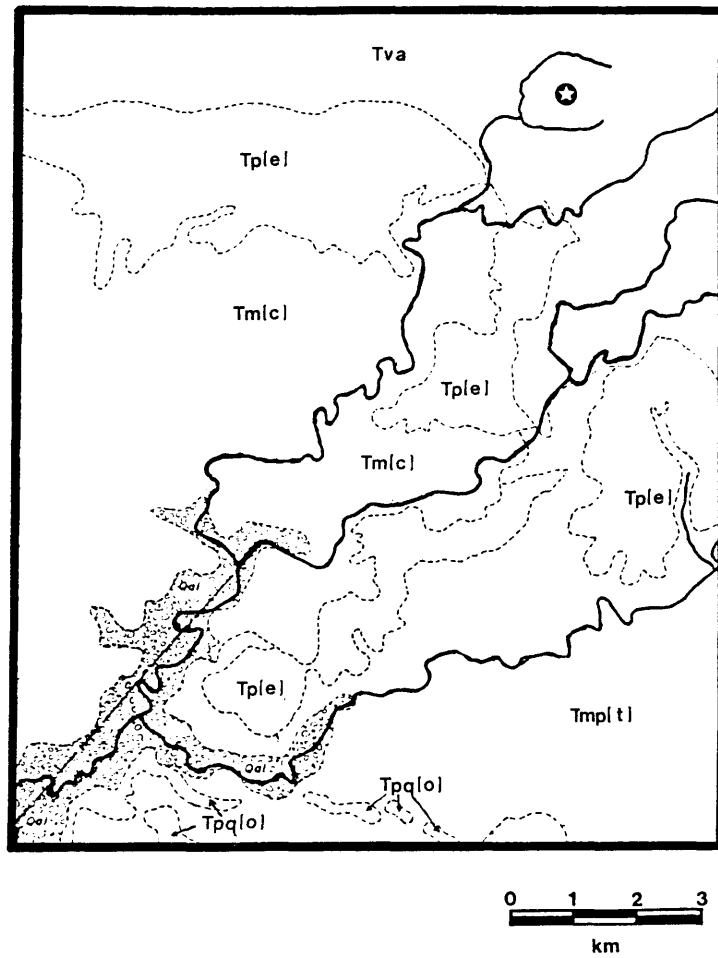


Figure 10. Geologic map of the Esparza Area (from Madrigal, 1970). See text for explanation of symbols.

thickness that can reach 200 meters; c) the La Garita Basalt Formation, composed of alkaline basalts with augite and olivine phenocrysts, interbedded with agglomerates and tuffs. The three formations are Tertiary in age and are the host rocks for most, if not all, of the ore bodies within the Costa Rican Gold Belt (Figure 3).

Orotina Formation Tp_q(o): This formation consists of nuee ardente deposits with fragments of pumice within a crumbly ashy matrix. The age of this unit is between 1.38 m.a. and 0.15 m.a. (Kussmaul and Sprechmann, 1984).

Esparza Formation Tp_e: This unit contains chaotic laharic deposits with large fragments of alkaline basalts within a muddy matrix.

Tivives Formation Tmp_t: This formation is a Plio-Pleistocene laharic deposit mainly composed of 0.1 up to 2.0 meter basaltic blocks within an ashy matrix.

From a chronostratigraphic point of view, the Esparza and Tivives formations are separate units; however lithologically both formations are identical as both are volcanic erosional products of the Aguacate Group.

Economic Geology

As previously stated this area was chosen because the the Santa Clara open pit gold mine provides an area of known mineralization. The Production Cost Update (Dec.

1984), published by the Metals Economics Group of Boulder, states proven reserves of 4.7 million short tons of 0.06 oz. Au/ton for this mine. United Hearne Resources of Canada is current owner and the mine is presently producing 1500 tons of ore a day (Metals Economics Group of Boulder, 1984).

The Santa Clara mine is a disseminated gold deposit hosted by strongly altered and deeply weathered porphyritic andesites interbedded with ignimbrites and lapilli tuffs. The gold ore is found in an east-west zone of brecciation and alteration 100 m wide and 600 m long.

The orebody was discovered by the Canadian corporation after an extensive exploration program which utilized geologic, geophysical, and soil geochemical surveys (OEA, 1978).

San Isidro Area

Geographic Aspects

The San Isidro Area is located in the foothills of the Talamanca Range, which constitutes the northern extension of the porphyry copper province of Panama. The study area is located northeast of San Isidro (Figure 11). It comprises 220 km² and is crossed by the Buenavista, Chirripo Pacifico, Quebradas, and Payner rivers.

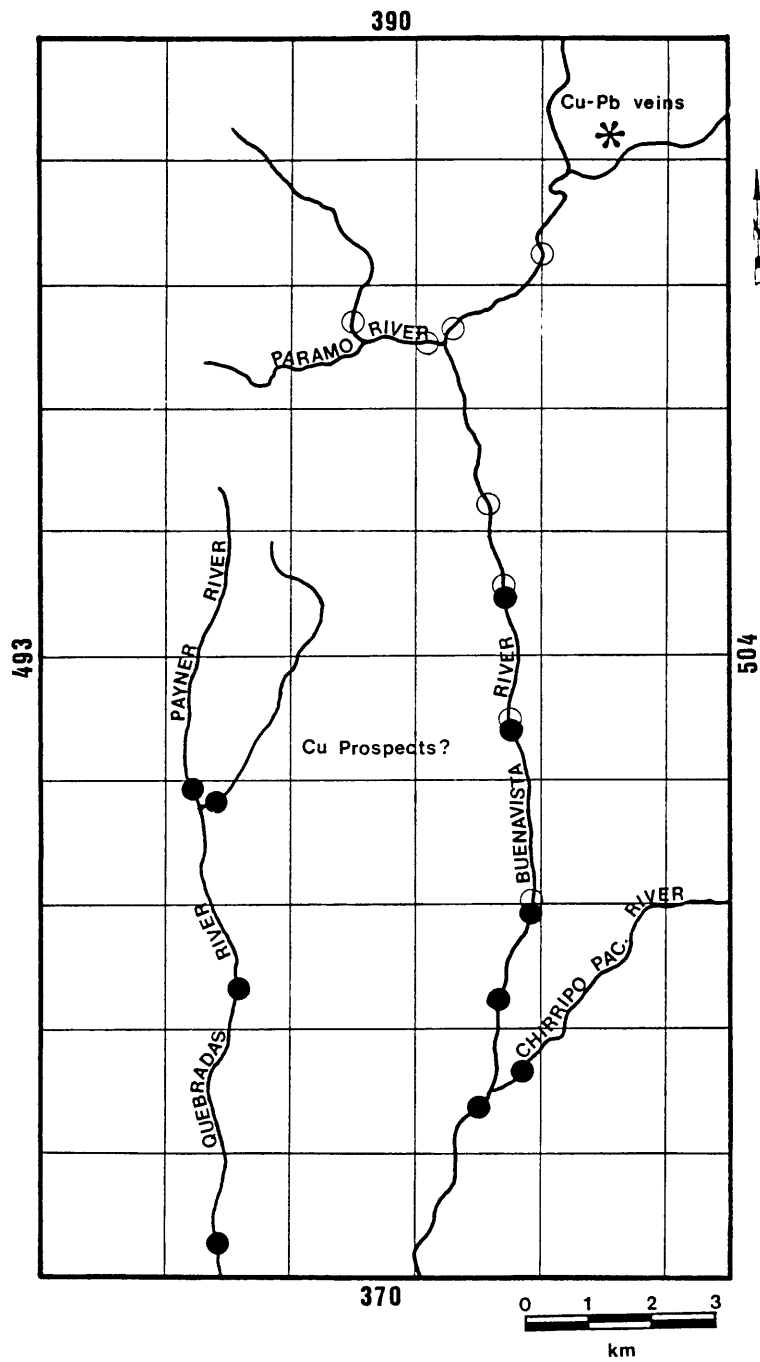


Figure 11. Location of sample sites, San Isidro. Open circles denote follow-up sample locations.

According to current literature, the area contains a major copper prospect, the Pueblo Nuevo Prospect (World Mining, 1983). However, the only known mineral deposits in the area are several small epithermal copper bearing quartz veins, described by Segura (1981 a,b). Access to the area is excellent, because the numerous gravel roads that connect the small towns in the region run parallel and very close to the major rivers. Agricultural activities include some cattle raising and vegetable growing. Virgin forest is still preserved along the streams, especially at higher altitudes. The prevailing climate is temperate and very humid, with over 3 meters of rain per year (Coen, 1983).

Bedrock Geology

The scarce geologic information available for the study area includes a regional 1:200,000 scale geologic map (MIEM, 1982) and two preliminary reports, submitted as part of a copper exploration program (Segura, 1981 a,b). This author believes the regional map is extremely generalized, as it only groups lithologic units under three major rock types (Figure 12). Segura (1981a,b), however, shows the complex time-stratigraphic relationships of these lithologic units (Figure 13). This author notes altered volcanic and intrusive (several superimposed phases) rocks

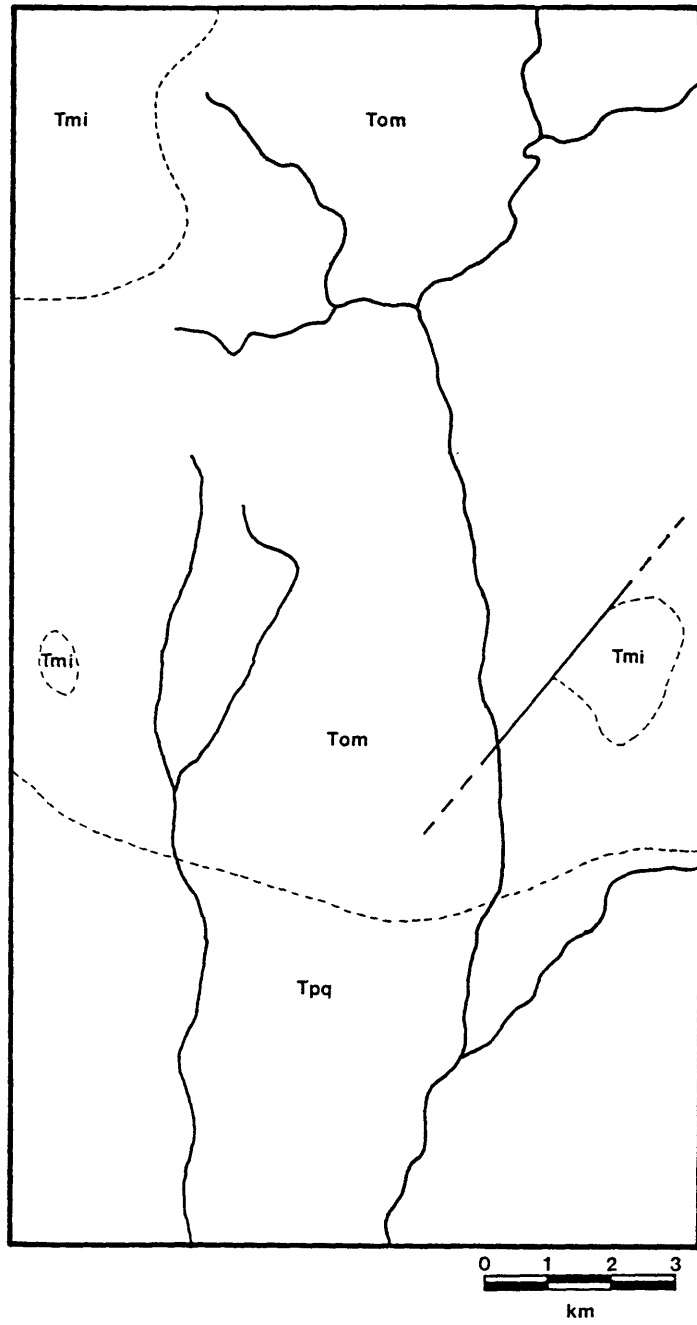


Figure 12. Regional geologic map for the San Isidro Area. See text for explanation of symbols (from Miem, 1982).

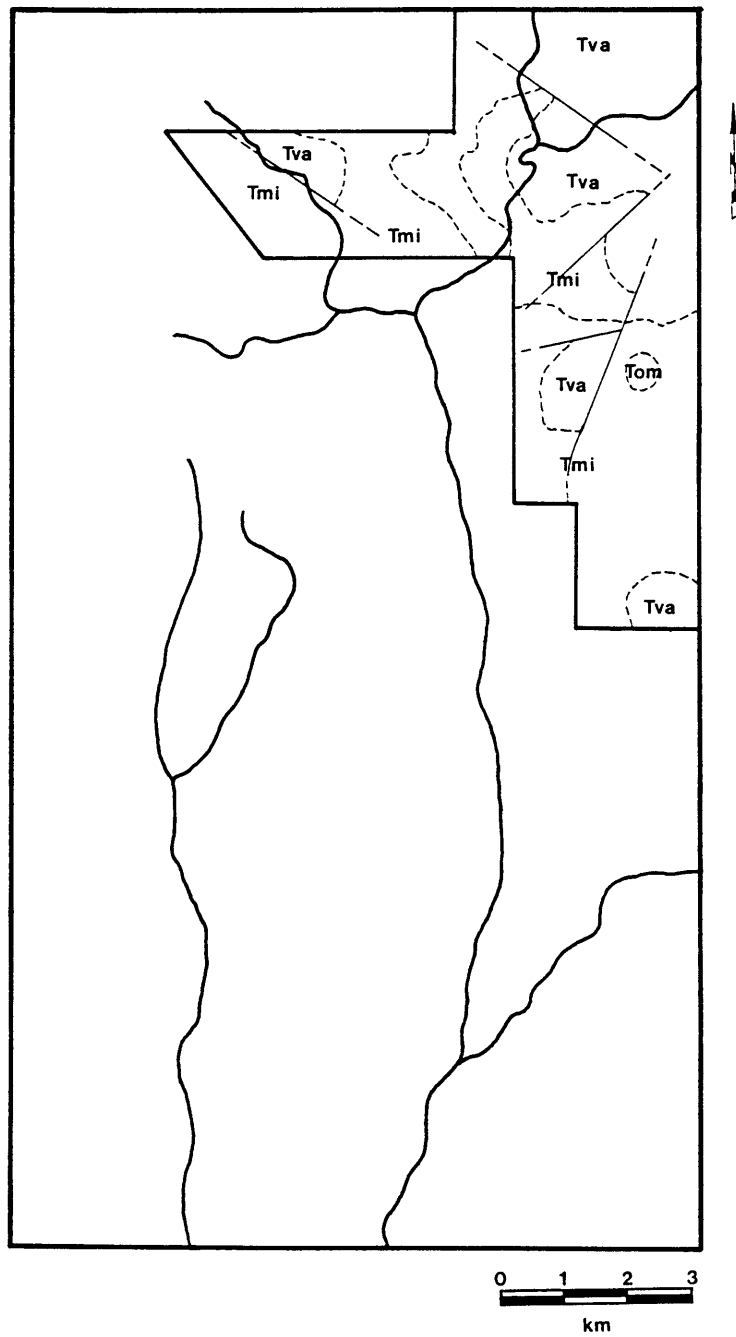


Figure 13. Geologic map for a section of the San Isidro Area from Segura (1981 a,b). See text for explanation of symbols.

predominant in the northern portion of the study area, whereas undisturbed sedimentary rocks outcrop to the south. Hydrothermal alteration, with pervasive pyrite and quartz veinlets, is characteristic of the northern section of the San Isidro Area.

Lithologies in the San Isidro Area are assembled into four major units:

Terraba Formation Tom: The Terraba Formation is composed of distal to proximal turbiditic sequences, ranging from siltstones, dark gray calcareous shales and limestones to conglomerates and graywackes. All units contain some volcanoclastic material.

Aguacate Group Tva: The Aguacate group is mainly composed of andesitic to dacitic lava flows and domes, interbedded with lapilli tuffs and andesitic breccias. All units have strong propylitic alteration.

Talamanca Comagmatic (intrusive) Group Tmi: Stocks of granitoid rocks are located along the crest of the Talamanca Range. "These rocks are mainly granodiorites, gabbros, and granites, with lesser proportions of mangerites, monzonites, diorites, and gabbro-diorites, intruded into the sequence of Tertiary sedimentary and volcanic rocks in the central part of the country in the Cordilleras of Talamanca, Aguacate, and Tilaran" (Castillo, 1983).

Berrange (1977), in a study of the Talamanca Cordillera, reports K-Ar ages between 11.5 and 9.3 m.a. for five samples of intrusive rock. These dates correspond to a deformation period at the beginning of the Miocene (Dengo 1962). "The intrusive activity produced a series of mineralizations, primarily metallic, that characterize the areas it influenced" (Castillo, 1983).

Surficial Plio-Pleistocene deposits Tpq: These are surficial deposits found on the foothills and lowlands immediately south of the Talamanca Range. The units include laterites, mudflow deposits, alluvial fans, etc.

Economic Geology

The San Isidro Area is located in the Talamanca Range. Essentially unexplored, the Talamanca Range constitutes the northern extension of the porphyry copper province of Panama (Castillo, 1984). Although the study area is supposed to include a major copper prospect (World Mining, 1983) no field evidence for this deposit was found. However, the area contains numerous subeconomic Cu-Pb epithermal veins that are ideally suited for an orientation survey. These small veins may represent the upper or peripheral levels of a major deposit.

The subeconomic veins are described by Segura (1981 b) as small polymetallic (Pb, Zn, Cu) epithermal quartz veins, with abundant barite and thicknesses between 40 and 20 cm. The veins are hosted by hydrothermally altered diorites.

METHODS OF INVESTIGATION

INTRODUCTION

Costa Rica's thick weathering profile and dense vegetation limit the effectiveness of geological and geophysical mineral exploration techniques. In areas of humid climate and high relief, typical of many regions of Costa Rica, both chemical and physical weathering are important erosional processes. The rate of chemical weathering reactions can be a hundred times more active in a tropical environment than in temperate or glacial climates (Agueda et al, 1977). These are ideal conditions for successful geochemical prospecting by stream sediment surveys.

The basis of a successful geochemical exploration program lies in the correct selection of sample collection, analytical and interpretative techniques (Laming and Gibbs, 1982). Most of the available geochemical exploration information comes from temperate and glacial regions (for example: USA, Canada, USSR, Norway, etc.), and some adjustments are mandatory for the proper use of these techniques under tropical conditions. Inadequate information on mobility and dispersion of the chemical elements under tropical weathering conditions can endanger the effectiveness of geochemistry as an exploration tool.

The objective of this orientation study is to identify these necessary adjustments for selecting the appropriate sampling technique for the Costa Rican tropical environment. Optimum specifications, in terms of sample type, number of subsamples per sample site, mesh size, sieving method, elemental suites necessary to identify mineralization, and sampling density will be determined in this investigation from a thorough study of data derived from 25 sample locations, 51 elements, three mesh fractions and two sieving procedures.

After field work was completed, the quality of the analytical data was assessed. Data quality studies were conducted for neutron activation, X-ray fluorescence and atomic absorption analyses. The definition of optimum sampling procedure was achieved by the study of dispersion patterns and sample site variability of selected elements for each mesh size and each sieving technique.

The possible use of a limited suite of elements for the study of dispersion processes was examined by statistical means. The elements of interest were those that would reflect the effects of mineralization, provided also that significant differences in elemental concentration were present between the various size fractions and/or between sieving procedures. Ideally, elements having those characteristics would provide the most useful

information for the determination of the optimum sampling technique in terms of size fraction, sieving procedure and sampling density.

The next step is field testing of the selected sampling procedure for a small area in the San Isidro region. The last step of this study is the recommendation of the optimum overall survey specifications for the Los Alamos regional geochemical survey. The detailed description of field sampling procedures, analytical techniques, and the detailed explanation of all interpretational procedures and parameters follow.

SAMPLE DESIGN

The orientation survey was conducted in two separate areas, the Esparza Area representing a gold deposit environment and the San Isidro Area representing a copper deposit environment (Figure 2). Specific study areas were selected because of known mineralization and relative ease of access. Both areas were also recommended by UCR professors and MIEM officials.

Within each area, ten sample sites were initially selected. This provided an average sampling density of 1 sample site per 8 km². At each site, samples were collected in triplicate to provide information on site sampling variability. As shown in Figures 9 and 11, drainages encompassing known mineralization were sampled to include areas where background metal concentrations were expected. In addition, all major tributaries to the main drainage were also sampled. After the results of the initial sampling were available, eight additional follow-up samples were collected in the San Isidro area to further test selected sampling techniques (Figure 11).

FIELD SAMPLING

For a reconnaissance-scale stream sediment survey, where a large number of samples are involved, sampling methods should be standardized to the greatest extent

possible. With this objective in mind, and following the recommendations and the expertise of the Los Alamos National Laboratory scientists, two sieving techniques and three mesh fractions were evaluated. At each sampling location, triplicate samples of minus 40, minus 80, and minus 100 mesh fractions were obtained by wet sieving. In addition, triplicate two pound bulk samples were collected at each locality for subsequent dry sieving.

Wet Sieving in the Field

This technique is used principally to reduce the volume of large samples containing insufficient fine material (Rose et al, 1979). It ensures sufficient material is obtained for chemical analysis without retaining bulky and heavy field samples (Bolviken et al, 1976). Wet sieving is especially useful in areas of high relief or in very remote areas where the weight of a sample is important in terms of logistics. Both of these situations are commonly encountered in Costa Rica.

Basic equipment for wet sieving in the field includes (1) two small plastic buckets with equal dimensions (approx. 25 to 35 cm). One of the buckets is bisected 15 cm below the rim; (2) nylon sieves of 40, 80, and 100 mesh size (0.425, 0.180, 0.150 mm of opening respectively); (3) plastic bags large enough to fit inside and wrap

over the bucket edge; and (4) plastic scoops. After carefully washing all the equipment with stream water, a pre-numbered plastic bag and nylon sieve are mounted, as illustrated in Figure 14. Once the equipment is mounted, the buckets are filled with stream water and placed on a flat surface. Stream sediments are collected from eight different locations covering (when possible) the entire width of the active channel. Sources of contamination, such as gold rings on fingers and trash in streams are avoided. The material is screened by stirring with the fingers. Coarse material not passing through the screen is discarded. The sample is allowed to settle in the bucket for several minutes after which the sieve is carefully removed and the water within the plastic bag is decanted. As the samples were still damp at the time of shipping to Los Alamos they were packed in double plastic bags and shipped in rigid plastic boxes to prevent breakage and contamination.

Bulk Samples

Triplicate bulk sediment samples were obtained by compositing scoops of fine to very coarse sand-sized material collected from 24 separate locations across the

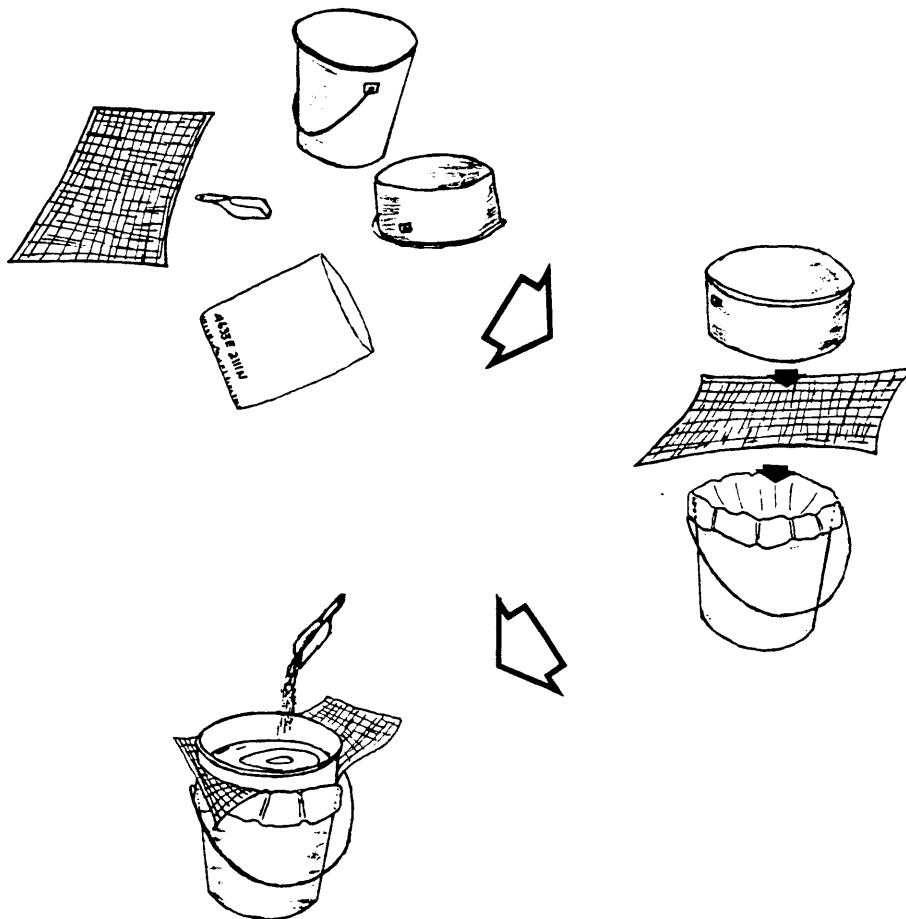


Figure 14. Wet sieving equipment and procedures.

stream channel. The material was placed in pre-numbered plastic bags and shipped to Los Alamos for further processing.

LABORATORY PROCEDURES

At Los Alamos, wet sieved samples were air-dried for several days. A 25g sample split of sediment was then submitted for chemical analysis. Bulk sediment samples were air-dried, then sieved into minus 40, minus 80 and minus 100 fractions using stainless steel sieves. A 25g sample split was also taken for chemical analysis. By the end of this process, there were eighteen samples per sample site (Figure 15).

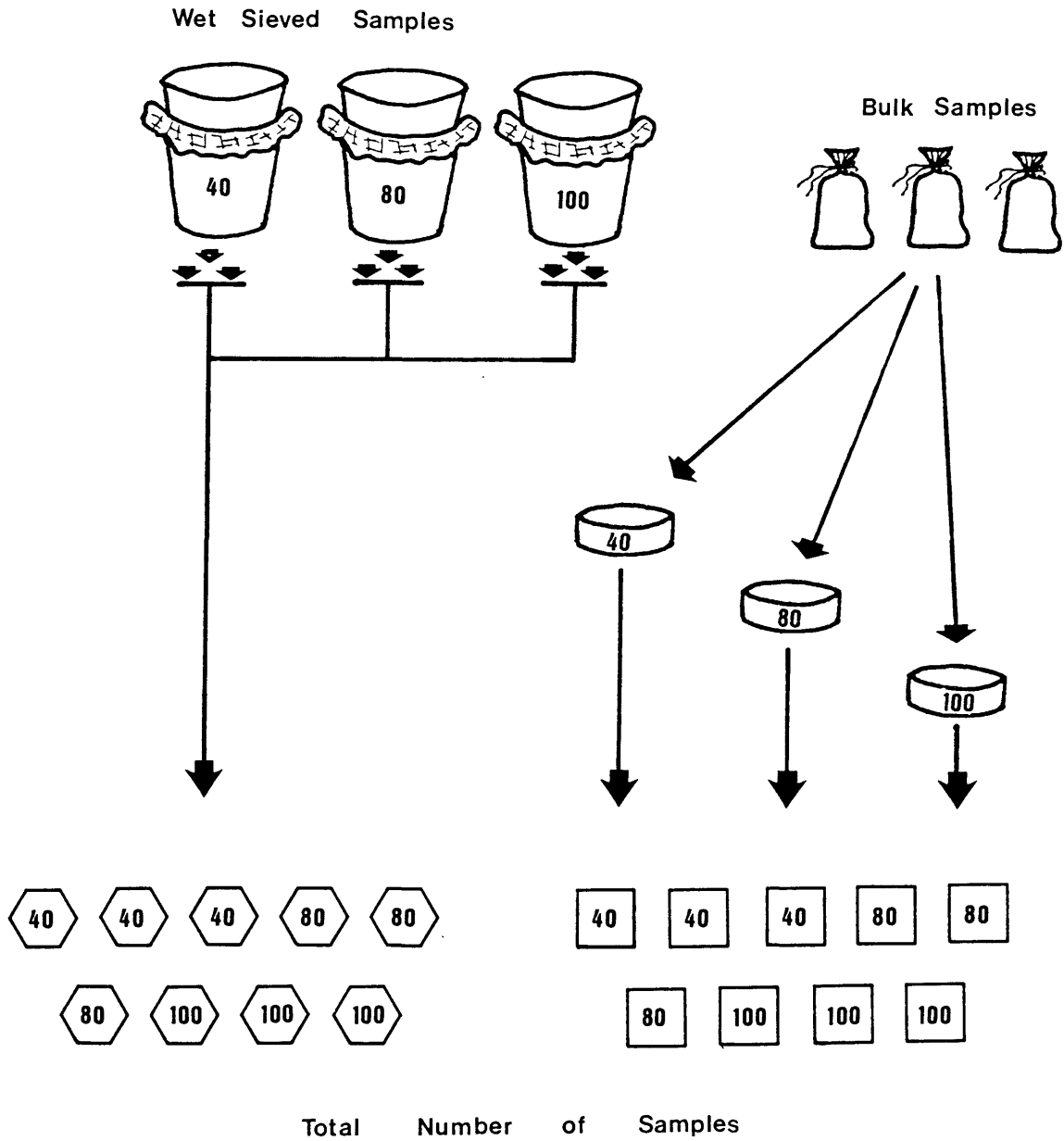


Figure 15. Representative samples for each sample location.

CHEMICAL ANALYSIS

Multi-elemental chemical analyses, utilizing instrumental neutron activation (INAA) and energy dispersive X-ray fluorescence (XRF) techniques, were conducted at Los Alamos. A total of 51 elements was analyzed by the above methods (Figure 16). Specific atomic absorption analyses for a few elements were obtained from a commercial laboratory to complement the Los Alamos data.

Instrumental Neutron Activation Analysis

Los Alamos National Laboratory operates the Omega West tank-type reactor, moderated and cooled by light water. Qualitative and quantitative determinations are based on the determination of both energy and the number of gamma rays emitted by a sample after thermal neutron activation. The Omega West Reactor is a fully automated non-destructive INAA system capable of detecting up to 46 elements: Na, Mg, Al, Cl, K, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Zr, Mo, Ag, In, Sb, I, Cs, Ba, Hf, Ta, W, Au, Hg, La, Ce, Nd, Sn, Eu, Tb, Dy, Yb, Lu, Th, and U.

Although the actual lower detection limit (LDL) for any of the elements listed above depends upon the composition of the analyzed sample, typical LDL values are listed

PERIODIC TABLE OF THE ELEMENTS

IA																		INERT GASES																														
		IIA												IIIA	IVA	VA	VIA	VIIA	He																													
H	Li	Be											B	C	N	O	F	Ne																														
Na	Mg			III B	IV B	V B	VI B	VII B	VIII			IB	II B	Al	Si	P	S	Cl	Ar																													
K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr																															
Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe																															
Cs	Ba		Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn																															
Fr	Ra																																															
		<table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <tr> <td>La</td><td>Ce</td><td>Pr</td><td>Nd</td><td>Pm</td><td>Sm</td><td>Eu</td><td>Gd</td><td>Tb</td><td>Dy</td><td>Ho</td><td>Er</td><td>Tm</td><td>Yb</td><td>Lu</td> </tr> <tr> <td>Ac</td><td>Th</td><td>Pa</td><td>U</td><td colspan="12"></td> </tr> </table>																La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Ac	Th	Pa	U												
La	Ce	Pr	Nd	Pm	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu																																		
Ac	Th	Pa	U																																													

EXPLANATION

* Neutron Activation
□ X-Ray Fluorescence

Figure 16. Methods of analyses for elements used in this study.

in Tables 2 a,b,c. Commonly, a 4 gram sample is analyzed. Garcia et al, (1982) provide details of the method and equipment.

Energy Dispersive X-Ray Fluorescence Analysis

The energy-dispersive XRF system at Los Alamos consists of an automatic 20-position sample changer, a lithium-drifted silicon detector, a pulsed molybdenum-type x-ray tube and multi-channel analyzer linked to a computer. A six gram sample of minus 325 mesh material is required for XRF analysis. In this investigation the following elements are determined by XRF: Ni, Cu, As, Se, Zr, Nb, Ag, Cd, Sn, W, Pb, and Bi. Lower detection limits for these elements are listed on Table 3. Additional details on the technique can be found in Fletcher (1981).

Atomic Absorption Analysis

Complementary atomic absorption analysis data from a private laboratory are used to evaluate the efficiency and reliability of the Los Alamos analytical methods. Atomic absorption analyses include Ag and Pb for the Santa Clara Area, and Mo, Ag, Pb, Hg for the San Isidro Area. Results for these analyses are listed in Plate II. Atomic absorption procedures included HF digestive analysis for Pb, and

Table 2a Typical Lower Limits of Detection
for INAA^{1,2,3}

Short Analysis

Isotope	Half-life	Principal Analytic Lines (keV)	Detection Limit (ppm)
Na ²⁴	15.0h	1368.6, 2753.85	1000
Mg ²⁷	9.46m	843.76, 1014.24	2700
Al ²⁸	134.40s	1779.00	3200
C ¹³⁸	37.00m	1642.68	120
K ⁴²	12.40h	1524.66	4500
Ca ⁴⁹	8.70	3084.15	1500
Ti ⁵¹	5.80m	320.08	750
V ⁵²	3.77m	1434.05	8.0
Mn ⁵⁶	2.58h	846.75, 1810.66	60
Cu ⁶⁶	5.10m	1039.00	350
Sr ⁸⁷	2.83h	388.52	400
In ¹¹⁶	54.1m	417.02, 1097.3	0.3
I ¹²⁸	24.98m	442.87, 526.38	40
Ba ¹³⁹	83.20m	165.85	200
Dy ¹⁶⁵	2.35h	94.68, 36.66	0.9
U ²³⁵		(DNC) ⁴	0.05

¹From Maasen et al, 1984²Lower limit values were calculated on the basis of a nominal 4 gram sample.³Based on a 20 sec. irradiation; 1275 sec. delay; 480 sec. gamma ray count.⁴Based on a 20 sec. irradiation; 10 sec. delay; 30 sec. neutron count. (DNC)=Delayed Neutron Counting

Table 2b Typical Lower Limits of Detection,
for INAA^{1,2,3}

Intermediate Analysis

Isotope	Half-life	Principal Analytic Lines (keV)	Detection Limit (ppm)
Na ²⁴	15.00h	1368.6, 2753.85	300
K ⁴²	12.40h	1524.66	4500
Ga ⁷²	14.10h	834.07, 630.0	45
As ⁷⁶	26.50h	657.04, 559.09	3.0
Br ⁸²	35.39h	776.5, 619.09	4.0
Mo ⁹⁹	2.7d	140.5	5
Sb ¹²²	2.70d	564.09	1.0
Ba ¹³¹	11.70d	496.2, 373.0	800
La ¹⁴⁰	40.28h	1596.2, 487.01	7.0
Sm ¹⁵³	47.00h	103.18	4.0
Yb ¹⁷⁵	4.21d	396.32	1.0
Lu ¹⁷⁷	6.70d	208.40	0.2
W ¹⁸⁷	23.8h	685.72	5.0
Au ¹⁹⁸	2.70d	411.79	0.001
U ²³⁹	2.35d	106.13, 277.9	10

¹From Maasen et al; 1984.²Lower limit values were calculated on the basis of a nominal 4 gram sample.³Based on a 240 sec. irradiation; 5 day delay; 1800 sec. ray count.

Table 2c Typical Lower Limits of Detection
for INAA^{1,2,3}

Long Analysis

Isotope	Half-life	Principal Analytic Lines (kev)	Detection Limit (ppm)
Sc ⁴⁶	83.80d	889.26	0.04
Cr ⁵¹	27.72d	320.08	2.5
Fe ⁵⁹	45.10d	1099.22, 1291.56	300
Co ⁶⁰	5.20y	1173.21, 1332.46	0.20
Zn ⁶⁵	242.94d	1115.52	15
Se ⁷⁵	120.02d	279.5, 264.5	5
Rb ⁸⁶	18.66d	1076.77	20
Ag ¹¹⁰	253.01d	657.74, 884.67	5
Sb ¹²⁴	60.20d	602.7, 1691.00	0.50
Cs ¹³⁴	2.05y	604.73, 795.84	0.60
Ba ¹³¹	11.70d	496.2, 373.0	300
Ce ¹⁴¹	32.50d	145.44	4.0
Nd ¹⁴⁷	10.98d	531.4	20
Eu ¹⁵²	13.4y	1408.02, 778.87	0.09
Tb ¹⁶⁰	71.99d	879.36	0.15
Yb ¹⁶⁹	30.69d	197.99, 307.68	0.50
Lu ¹⁷⁷	6.70d	208.40	0.06
Hf ¹⁸¹	42.00d	482.18	0.35
Ta ¹⁸²	115.00d	1221.38, 1189.02	0.45
Hg ²⁰³	46.76d	279.17	2
Th ²³³	27.40d	311.9	0.35

¹From Maasen et al, 1984²Lower limit values were calculated on the basis of a nominal 4 gram sample.³Based on a 240 sec. irradiation; 21 day delay; 2 hour gamma ray count.

Table 3 Lower Limits of Detection for Energy
Dispersive XRF¹ Analysis

Element	Detection Limit (ppm)
Ag	5
As	5
Bi	5
Cd	5
Cu	10
Nb	20
Ni	15
Pb	5
Se	5
Sn	10
W	15
Zr	5

¹From Maassen et al, 1984.

graphite furnace analysis for Ag. Lower detection limits reported by the private laboratory for AA analysis are: 2 ppm for Mo and Pb, 0.02 ppm for Ag and 0.01 (upper limit of 1.0) for Hg.

DATA QUALITY

Prior to geochemical interpretation it is necessary to consider the quality of the data. Three aspects of data quality are considered in this investigation: 1) analytical quality, 2) sensitivity, and 3) sample representivity.

Analytical quality assessment involves contamination, accuracy, and precision. These parameters are measured by the use of blanks, reference materials, and replicate analysis, respectively. Los Alamos National Laboratory analytical procedures systematically include blanks and reference materials in each batch of samples submitted for analysis. Contamination and accuracy of the data are evaluated by the analysts and the data are released only after satisfactory performance has been achieved. In this investigation precision is estimated graphically based upon replicate analysis of 10 percent of the total number of samples.

Sensitivity, or limit of detection, refers to the minimum content of an element that can be measured by any specific analytical method. Ideally, all concentration levels in every sample for every element would be above the limit of detection, but this is generally not the case for most stream sediment samples. It is therefore

important to identify which elements provide the best analytical information for interpretation. One approach is to determine the percentage of the data which falls within the detectable range of the analytical method employed. For this study, only those elements detected in at least 50 percent of the samples were considered appropriate for subsequent statistical and interpretive evaluation.

Sample representivity refers to the reproducibility of results at a specific sample site and reflects the combined effects of analytical variance and natural variance. In this study, field sampling was carried out in triplicate. Average sample representivity has been estimated for each element in each of the three size fractions isolated for each of the wet and dry sieving methods using the following relationship:

$$\text{C.V.} = (\text{S.D.} / \bar{X}) 100$$

where C.V. or coefficient (percentage) of variation is the estimated sample representivity, S.D. is the standard deviation, and \bar{X} is the mean for each set of triplicate samples.

STATISTICAL METHODS USED IN DATA ANALYSIS

The geochemical data base for this study consists of 360 samples analyzed for 51 chemical elements. Statistical methods were essential in describing, summarizing, and comparing results from these data. The ultimate objective of the statistical analysis techniques employed here is the identification of a small number of elements which can be confidently assessed in the selection of the appropriate sampling techniques. The most useful elements will have significant concentration differences between the various size fractions and/or sieving procedures. These elements should also reflect mineralization. This small subset of elements will, in effect, provide information equivalent to the data for the 51 elements. Statistical tools used for these purposes include basic statistical parameters, paired T-tests and correlation analysis.

Basic Statistics

Basic statistical parameters, including the mean (\bar{X}), standard deviation (S.D.) and the coefficient of variation (C.V.), were calculated for each set of triplicate samples. The results, presented in Plate III, were used to summarize the geochemical data, assess sampling

variability and, in conjunction with the paired T-test, serve as a basis of comparison between results for different size fractions and sieving procedures.

Paired T-Tests

One of the principal objectives of this study is to determine the optimum sampling method, in terms of size fraction and sample screening procedures. Metal concentration between different size fractions is well established in geochemical exploration (Rose et al, 1979). Three sediment size fractions (minus 40, minus 80, and minus 100) are being considered in this investigation. Variations in metal content might also be expected for material of the same size fraction obtained by different sieving procedures (wet versus dry). Paired T-tests, based upon the T probability distribution, are useful for testing hypotheses about the equivalency of two statistical samples or for establishing the likelihood that a given sample could be a member of a given population with specific characteristics (Davis, 1986). The paired T-test is used in this investigation to test the hypotheses of equivalency of mean metal contents between sample fractions and sample sieving procedures and as a criteria for selecting, in conjunction with correlation analysis, a

limited elemental suite for the proper study of dispersion patterns and the selection of the optimum sampling method.

Correlation Analysis

Chemical and geochemical associations, initially established by the work of Mendeleev and Goldschmidt, are fundamental aspect in the study of elemental distributions within the crust. The identification of these associations and their characterization of specific geological and geochemical processes contribute significantly to data interpretation. In this investigation, correlation analysis utilizing the Pearson Product-Moment correlation coefficient (r) is used to define geochemical associations on the basis of their linear correlation.

The correlation coefficient is a unitless number that ranges between +1.0 and -1.0. A perfect direct relationship is indicated by a value of +1.0 whereas perfect antipathetic relationship is indicated by a value of -1.0. The lowest absolute value of a correlation coefficient that is statistically significant at a given level of confidence is defined by the number of samples used to calculate r (Brooks, 1983).

In this investigation, correlation analysis is performed on data from each study area separately. Due to the limited data for each subset, all available data are used. This approach is considered appropriate because the technique is being used solely to identify geochemical associations and not as a basis for additional multivariate data analysis assessment. Correlation analysis and paired T-test results provide data that allow the definition of the optimum number of elements necessary for the assessment of variations in dispersion characteristics between different sampling techniques.

CHARACTERIZATION OF DISPERSION PATTERNS

Stream sediment samples represent material derived from the catchment area upstream from each sample station. Metal concentrations in this catchment basin derived from a single mineralized source will be diluted by metal concentrations from rocks surrounding the mineralized terrain. In the simple case, at some point downstream sufficient dilution will have taken place and will mask the anomalous metallic contribution from the mineralized source. Figures 17 and 18 show the catchment basins upstream from each sampling location. The size of the catchment area rapidly increases downstream from the mineralized areas. A simple way to visualize the effect of dilution on a dispersion pattern is through elemental content versus drainage area diagrams, which provide a reliable and direct tool in the assessment of dispersion patterns, and in the selection of the optimum sampling technique. Drainage area diagrams are constructed for both the Esparza and the San Isidro areas, following the course of the drainages highlighted in Figures 17 and 18.

Three specific aspects of dispersion are considered: contrast, dispersion pattern length and sample homogeneity. Contrast is here defined as the ratio of the peak metal content for a given element/sample type, divided by

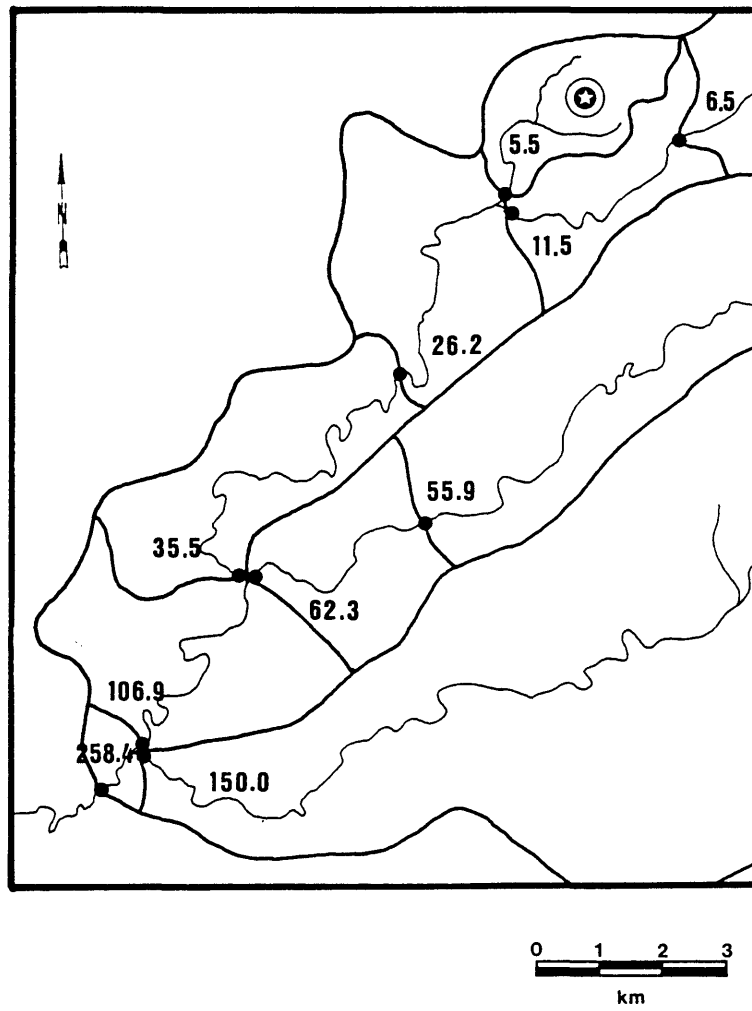


Figure 17. Catchment basins upstream from each sample location, in km², Esparza Area.

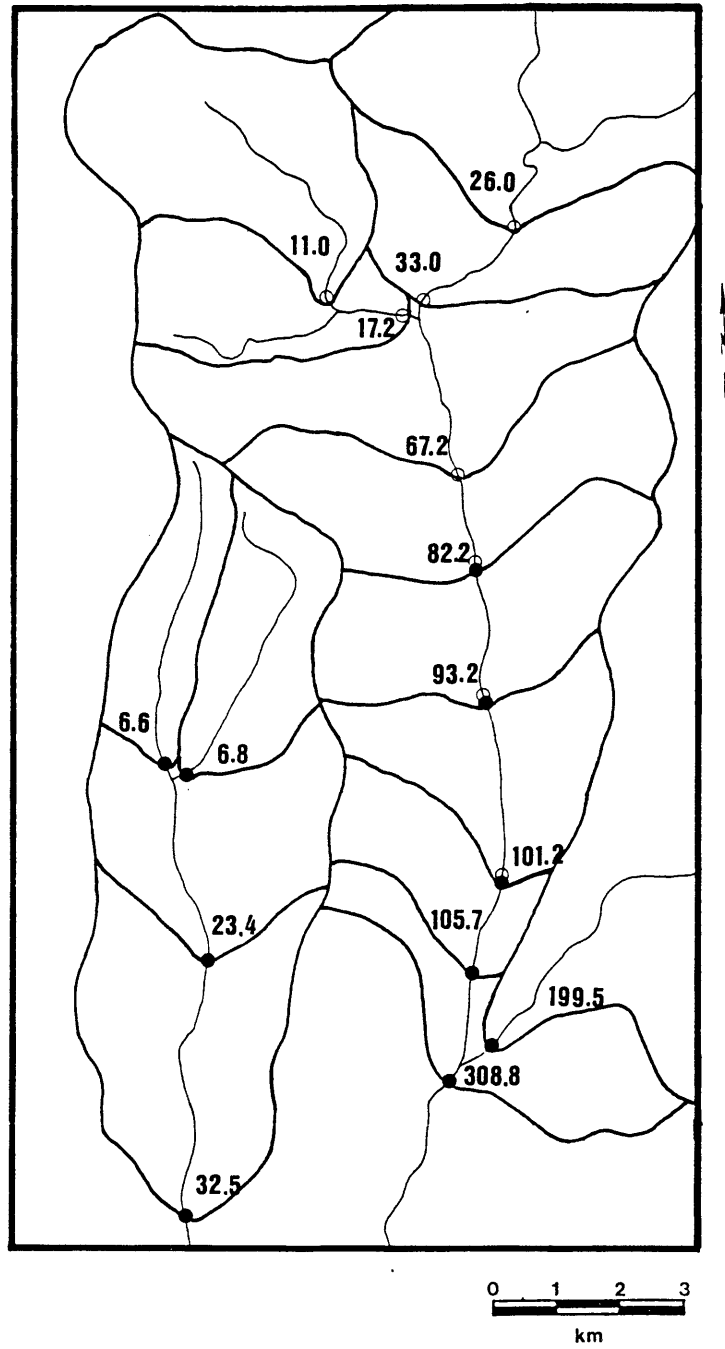


Figure 18. Catchment basins upstream from each sample location, in km², San Isidro Area.

the background content in the sample. The dispersion pattern length is defined as the distance downstream from a mineralized source at which the contribution from un-mineralized terrain dilutes the signal from mineralization to the point it is not recognized above background. The degree of homogeneity of a specific sampling medium is reflected by its sample site variability, measured by the relationship $C.V. = (SD/\bar{X}) \cdot 100$, for each set of triplicate samples. Recommendations made for the optimum overall survey specifications are largely based on interpretation of drainage area diagram and from the evaluation of sample representivity.

FOLLOW-UP STUDY

The San Isidro Area was initially selected because of the report of a major copper prospect in the area and based on recommendation of MIEM officials. World Mining (1983) indicates the existence of "at least several million tons of very high-grade copper mineralization", perhaps "6,000,000 to 8,000,000 tons of material grading 26 percent copper, 18 ounces silver and 0.09 ounce gold per ton..." in an area close to Pueblo Nuevo.

Even though anomalous Cu values were detected in the area initially selected, the resultant anomaly was too weak to be solely attributed to such a high grade deposit.

In addition, no field evidence for a large ore body, other than various degrees of pervasive hydrothermal alteration (hydrothermal alteration is conspicuous in the Talamanca Range) was found in the area initially selected. Thorough search of MIEM internal reports identified the possibility for a deposit north of the area initially selected, where Segura (1981 a,b) described several small polymetallic (Pb, Cu, Zn) epithermal quartz veins. The area north of Pueblo Nuevo (Figure 11) was considered ideally suited for follow-up studies once the proper sampling procedures and size fractions were defined from study of previously collected samples.

Specific sample locations, and selected sampling techniques are described in the next section of this thesis. Special interest during the follow-up study was directed towards those elements related to mineralization by the correlation analysis in the San Isidro Area.

RESULTS FROM ORIENTATION SURVEY

DATA ASSESSMENT

Analytical data quality was assessed through a study of sensitivity and precision levels for each of the 51 elements analyzed. INAA and XRF analytical techniques at Los Alamos were sensitive enough for 34 of 51 elements to have at least 50% of the analyses above detection limits (Tables 4a and 4b). Seventeen elements, including Cl, Sr, In, I, Ga, Mo, W, Se, Ag, Nd, Ta, Hg, Bi, Cd, Nb, Ni, and Sn, were excluded from evaluation because the analytical methods utilized were not sensitive enough to produce sufficiently reliable data, probably because the samples involved contained little or none of the elements in question.

Gold data were characterized by poor sensitivity and on that basis would normally be excluded from subsequent geological interpretation. However, gold constitutes the deposit target in one instance (Esparza) and a potential pathfinder for the second deposit target (San Isidro). Therefore, gold data were used qualitatively in the geochemical interpretation process.

Analytical precision of $\pm 25\%$ at the 95% confidence level is considered satisfactory for the purposes of this study. Results of graphical precision estimation are

Table 4a Samples above LDL and precision for
INAA analyses

Element	Samples above LDL (%)	Estimated % Precision
Na	99.7	22
Mg	99.7	42
Al	99.7	15
Cl	29.0	-
Ca	98.6	25
Ti	99.7	35
V	99.7	20
Mn	99.7	20
Cu	1.9	-
Sr	3.8	-
In	0.8	-
I	0.0	-
Ba	99.2	35
Dy	97.7	40
U	100.0	25
K	98.6	35
Ga	20.0	-
As	100.0	35
Br	66.7	25
Mo	26.3	-
Sb	95.1	18
La	100.0	18
Sm	100.0	21
Yb	100.0	16
W	30.3	-
Au	32.0	40
Sc	100.0	15
Cr	97.0	25
Fe	100.0	21
Co	100.0	15
Zn	62.6	92
Se	16.0	-
Rb	66.7	50
Zr	7.6	-
Ag	0.8	-
Cs	90.5	42
Ce	100.0	18
Nd	1.4	-
Eu	100.0	18
Tb	99.5	50
Lu	99.5	35
Hf	100.0	25
Ta	14.6	-
Hg	2.4	-
Th	97.8	35

Table 4b Samples above LDL and precision for
XRF analyses

<u>Element</u>	<u>Samples above LDL (%)</u>	<u>Estimated % Precision</u>
Ag	7.7	-
Bi	2.4	-
Cd	20.4	-
Cu	100.0	25
Nb	0.5	-
Ni	15.1	-
Pb	57.1	60
Sn	21.2	-
W	23.3	-
As	98.4	50
Se	0.0	-
Zr	100.0	18

listed also in Tables 4a and 4b. A total of eighteen elements, including Na, Al, Ca, Mn, U, Sb, La, Sn, Yb, Sc, Cr, Fe, Co, Ce, Eu, Hf, Cu, and Zr, satisfy the ideal $\pm 25\%$ precision range criteria. Key elements not meeting the above criteria, but thought to provide supporting information about mineralization and/or alteration are included in this study, provided that their analytical data lie within the $\pm 25\%$ to $\pm 50\%$ precision range. These elements, 13 in total, are: Mg, Ti, V, Ba, Dy, K, As, Au, Rb, Cs, Tb, Lu, and Th. Two elements, Zn from INAA and Pb from XRF are rejected because of their extremely poor precision estimates ($\pm 92\%$ and $\pm 60\%$ respectively).

In an attempt to improve poor analytical data, selected orientation survey samples were analyzed by atomic absorption procedures (Plate II). Atomic absorption proved to be a more reliable technique in terms of sensitivity for Pb, Ag, and Hg than standard INAA and XRF procedures.

ASSESSMENT OF STATISTICAL DATA

Paired T-Tests

Statistical tests for paired observations are used to compare geochemical data from the different sampling procedures. This statistical parameter is used to select a suite of elements that has significant concentration differences resulting from size fraction variations and/or sieving procedures. Results are given in Plate III and are summarized in Tables 5 to 13.

For 22 elements, no significant differences can be attributed to the effect of different sieving procedures. Concentrations for Na, Mg, Al, Ca, Mn, Ba, Dy, U, K, Br, Sb, La, Sm, Yb, Sc, Fe, Co, Zr, Eu, Tb, Lu, and Hf were not significantly affected by the intrinsic differences between wet and dry sieving techniques. The remaining ten elements (one third of the data set) evidenced significant variations that can be attributed to sieving procedure variations. Five elements, including Ti, V, Cu, As, and Au have significantly higher concentrations in wet sieved material in at least one of the mesh fractions. Gold content in wet sieved samples was considerably higher than in dry sieved ones, 83% in the minus 80 mesh and 97% in the minus 40 mesh. On the other hand, Rb, Cs, Ce, Th, and Cr have higher concentrations in dry sieved material.

Table 5. Paired T-tests comparisons for minus 80 and minus 40 mesh fractions, wet sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	40	6.5	Yes
Mg	L	80	0.3	
Al	L	80	9.1	Yes
Ca	L	40	1.6	
Ti	L	80	2.9	
V	S	80	1.8	
Mn	L	80	6.3	
Cu	C	80	2.3	
Ba	L	80	5.1	
Dy	L	80	2.6	
U	L	80	13.0	Yes
K	L	40	1.1	
As	C	40	16.1	
Br	H	80	77.0	Yes
Sb	C	40	19.6	
La	L	80	10.4	Yes
Sm	L	80	10.6	Yes
Yb	L	80	8.1	Yes
Au	N/C	80	26.4	
Sc	L	80	5.3	Yes
Cr	S	80	1.2	
Fe	L	80	0.4	
Co	S	80	0.4	
Rb	L	80	13.2	
Zr	L	80	13.1	
Cs	L	80	13.6	
Ce	L	80	8.6	
Eu	L	80	8.8	Yes
Tb	L	80	---	
Lu	L	80	5.6	Yes
Hf	L	80	20.2	Yes
Th	L	80	12.4	Yes

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 6. Paired T-tests comparisons for minus 80 and minus 100 mesh fractions, wet sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	100	0.1	
Mg	L	80	2.8	
Al	L	100	5.7	
Ca	L	80	0.8	
Ti	L	80	16.4	Yes
V	S	80	24.7	Yes
Mn	L	80	2.5	
Cu	C	80	0.6	
Ba	L	100	1.2	
Dy	L	100	15.0	
U	L	100	3.7	
K	L	100	4.6	
As	C	80	4.9	Yes
Br	H	100	29.3	
Sb	C	80	1.8	
La	L	100	3.3	
Sm	L	100	4.9	
Yb	L	100	4.2	
Au	N/C	80	8.8	
Sc	L	80	0.5	
Cr	S	80	21.3	Yes
Fe	L	80	17.2	Yes
Co	S	80	12.9	
Rb	L	100	4.9	
Zr	L	100	7.2	
Cs	L	100	14.8	
Ce	L	100	4.6	
Eu	L	100	3.4	
Tb	L	80	---	
Lu	L	100	7.6	
Hf	L	100	10.8	
Th	L	100	7.3	Yes

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 7. Paired T-tests comparisons for minus 100 and minus 40 mesh fractions, wet sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	40	6.6	
Mg	L	40	2.5	
Al	L	100	14.8	
Ca	L	40	2.4	
Ti	L	40	13.5	
V	S	40	22.9	Yes
Mn	L	100	3.8	
Cu	C	100	1.7	
Ba	L	100	6.3	
Dy	L	100	17.6	
U	L	100	16.7	
K	L	100	3.5	
As	C	40	21.0	Yes
Br	H	100	106.3	Yes
Sb	C	40	21.4	Yes
La	L	100	13.7	Yes
Sm	L	100	15.5	Yes
Yb	L	100	12.3	
Au	N/C	100	18.0	
Sc	L	100	4.8	
Cr	S	40	20.1	Yes
Fe	L	40	16.9	Yes
Co	S	40	12.5	
Rb	L	40	8.3	
Zr	L	100	20.3	
Cs	L	100	28.4	Yes
Ce	L	100	13.2	Yes
Eu	L	100	12.2	Yes
Tb	L	100	6.9	
Lu	L	100	13.2	
Hf	L	100	31.0	Yes
Th	L	100	19.7	Yes

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 8. Paired T-tests comparisons for minus 80 and minus 40 mesh fractions, dry sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	40	2.2	
Mg	L	40	3.5	
Al	L	80	7.1	Yes
Ca	L	40	0.5	
Ti	L	80	11.7	Yes
V	S	80	9.5	
Mn	L	80	12.6	Yes
Cu	C	80	9.7	
Ba	L	80	7.7	
Dy	L	80	10.0	Yes
U	L	80	7.2	Yes
K	L	40	4.8	Yes
As	C	40	16.3	Yes
Br	H	80	67.0	Yes
Sb	C	40	17.8	
La	L	80	4.3	Yes
Sm	L	80	4.4	Yes
Yb	L	80	4.4	Yes
Au	N/C	80	36.2	
Sc	L	80	5.5	Yes
Cr	S	80	8.6	Yes
Fe	L	80	1.9	
Co	S	80	1.9	
Rb	L	80	0.2	
Zr	L	80	10.3	
Cs	L	80	4.7	
Ce	L	80	2.6	
Eu	L	80	4.4	Yes
Tb	L	80	6.3	
Lu	L	80	4.1	
Hf	L	80	13.2	Yes
Th	L	80	1.4	

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 9. Paired T-tests comparisons for minus 80 and minus 100 mesh fractions, dry sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	80	1.6	
Mg	L	100	2.6	
Al	L	100	8.3	Yes
Ca	L	80	1.2	
Ti	L	80	7.2	Yes
V	S	80	10.8	Yes
Mn	L	100	3.0	
Cu	C	80	0.8	
Ba	L	100	0.2	
Dy	L	100	2.5	
U	L	100	2.6	Yes
K	L	100	3.0	
As	C	80	3.1	Yes
Br	H	100	49.7	Yes
Sb	C	80	3.4	
La	L	100	4.2	Yes
Sm	L	100	5.9	Yes
Yb	L	100	3.2	Yes
Au	N/C	100	63.8	
Sc	L	100	1.0	
Cr	S	80	8.5	Yes
Fe	L	80	8.2	Yes
Co	S	80	5.1	Yes
Rb	L	80	4.2	
Zr	L	100	1.6	
Cs	L	100	0.4	
Ce	L	100	3.1	Yes
Eu	L	100	1.9	
Tb	L	100	2.9	
Lu	L	100	3.5	
Hf	L	100	4.1	
Th	L	100	4.1	

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 10. Paired T-tests comparisons for minus 100 and minus 40 mesh fractions, dry sieved samples.

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	40	3.8	
Mg	L	40	0.9	
Al	L	100	15.4	Yes
Ca	L	40	1.7	
Ti	L	100	4.5	
V	S	40	1.3	
Mn	L	100	15.6	Yes
Cu	C	100	8.9	Yes
Ba	L	100	7.9	Yes
Dy	L	100	12.5	Yes
U	L	100	9.8	Yes
K	L	40	1.8	
As	C	40	19.4	Yes
Br	H	100	116.7	Yes
Sb	C	40	21.2	Yes
La	L	100	8.5	Yes
Sm	L	100	10.2	Yes
Yb	L	100	7.6	Yes
Au	N/C	100	100.0	
Sc	L	100	6.5	Yes
Cr	S	100	0.1	
Fe	L	40	6.3	Yes
Co	S	40	3.2	
Rb	L	40	4.4	
Zr	L	100	11.9	
Cs	L	100	5.1	
Ce	L	100	5.7	Yes
Eu	L	100	6.3	Yes
Tb	L	100	9.2	Yes
Lu	L	100	7.6	Yes
Hf	L	100	17.3	Yes
Th	L	100	5.5	

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 11. Paired T-tests comparisons for sieving procedures, minus 40 mesh fraction. W = wet sieving; D = dry sieving

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	D	5.1	
Mg	L	D	4.8	
Al	L	D	4.1	
Ca	L	D	2.1	
Ti	L	W	21.1	Yes
V	S	W	25.3	Yes
Mn	L	W	4.7	
Cu	C	W	8.6	Yes
Ba	L	D	1.0	
Dy	L	D	3.9	
U	L	D	2.0	
K	L	D	7.8	
As	C	W	5.3	
Br	H	W	11.8	
Sb	C	W	3.8	
La	L	D	2.0	
Sm	L	D	4.7	
Yb	L	D	6.5	
Au	N/C	W	96.9	Yes
Sc	L	D	8.0	
Cr	S	W	9.5	
Fe	L	W	6.2	
Co	S	W	1.3	
Rb	L	D	12.6	Yes
Zr	L	W	1.0	
Cs	L	D	14.6	Yes
Ce	L	D	7.9	Yes
Eu	L	D	8.3	
Tb	L	D	4.6	
Lu	L	D	9.0	
Hf	L	D	6.9	
Th	L	D	9.6	Yes

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 12. Paired T-tests comparisons for sieving procedures, minus 80 mesh fraction. W = wet sieving; D = dry sieving

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	D	9.2	
Mg	L	D	1.0	
Al	L	D	2.3	
Ca	L	D	3.1	
Ti	L	W	11.6	
V	S	W	16.5	Yes
Mn	L	D	1.2	
Cu	C	W	1.2	
Ba	L	D	3.4	
Dy	L	D	10.3	
U	L	W	3.3	
K	L	D	4.3	
As	C	W	5.5	Yes
Br	H	W	18.5	
Sb	C	W	1.6	
La	L	W	3.7	
Sm	L	W	1.1	
Yb	L	D	3.2	
Au	N/C	W	83.2	Yes
Sc	L	D	8.1	
Cr	S	W	2.0	
Fe	L	W	4.6	
Co	S	D	0.2	
Rb	L	D	24.0	
Zr	L	W	3.6	
Cs	L	D	7.4	
Ce	L	D	2.6	
Eu	L	D	4.4	
Tb	L	W	---	
Lu	L	D	9.0	
Hf	L	D	1.0	
Th	L	W	0.2	

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

Table 13. Paired T-tests comparisons for sieving procedures, minus 100 mesh fraction. W = wet sieving; D = dry sieving

Element	Geoch. Assoc.*	Size fraction with highest [Me]	Difference(%) μ	Significance 90% conf.level
Na	L	D	7.9	
Mg	L	D	6.4	
Al	L	D	4.7	
Ca	L	D	2.7	
Ti	L	W	0.2	
V	S	D	2.1	
Mn	L	D	6.0	
Cu	C	W	1.4	
Ba	L	D	2.5	
Dy	L	W	0.4	
U	L	W	4.1	
K	L	D	2.9	
As	C	W	3.2	
Br	H	W	6.4	
Sb	C	W	3.6	
La	L	W	2.7	
Sm	L	D	0.2	
Yb	L	D	2.3	
Au	N/C	W	16.2	
Sc	L	D	9.4	
Cr	S	D	12.5	Yes
Fe	L	D	5.8	
Co	S	D	8.5	
Rb	L	W	10.7	
Zr	L	W	8.6	
Cs	L	W	4.2	
Ce	L	D	1.4	
Eu	L	D	3.2	
Tb	L	D	6.6	
Lu	L	D	4.4	
Hf	L	W	3.9	
Th	L	W	2.6	

*from Beus and Grigorian, 1977.

L = lithophile
 S = siderophile
 C = chalcophile
 H = hydrophile
 N = noble

The higher difference for these elements was detected for Rb, 24% higher in the minus 80 mesh dry sieved fraction than Rb in the minus 80 wet sieved size fraction. Concentrations of lithophile elements tend to be significantly higher in the dry sieved material than in the wet sieved samples whereas the chalcophiles tend to be enriched by the wet sieving procedures (for example: As, Cu, Au).

Metal content variation between different size fractions of stream sediments is well established in geochemical exploration (Rose et al, 1979; Levinson, 1980). This was also evaluated through the use of paired T-tests.

Results indicate at least three elements, Na, As and Sb, are significantly higher in the minus 40 fraction when compared to the minus 80 and minus 100 fractions, for both dry and wet sieved material. Conversely, the elements Al, Ba, U, Br, Cs, Th, and REE tend to be enriched in finer fractions, especially the minus 100 mesh. The elements Ti, V, Cr, Fe, and Co are enriched in the intermediate fractions of the minus 80 mesh. Even though not as strongly defined, Mn and Au tend to be enriched in minus 80 and minus 100 mesh fractions, while K and Rb tend to concentrate in the minus 40 fraction.

Correlation Analysis

Correlation analysis was used to detect elemental associations that may correspond, as Levinson (1980) points out, to given environmental conditions directly related to geologic and/or geochemical events. Based on correlation coefficients, elemental associations can be interpreted as the result of specific geologic factors (such as bedrock lithology), surficial geochemical conditions (pH, the presence of Mn and Fe hydroxides) or can be attributed to the effect of a mineralizing event.

Results of the correlation analysis for both the Esparza and San Isidro areas are presented separately in Plate III and are summarized as correlation matrices in Figures 19 and 20. By careful assessment of the correlation matrix from the Esparza Area, seven major elemental associations can be defined. These groups are listed in Table 14.

These seven groups can be clustered and interpreted as the result of specific geologic and/or geochemical factors (Table 15). The group Au-As-Sb is clustered with the group K-Rb-Cs. These associations are interpreted as the result of a single geologic phenomenon, perhaps a hydrothermal process that causes precious metal mineralization (Berger and Eimon, 1983) and hydrothermal

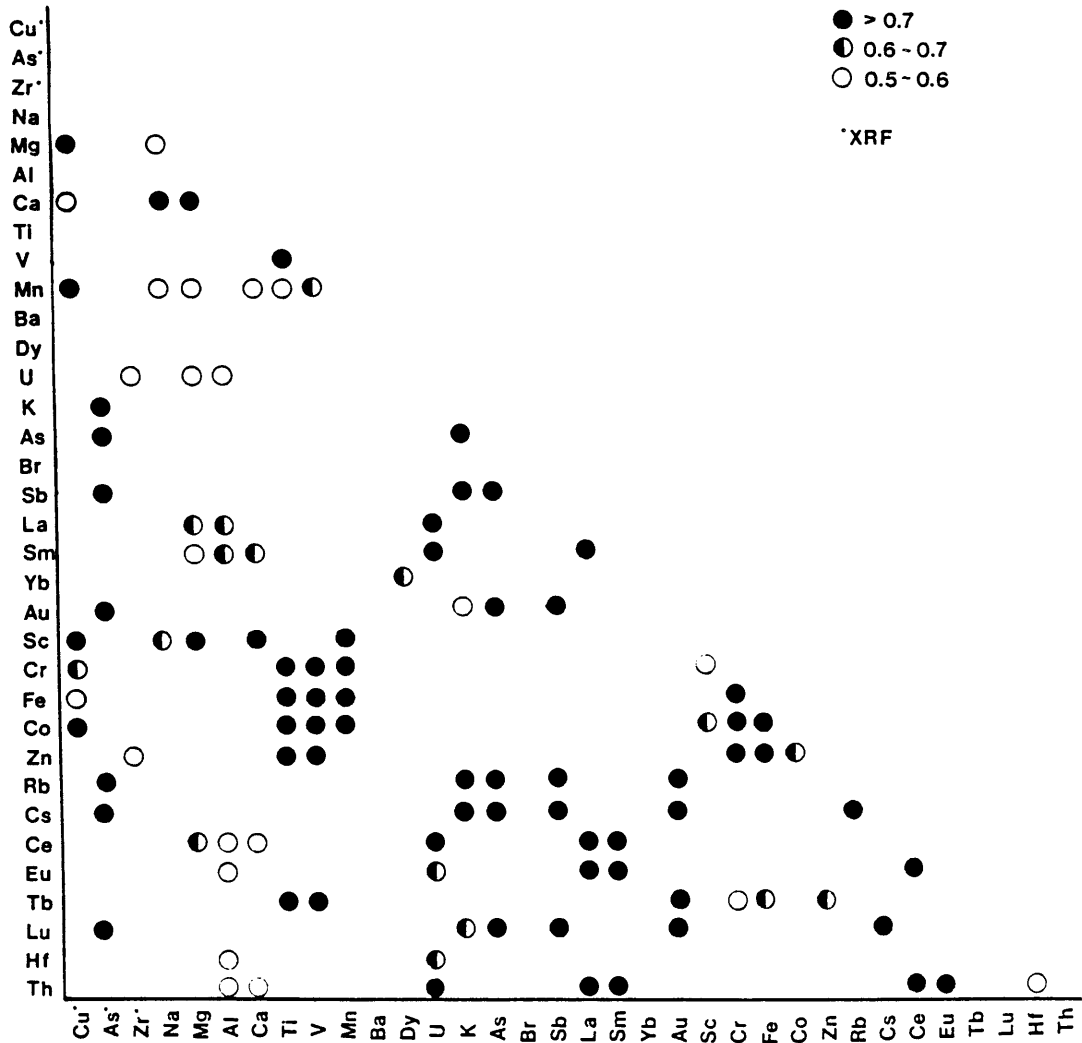


Figure 19. Correlation matrix for samples from the Esparza Area.

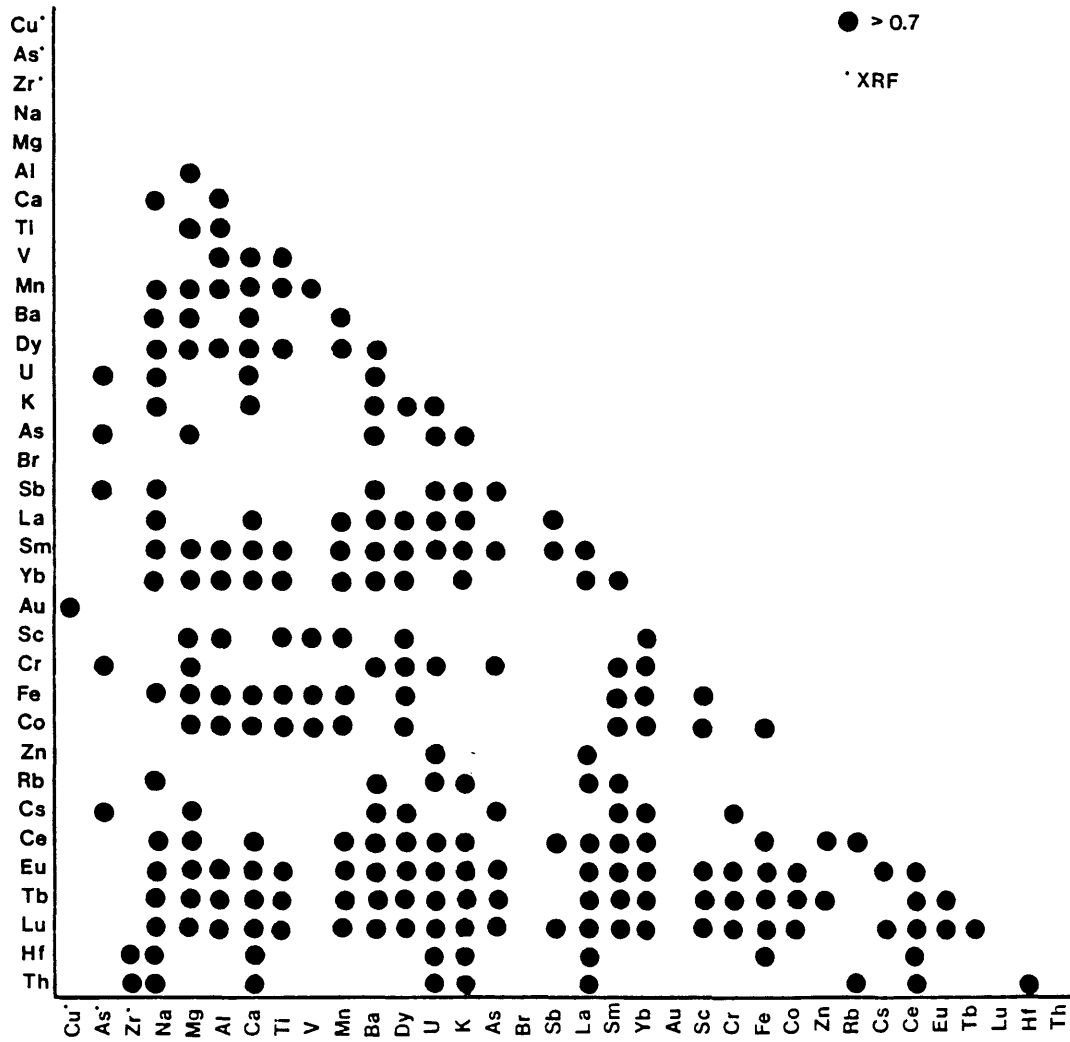


Figure 20. Correlation matrix for samples from the San Isidro Area.

Table 14 Elemental associations for the Esparza Area,
based on correlation analysis.

- 1) Au,As,Sb
- 2) K,Rb,Cs
- 3) Ca,Na,Mg,Mn,Al
- 4) Fe,Cr,Ti,V,Cu,Zn
- 5) U,Th,Zr
- 6) Dy,La,Sm,Yb,Ce,Eu,Tb,Lu,Hf
- 7) Br,Ba

Table 15 Grouping and interpretation of elemental associations, for the Esparza Area.

1) Au, Ag, Sb = Mineralization	➔ Hydrothermal Process
2) K, Rb, Cs = Hydrothermal Alteration	
<hr/>	
3) Ca, Na, Mg, Mn, Al = Rock-Forming Minerals	
4) Fe, Cr, Ti, V, Cu, Zn = Mafic Minerals	➔ Bedrock
5) U, Th, Zr = Zircon	
6) Dy, La, Sm, Yb, Ce, Eu, Tb, Lu, Hf = Rare Earth Elements	
<hr/>	
7) Br, Ba = not correlated	➔ Independent

alteration. Groups three through six in Table 14 cluster together when interpreted in the light of correlation analysis (Table 15). This combined group, which includes all major elements except K, may represent the effect of bedrock geology on the stream sediments of the Esparza Area.

Elemental associations from the San Isidro Area are not so clearly defined and geochemical interpretation is more difficult. Copper, the element that typifies mineralization in this area, correlates poorly with most other elements. Of the 32 elements shown in Figure 20, only Au has a strong correlation with Cu ($r=0.7$). Other elements that do correlate with Cu, but not shown in Figure 20 are Zr ($r=0.6$), and Pb and Ag from the atomic absorption analysis ($r=0.4$ and $r=0.6$ respectively). Other chalcophile elements such as As ($r=-0.7$) are negatively correlated with Cu.

Although not obvious in the correlation matrix, the set Na, Ca, K, U, and REE is the best defined elemental association in the San Isidro Area. Iron also shows good correlation with major and minor elements including Na, Al, Ca, Ti, V, Mn, and Co. Correlation between Fe and Cu, strong in the Esparza Area, is almost nonexistent in the San Isidro Area. Perhaps correlations for the San

Isidro Area tend to highlight the effect of bedrock geology in the stream sediments, whereas the mineralization contribution is very weak.

The interpretation and rationale behind the elemental clustering described above will be discussed in detail at the end of this chapter.

CHARACTERIZATION OF DISPERSION PATTERNS

Statistical analysis, through the use of paired T-tests and correlation analysis, is employed to define the ideal suite of elements for the study of dispersion characteristics. Gold, As, Sb, K, Rb, and Cs for the Esparza Area, and Cu for the San Isidro Area, show concentration variations between the different size fractions and sieving method combinations, and directly relate to mineralization.

For each of the elements above, a set of concentration versus drainage area diagrams are plotted. A summary chart, which includes specific characteristics of the dispersion patterns such as contrast, length of dispersion (persistence) and sampling representivity, is also constructed (Table 16). In this chart a score between 1 (best) and 6 (worse) is assigned to each of the size fraction and sieving method combinations. At the bottom of the score chart, an overall ranking from 1 to 6 is assigned for each combination. The final selection of the optimum sampling technique is based on the results of this ranking. A description of dispersion characteristics for selected elements is included below.

Table 16 Summary chart of dispersion characteristics of selected elements. (W = wet sieving; D = dry sieving; C = contrast; P = persistence; R = representivity)

Element	Disp. Char.	Disp.					
		-40W	-40D	-80W	-80D	-100W	-100D
Au	C	5	6	2	4	1	3
	P	2	6	3	5	1	4
	R	5	3	2	5	1	4
As	C	4	2	3	6	1	5
	P	1	2	3	5	4	6
	R	4	2	1	6	5	3
Sb	C	5	1	2	6	4	3
	P	6	4	1	5	4	6
	R	6	3	5	2	4	1
K	C	4	5	2	3	1	3
	P	6	4	1	5	2	3
	R	6	3	5	2	4	1
Rb	C	3	6	1	5	2	4
	P	2	1	2	1	2	1
	R	6	3	5	1	4	2
Cs	C	2	3	4	1	2	4
	P	6	2	3	1	4	5
	R	6	2	4	3	5	1
Cu	C	3	3	1	1	2	2
	P	4	1	2	4	3	3
	R	3	6	1	4	2	5
Total		80	64	53	78	60	72
Ranking		6	3	1	5	2	4

Gold

Gold concentration in stream sediments surrounding the Santa Clara mine varies widely from not detected (<0.001 ppm) to 1.005 ppm. In general, gold tends to be enriched in the finer sampled fractions, especially in the minus 100 mesh material. In coarser fractions, the intensity of the gold anomaly diminishes remarkably (Figure 21). Wet sieved samples better define the gold anomaly near the Santa Clara mine, not only in terms of intensity and contrast but also in terms of downstream persistence of the dispersion pattern. Gold in the San Isidro Area is detected only in one sample location, which coincidentally contains the highest Cu values.

Arsenic

Arsenic values in the Esparza Area range between 9 and 465 ppm. Unlike gold, higher values are detected for arsenic in the minus 40 mesh fraction. Wet sieved samples prove to be higher in As content than those from dry sieving (Figure 22).

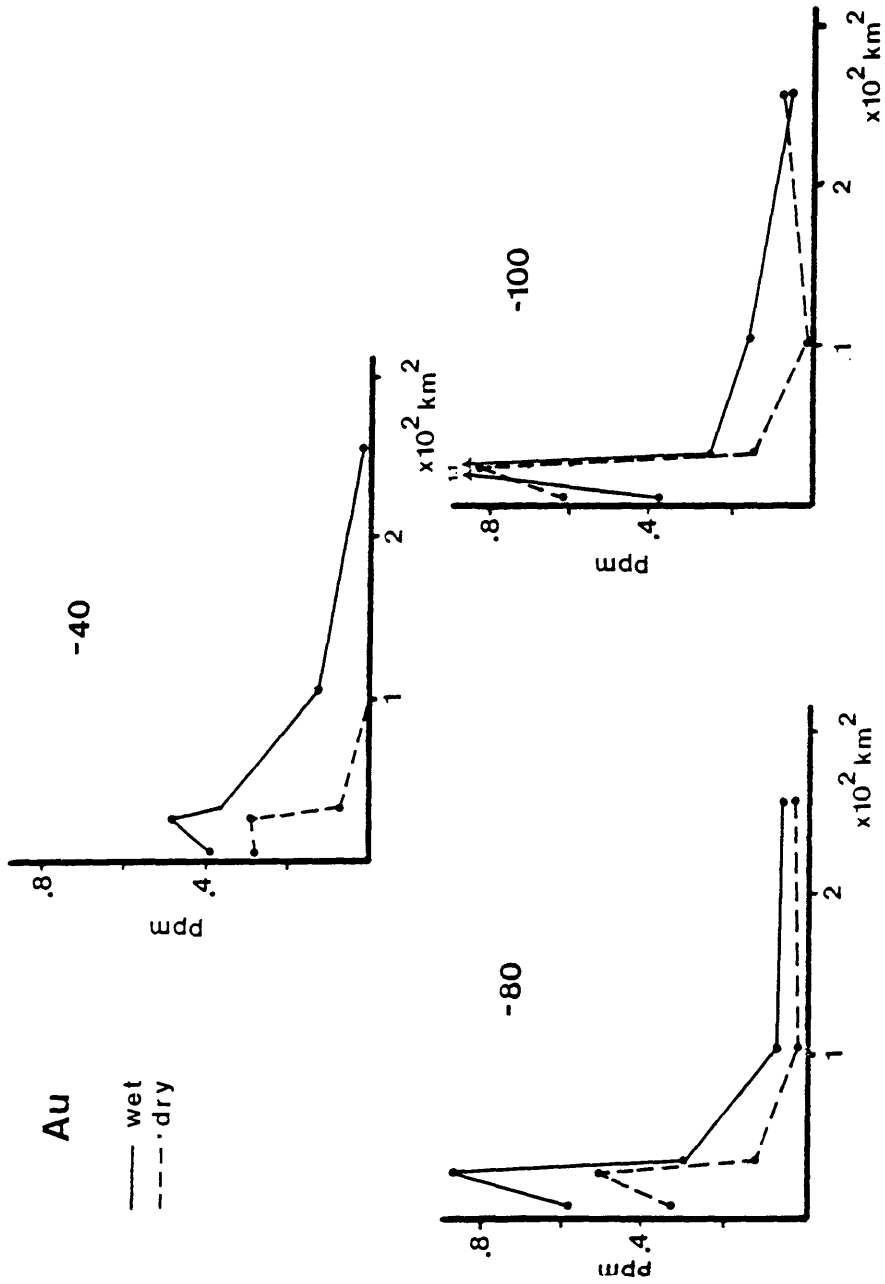


Figure 21. Au content versus drainage area diagram, Esparza Area.

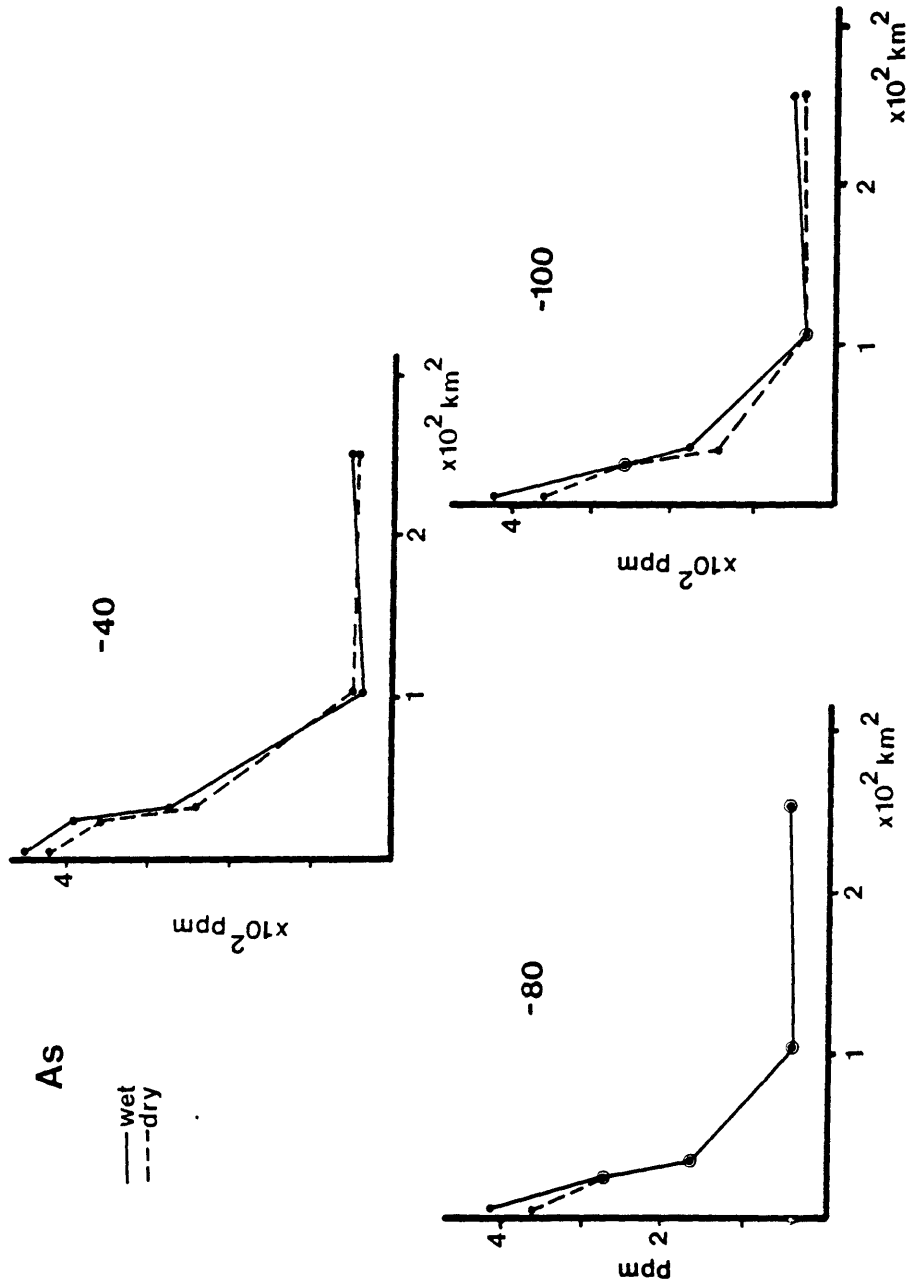


Figure 22. As content versus drainage area diagram, Esparza Area.

Antimony

Antimony shows excellent correlation with gold in the Esparza Area. Background values range between 1 and 4 ppm, with anomalous values as high as 47 ppm. The antimony anomaly is strongly defined by the use of the minus 40 mesh, but fewer differences are present in terms of sieving procedures. Results for wet and dry sieving are almost identical, with the exception of the minus 80 mesh fraction where wet sieved samples are slightly higher in antimony content than those from dry sieved samples (Figure 23).

Potassium

An average background value for K in the Esparza Area is 0.8 percent. Highest K values detected in the proximity of the Santa Clara deposit reach 2.4 percent. As shown in Figure 24, the strongest K anomalies are detected in the finer (minus 80 and minus 100) wet sieved material.

Rubidium

Rubidium dispersion patterns are rather irregular and background values vary, for the Esparza Area, between 5 and 40 ppm (Figure 25). The highest anomalous value, 121

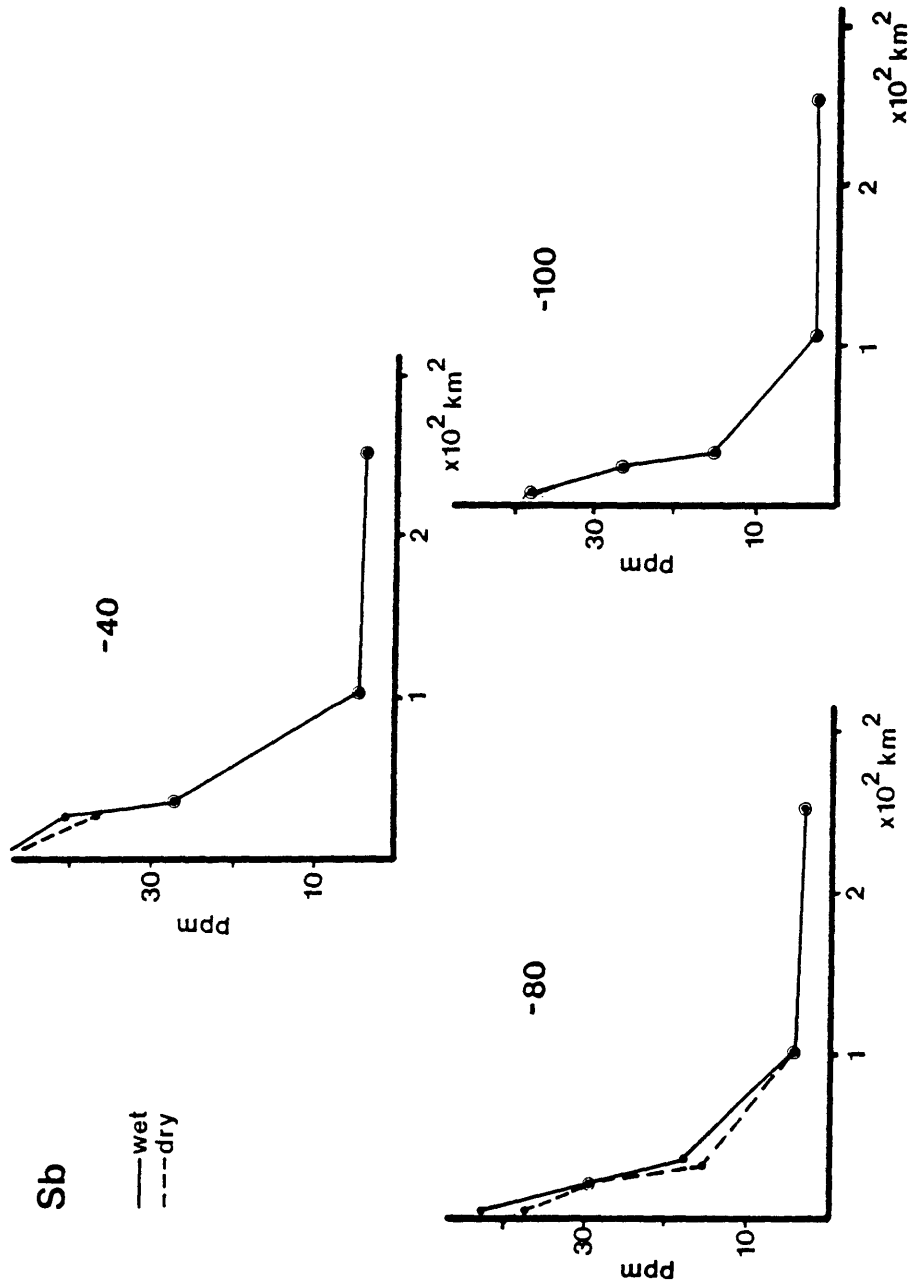


Figure 23. Sb content versus drainage area diagram, Esparza Area.

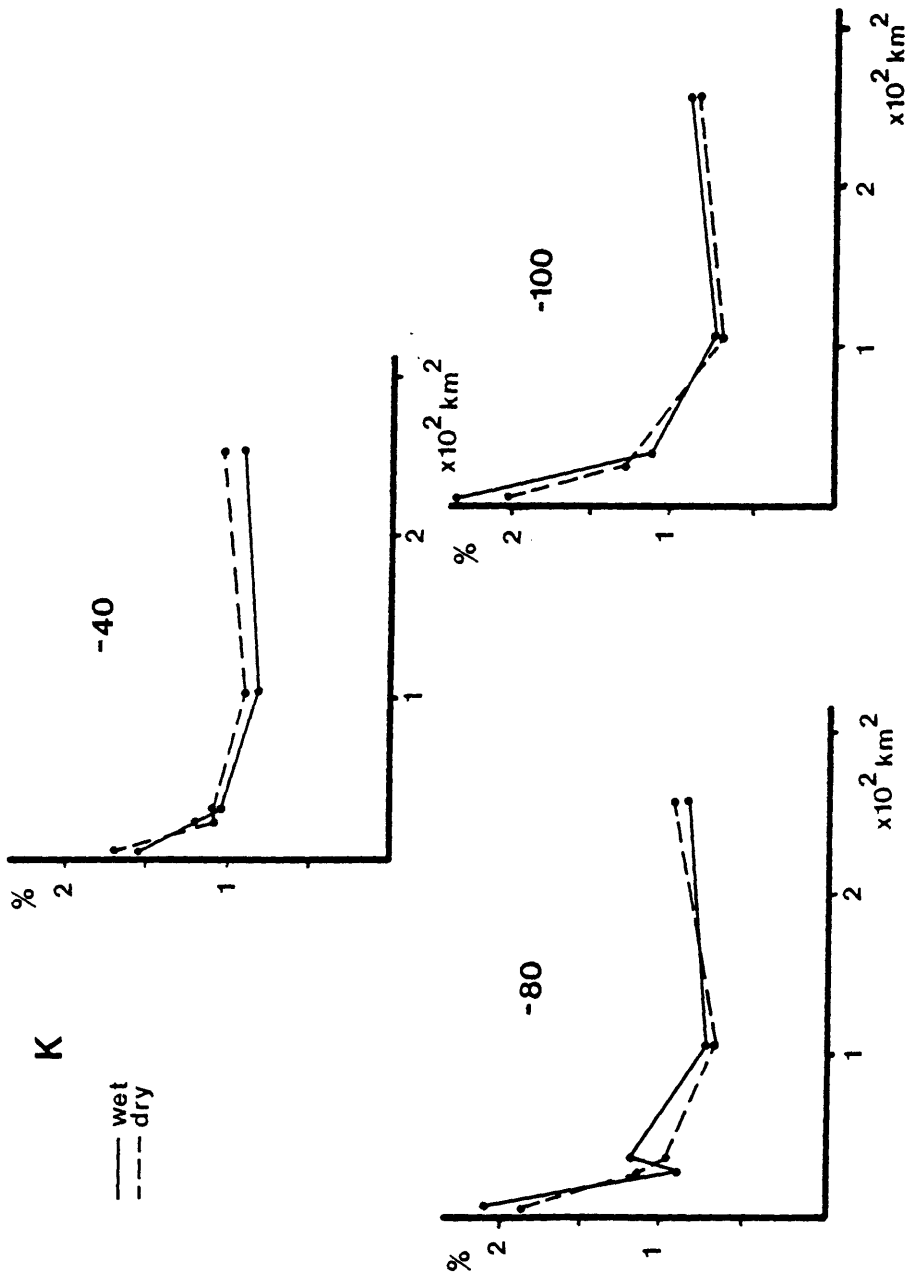


Figure 24. K content versus drainage area diagram, Esparza Area.

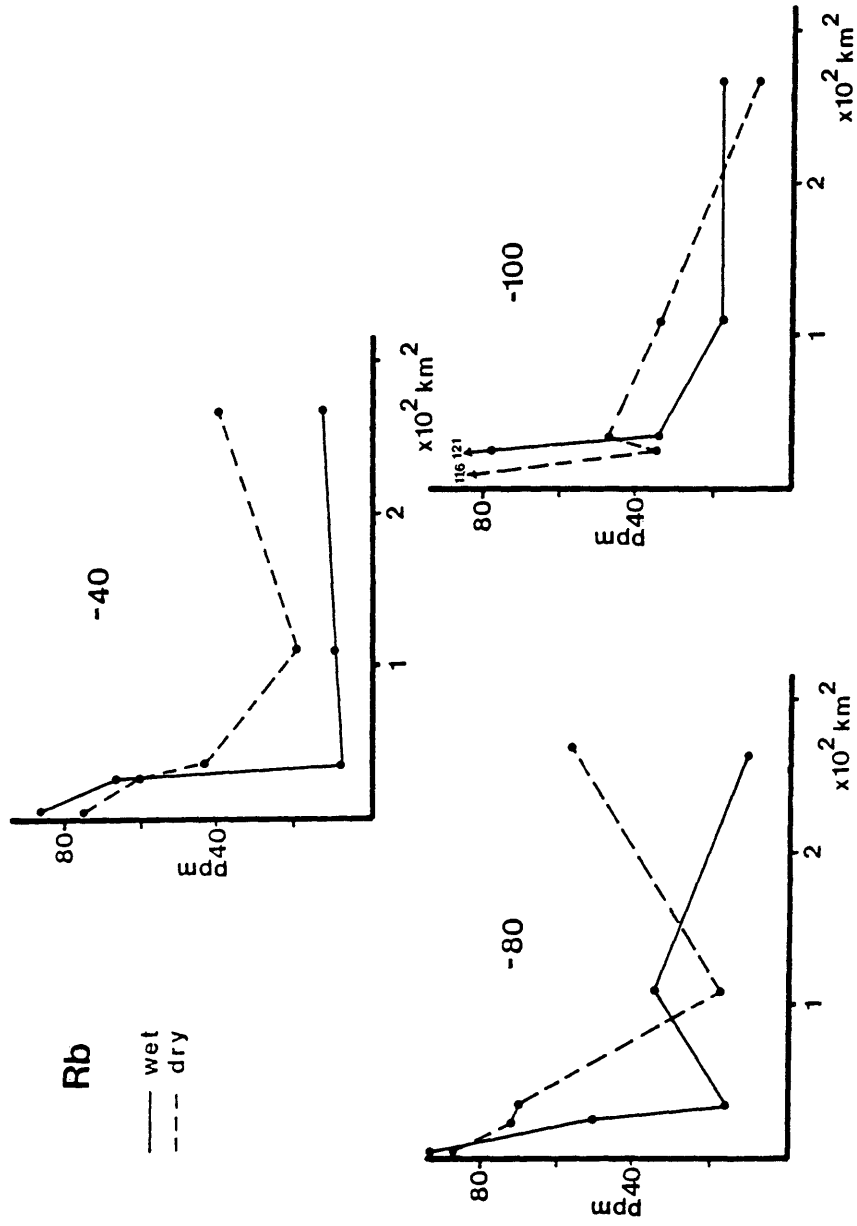


Figure 25. Rb content versus drainage area diagram, Esparza Area.

ppm, is obtained in the wet sieved minus 100 mesh fraction in the proximity of the Santa Clara mine. However, dry sieved samples show longer downstream anomalies.

Cesium

Typical background values for the Esparza Area lie between 1.0 and 2.0 ppm Cs, increasing to 7.8 ppm in the proximity of the Santa Clara Mine (Figure 26). Cesium content is higher in the wet sieved and finer fractions (minus 100 mesh). However, the coarser (minus 80 and minus 40) dry sieved samples give better results in terms of contrast and sample site variability.

Copper

Normal Cu background values for the San Isidro Area vary from 90 to 110 ppm, reaching 155 ppm in anomalous samples. The highest anomalies are detected in the San Isidro Area from wet sieved minus 80 and minus 100 size fractions (Figure 27). Anomalies from the minus 40 mesh for both wet and dry sieved material are weak and low in contrast. Highest contrast is achieved in the minus 80 mesh fraction.

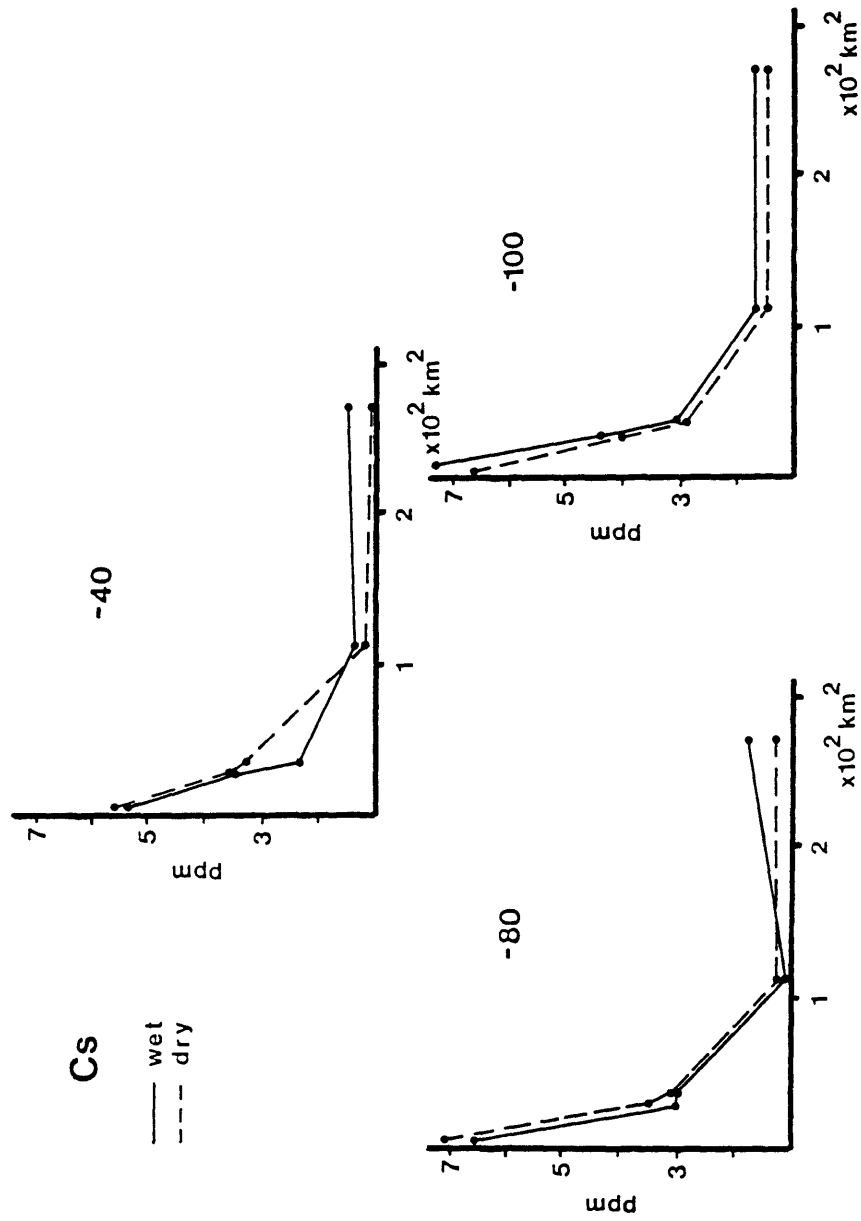


Figure 26. Cs content versus drainage area diagram, Esparza Area.

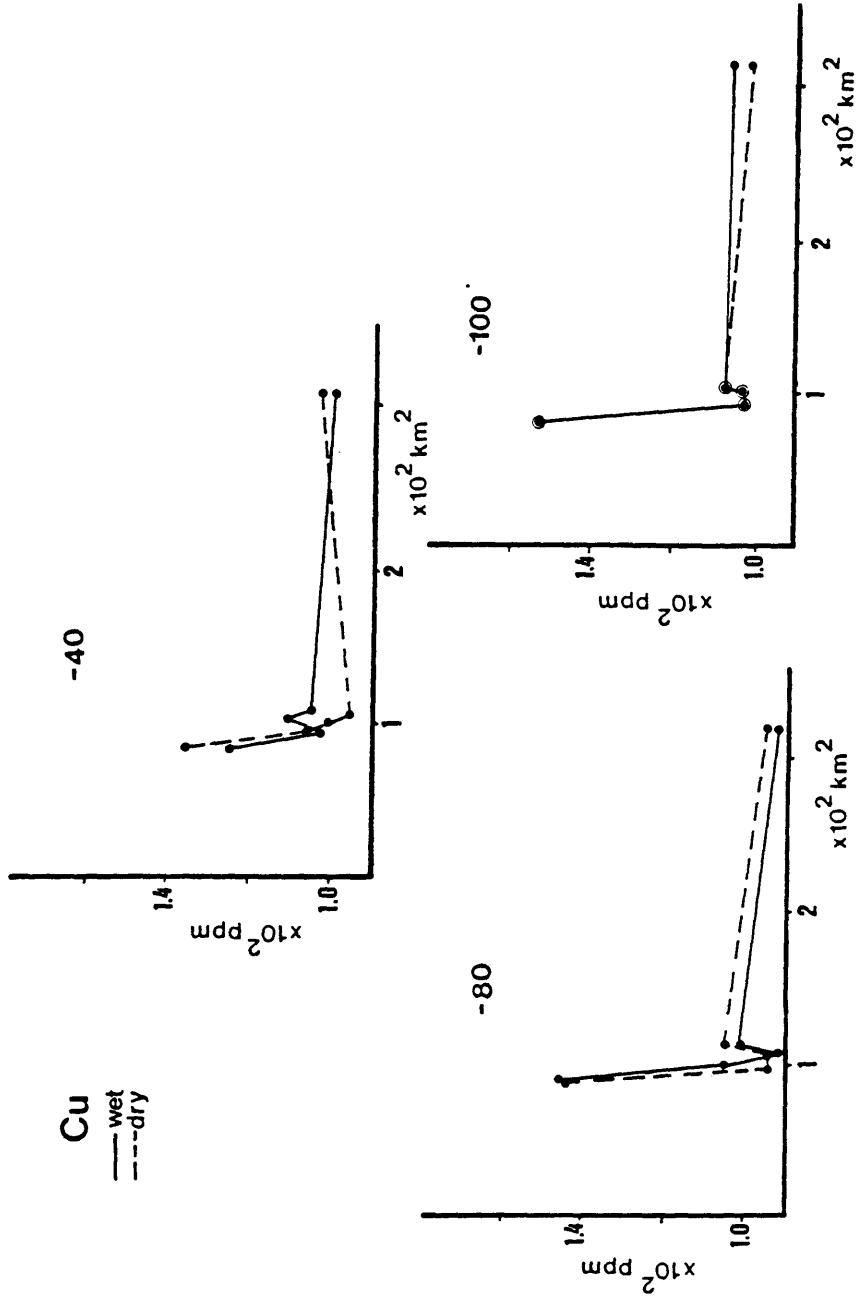


Figure 27. Cu content versus drainage area diagram, San Isidro Area.

Silver

Although INAA and XRF data for Ag are considered inadequate because of low analytical sensitivity, atomic absorption data demonstrate that Ag in the Esparza Area strongly correlates with gold. Atomic absorption analysis conducted on the minus 80 wet sieved samples detecte Ag contents between 0.06 and 0.24 ppm in the sediments derived from the proximity of the Santa Clara mine (Figure 28).

The results of the ranking of size fraction and sieving method combinations are presented in Table 16. This ranking indicates that the best sampling technique for the Costa Rican secondary environment is the minus 80 mesh/wet sieving combination. This sampling technique was tested in the follow-up study.

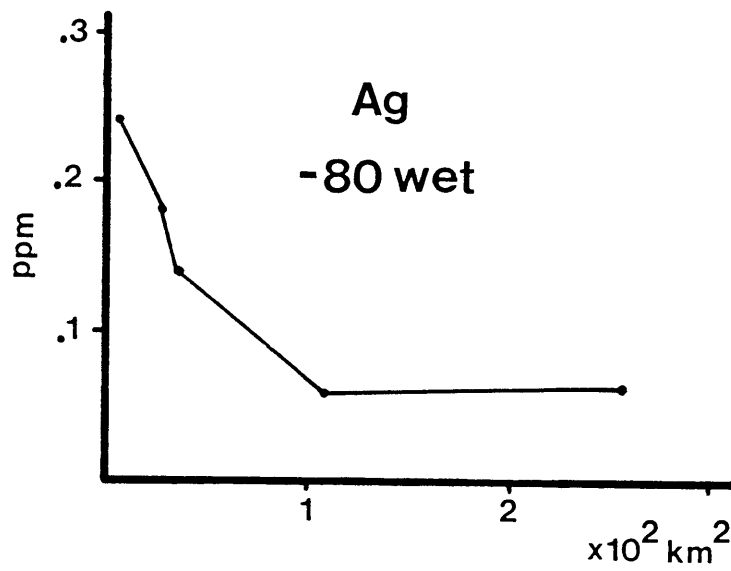


Figure 28. Ag content (minus 80 mesh, wet sieving) versus drainage area diagram, Esparza Area.

FOLLOW-UP RESULTS

Follow-up sampling was conducted in the San Isidro Area, north of Pueblo Nuevo and north of the previously collected sample sites. A total of eight samples, including a three sample overlap (Figure 11), were wet sieved to a minus 80 mesh fraction. Follow-up samples were analyzed for 51 elements by INAA and XRF techniques. Additional analyses included Ag (Graphite furnace), Pb (HF digestion) and Hg by atomic absorption analysis. These three elements were analyzed in an attempt to improve data quality.

Based on correlation analysis results, elemental content versus drained area diagrams were constructed specifically for Cu (XRF), Pb (AA), Zr (XRF), Au (INAA), Ag (AA), and Hg (AA). Conclusions from the follow-up study are discussed below for each of these elements.

Copper

Copper values in the follow-up samples continue to increase upstream to the area where the polymetallic veins described by Segura (1981a,b) are located (Figure 29). The highest Cu value, obtained from the sample closest to the veins, is 168 ppm, 1.7 times normal background. This weak Cu anomaly is interpreted as the result of secondary

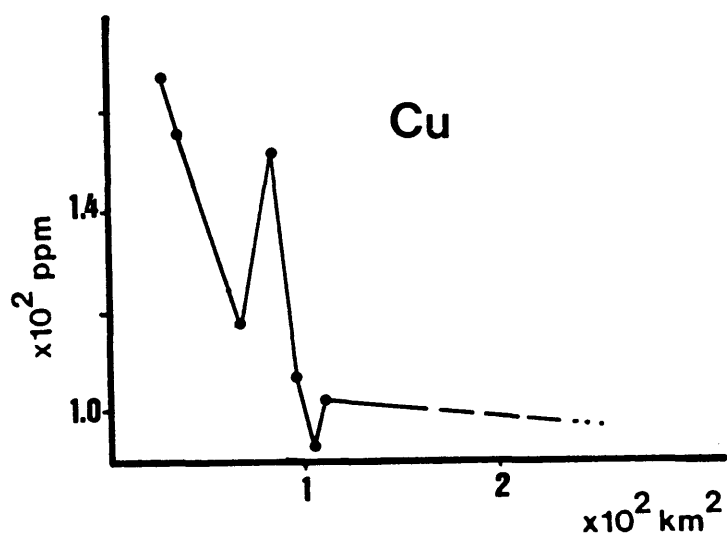


Figure 29. Cu drainage area diagram, including follow-up study for minus 80 mesh/wet sieving procedure.

dispersion from the small sub-economic veins rather than an anomaly produced by the major copper deposit initially postulated for the area.

Lead

As shown in Figure 30, lead follows the same dispersion pattern as Cu. Lead reaches 48 ppm near the polymetallic veins, with a contrast of four times background.

Mercury

Although detected in all follow-up samples, mercury does not show anomalous values and its dispersion pattern can not be directly related to the presence of epithermal veins (Figure 31).

Gold

Gold in the San Isidro Area is commonly present in concentrations below the analytical detection limit. However, erratic anomalous values do occur in several samples proximal to the known vein deposit (Figure 32).

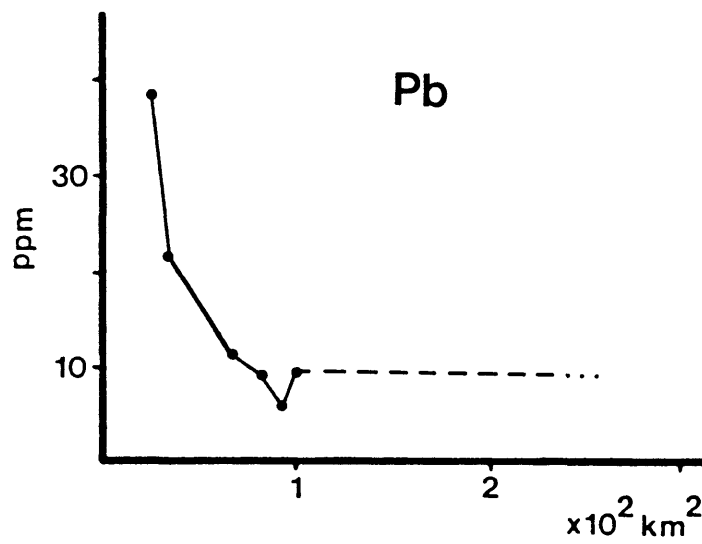


Figure 30. Pb drainage area diagram, from follow-up study for minus 80 mesh/wet sieving procedure.

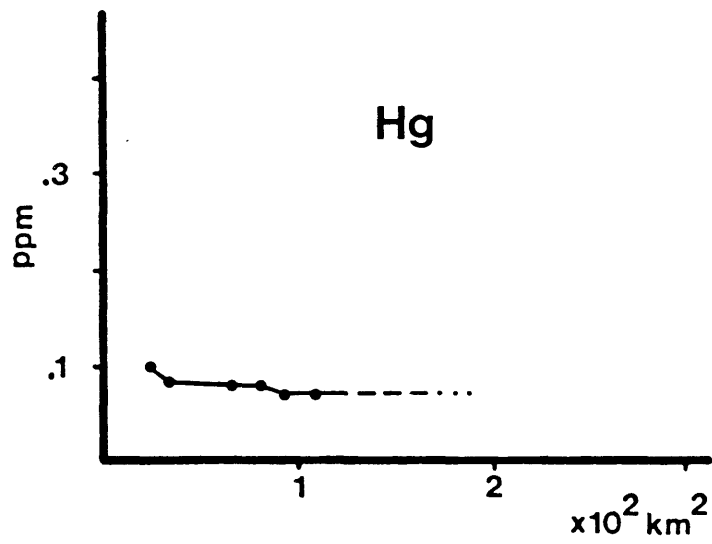


Figure 31. Hg drainage area diagram, from follow-up study for minus 80 mesh/wet sieving procedure.

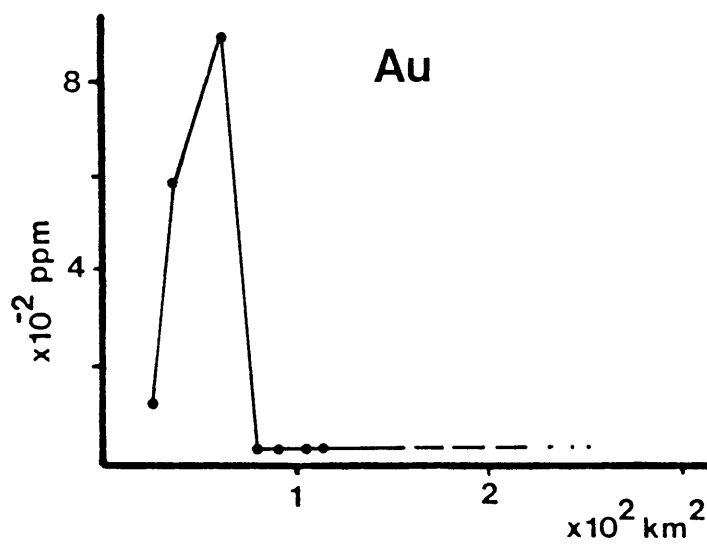


Figure 32. Au drainage area diagram, including follow-up study for minus 80 mesh/wet sieving procedure.

Silver

Silver values in the proximity of the polymetallic veins are definitely anomalous. Background values for Ag (A.A.) are usually below 0.10 ppm, with anomalous values reaching as high as 0.5 ppm (Figure 33). Silver values tend to mimic Pb values in the follow-up area (compare Figures 30 and 33). This geochemical association is frequently found in lead minerals, especially in galena.

Zirconium

Zirconium strongly correlates with Cu for the data in the initial stages of this study. However, statistical approaches in geochemical studies should always be interpreted in light of geologic and spatial relationships. Below the confluence of the Buenavista and Paramo rivers, Zr values mimicked Cu dispersion patterns (Figure 34). Above the confluence, Zr values suddenly drop as the Cu values continued to increase for samples upstream in the Buenavista River. However, the Zr dispersion pattern continues its ascending trend in the Paramo drainage. This indicates two different sources for Cu and Zr, whose dispersion patterns confluence in the same stream and are

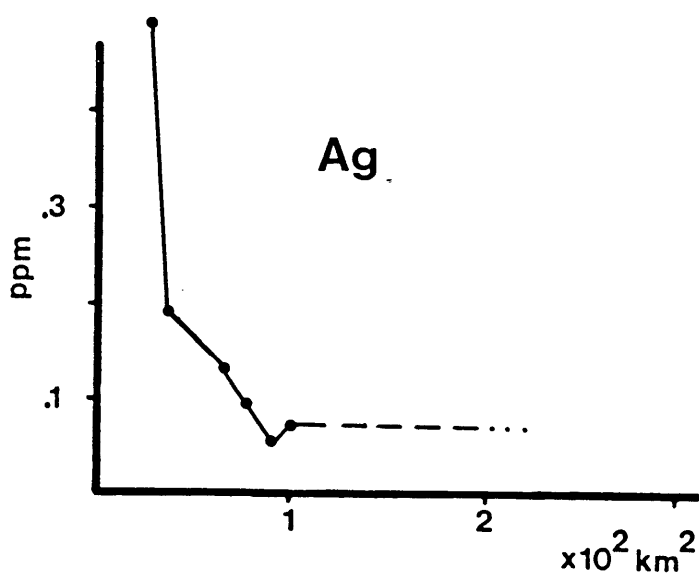


Figure 33. Ag drainage area diagram, from follow-up study for minus 80 mesh/wet sieving procedure.

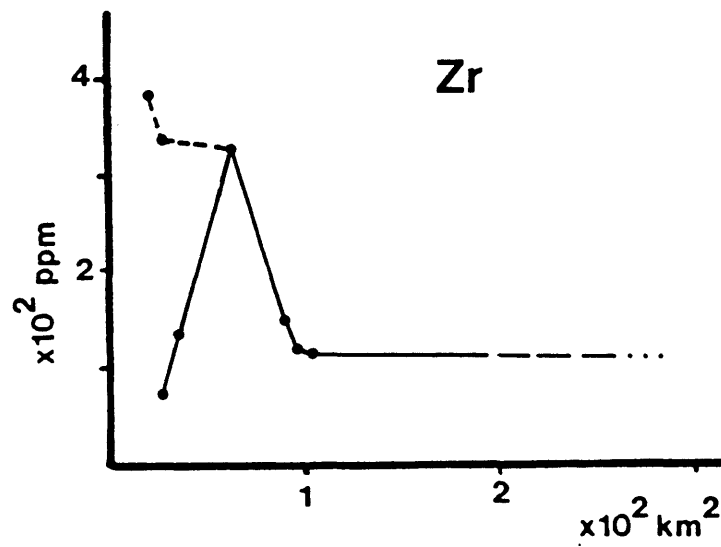


Figure 34. Zr drainage area diagram, including follow-up study results, for minus 80 mesh/wet sieving procedure. Dashed line on the left denotes Zr values in the Paramo drainage.

diluted down to background levels. The zirconium anomaly might be attributed to the existence of zircon rich rocks, perhaps felsic intrusives in the area (Figure 12).

DISCUSSION AND CONCLUSIONS

Analytical Data Quality

This study is based on analytical data obtained from three different analytical methods. The Los Alamos National Laboratory uses two highly sensitive, non-destructive analytical methods: instrumental neutron activation and X-ray fluorescence. Together, these two methods provide determination of 51 elements in stream sediment samples.

Instrumental neutron activation analysis provides reliable data for 30 (out of 46) major, minor, and trace elements. No any other analytical technique can provide such an enormous amount of reliable data. However, INAA has poor sensitivity for Mo, W, Ag and Hg, and low precision for Zn. These elements are considered important for the regional mineral assessment of Costa Rica and improvements in their data quality are necessary.

X-ray fluorescence provides reliable data only for Cu, As and Zr. Analytical problems in XRF are present for Bi, Cd, Nb, Ni, Sn, W, and Ag (poor sensitivity), and for Pb (low precision).

Specific atomic absorption analysis from a commercial laboratory are strongly recommended for ore and pathfinder elements such as Zn, Pb, Ag, Mo, and Hg. Because As data

from INAA is excellent and Cu data can also be obtained by atomic absorption, the XRF analyses might be omitted in the reconnaissance scale work.

Paired T-Tests Results

Most orientation survey studies involving stream sediments analyze several mesh fractions to determine the optimum grain size for sampling procedures. This study detected, through the use of paired T-tests, important elemental variations not only between size fractions but also between sieving procedures. There are some obvious, and some not so evident sources of variation between wet sieving in the field and dry sieving in the laboratory. An obvious variant, observed during the sample collection stage, is that there is an appreciable and inevitable loss of fine material (believed to be clays and organic material) during wet sieving that does not occur during dry sieving. Less obvious differences between the sieving procedures are given below: (1) Wet sieving under field conditions is less efficient than dry sieving in the laboratory, in terms of the amount of material recovered below the sieve. Simple laboratory experiments conducted by the author at Los Alamos, under simulated field conditions, demonstrated that more material (up to 2x) can be recovered under a dry sieve method than by a wet sieve technique. (2) However, it can be proven in the laboratory that very fine particles stick to the surface of coarser grains during the drying of the samples. Those particles

still adhered to the coarser material during the dry sieving procedures and do not pass through the dry mesh, whereas during wet sieving they are washed through the mesh.

Because two thirds of the data are not affected by differences between wet sieving in the field and conventional dry screening in the laboratory, wet sieving can be a reliable tool in reducing the weight of heavy samples, especially for remote areas. Particular enrichment of chalcophile elements in wet sieved samples and lithophile enrichment in dry sieving samples can be explained based on the author's observations under simulated conditions. It is the author's belief that, even when less material is proportionally recovered under wet sieving than under dry sieving, material recovered under the wet sieving is proportionally higher in heavy mineral content.

Correlation Analysis

Study of correlation coefficients from the Esparza and the San Isidro areas define several elemental associations. In the Esparza Area, seven major elemental groups are defined (Table 14). Each cluster of elements is interpreted as the result of a specific lithological geochemical factor (Table 15).

The chemical association Au-As-Ag-Sb with K-Rb-Cs is interpreted as the result of the hydrothermal process that causes both mineralization and hydrothermal alteration. Berger and Eimon (1983) define a similar elemental association in their hot spring model for epithermal precious metal deposits (Figure 35). Textural features of the Santa Clara gold deposit and the fact that neither Hg, Cu, Pb, or Zn are detected downstream (in anomalous concentrations) from the mine, might suggest a specific depositional/erosional level within the model. Further studies of this question are recommended.

The geochemical association U-Th-Zr is very strong in the Esparza Area, perhaps reflecting zircon mineralogy. The mafic association Fe-Ti-V-Cu-Cr-Co, and the Al-REE group are also clearly defined in the Esparza Area. These

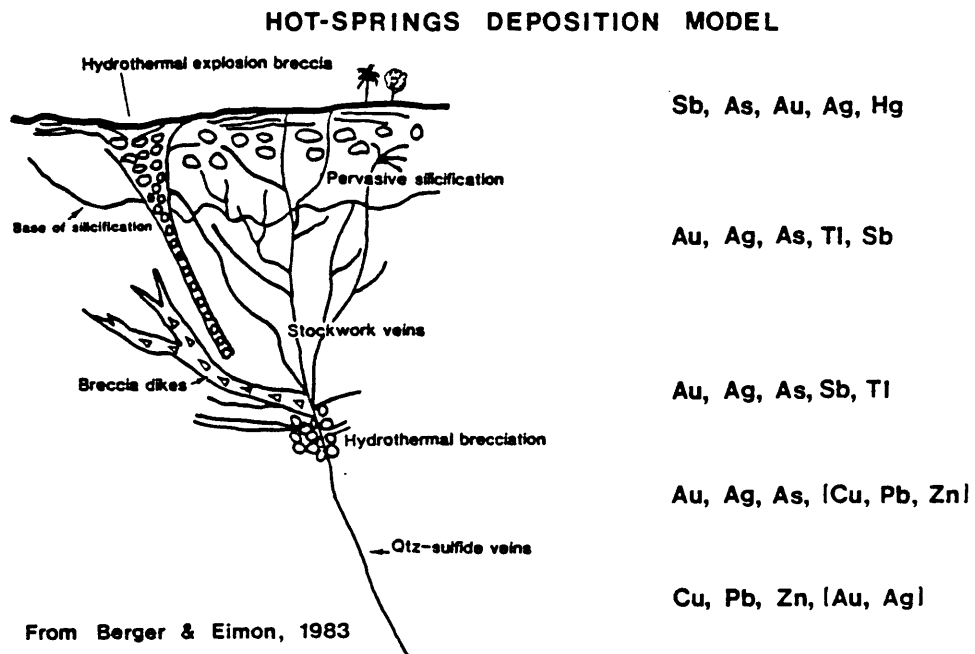


Figure 35. Hot-springs deposition model for precious metals (from Berger and Eimon, 1983).

three groups, together with the major elements Ca, Na, and Mg, reflect the influence of bedrock lithologies on stream sediments downstream from the Santa Clara Mine.

Copper, Au, Pb, and Ag from the San Isidro Area weakly outlined the presence of copper vein deposits. Zirconium, initially correlated with Cu, was recognized during follow-up studies to originate from a different spatial source. Correlation analysis in the San Isidro Area indicates that stream sediment geochemistry predominantly reflects the effect of bedrock geology while the contribution from mineralization is very weak.

On the overall study, correlation analysis proved to be an efficient tool in detecting those elements related to mineralization and, together with paired T-tests statistical studies, defined the elemental suite successfully used in the study of dispersion patterns in Costa Rican secondary environment.

Dispersion Patterns and Follow-up Study

A thorough study of dispersion patterns is the most reliable way to establish the proper sampling procedure and sampling density for the Los Alamos Project. Elements selected by statistical methods (paired T-tests and correlation analysis) give valuable data for the assessment of three size fractions (minus 40, minus 80, and minus 100) and two sieving procedures. The evaluation of dispersion characteristics, such as contrast, persistence and sample-site variability, contributed significantly to determine the optimum size fraction/sieving method combination, eliminating biased results arising from statistical studies alone. A thorough study of dispersion patterns indicates the minus 80 mesh wet sieving procedures provide the optimum data for detecting Au and Cu mineralization in the study areas. A second objective was achieved from the study of drainage area diagrams; the length of the dispersion patterns define the lowest required sampling density for detecting an anomaly produced by a mineral deposit. The optimum sampling density should maximize the probability of detecting a mineral deposit similar or larger than those studied in the orientation survey. Rose et al (1979) suggest "as a rule of thumb", that a reconnaissance scale survey should be designed so that the

presence of an important orebody will be indicated by at least two distinctive anomalous samples. The length of dispersion patterns in the studied areas range between 60 km² for Cu in San Isidro and 30 km² for K in Esparza. To maximize the probability of detecting mineral deposits with similar dispersion patterns, a sampling density between 30 and 20 km² is strongly recommended at the reconnaissance level.

Sample-site variations can compromise the effectiveness of the selected sampling density. It is a major objective of this thesis to help reduce to a minimum the sample-site variations detected in the orientation study (Table 17). One way to reduce the risks of missing anomalous patterns related to mineralization, because of a poor sample representivity, is to increase, perhaps double, the number of subsamples (scoops) per sample site initially selected for the wet sieving technique. This would result in 16 scoops per sample site.

Table 17. Percentage of sample-site variation (C.V.)
from triplicate analysis (W = wet sieving;
D = dry sieving)

Element	-40W	-40D	-80W	-80D	-100W	-100D
Au	103.4	67.8	51.8	103.4	46.3	101.3
As	15.3	14.8	14.2	25.5	23.9	14.9
Sb	13.7	8.8	14.8	23.5	27.7	18.1
K	27.7	10.7	17.6	8.7	15.2	7.3
Rb	114.5	67.6	108.8	47.8	87.4	65.9
Cs	46.6	21.5	34.3	33.1	46.3	16.1
Cu	7.0	8.2	5.7	7.6	6.7	7.1

SUMMARY AND RECOMMENDATIONS
FOR LOS ALAMOS PROJECT

This orientation study is based on the interpretation of analytical data for 51 chemical elements for 360 stream sediments samples collected using three different size fractions and two different sieving methods. Size fractions studied are the minus 40, minus 80, and minus 100 mesh. Although specific elements may be enriched in either finer or coarser fractions, the intermediate minus 80 mesh fraction is determined to be adequate for the reconnaissance project in Costa Rica.

Wet sieving in the field is compared to conventional dry sieving in the laboratory, for the above mentioned size fractions. Wet sieving by using simple equipment like plastic buckets and nylon screens proved to be as effective as dry sieving for two thirds of the studied elements. Further, wet sieving techniques actually enhanced anomalies of important ore indicators and pathfinder elements including Au, As, Sb, and Cu.

The combination minus 80 mesh and wet sieving proved to be the optimum sampling technique for stream sediment surveys in Costa Rican secondary dispersion environment. This combination provides high contrast, long dispersion trains and the lowest sample-site variability.

The study of dispersion patterns of selected elements indicates a sampling density of 1 sample/30 km² to 1 sample/20 km² is suitable for reconnaissance scale mineral evaluation. This sampling density should maximize the probability of detecting mineral deposits similar or larger than those studied in this orientation survey.

In the orientation study, elemental signature from two separate mineralized areas are thoroughly assessed. Anomalous dispersion patterns downstream from the Santa Clara gold mine, in the Esparza Area, are characterized by the association of Au, Ag, As, Sb, K, Rb, and Cs; the copper mineralization in the San Isidro Area is characterized by the geochemical association of Cu, Pb, Au, and Ag.

Data quality studies on analytical techniques demonstrate the efficiency of INAA. In most cases INAA provides acceptable results in terms of sensitivity and precision. Poor data sensitivity and precision were obtained for elements analyzed by XRF techniques. Atomic absorption analysis of selected elements provides satisfactory data. For the needs of the reconnaissance project, INAA and selected AA analyses are recommended.

RECOMMENDATIONS FOR FURTHER STUDY

This thesis was conducted in two separate areas in an effort to detect geochemical signatures from two different metallogenic provinces in slightly different physiographic regions. Small, local pilot studies are recommended for those regions of Costa Rica where other types of mineralization are expected (for example, podiform chromite) or in different climate regions (for example, drier areas of the Nicoya and Santa Elena peninsulas).

Wet sieving in the field proved to be an effective and useful tool for geochemical exploration in Costa Rica's tropical environments. From a logistical standpoint, wet sieving reduces the weight of stream sediments samples, and still ensures enough material for the chemical analysis. Also, it enhances the intensity and persistence of anomalous patterns for some indicator and pathfinder elements, perhaps because wet sieving increases the proportion of heavy minerals in the collected sample. Detailed investigations on wet sieving as an exploration tool and its effect on geochemical samples are highly recommended.

Studies on the effect of different bedrock lithologies on the overall background values for each one of the selected areas would be desirable.

The author believes that the similarity between geochemical signatures from the Santa Clara gold deposit, and elemental associations suggested by Berger and Eimon (1983) for their hot springs depositional model, is not just coincidence. Detailed geologic and geochemical studies of the Santa Clara gold deposit are necessary and mandatory in order to provide Costa Rica with the necessary information for the exploration for similar gold deposits within the country's gold belt.

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