# GEOLOGICAL AND GEOCHEMICAL RECONNAISSANCE IN THE CENTRAL SANTANDER MASSIF, DEPARTMENTS OF SANTANDER AND NORTE DE SANTANDER, COLOMBIA

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U. S. Geological Survey



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# GEOLOGICAL AND GEOCHEMICAL RECONNAISSANCE IN THE CENTRAL SANTANDER MASSIF, DEPARTMENTS OF SANTANDER AND NORTE DE SANTANDER, COLOMBIA

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## ABSTRACT

The central Santander Massif is composed of Precambrian Bucaramanga Gneiss and pre-Devonian Silgarå Formation intruded by Mesozoic quartz diorite, quartz monzonite, and alaskite and Cretaceous or younger porphyry. Triassic (Bocas Formation), Jurassic (Jordån and Girón Formations), and Cretaceous (Tambor, Rosa Blanca, Paja, Tablazo, Simití, La Luna, and Umir Formations) sedimentary rocks overlie the metamorphic rocks and are younger than most of the intrusions. A geological and geochemical reconnaissance of part of the central Santander Massif included the Vetas and California gold districts.

At Vetas the gold is generally in brecciated aphanitic quartz and phyllonite. Dark-gray material in the ore may be graphite. The ore veins follow steep west-northwest- and north-northeast-striking fracture zones. No new gold deposits were found. Additional geochemical studies should concentrate on western Loma Pozo del Rey and on improvement of the gold extraction process.

At California the gold is in pyritiferous quartz veins and quartz breccia. Ore containing black sooty material (graphite?) is highly radioactive. Some of the mineralization is post-Lower Cretaceous.

Soil samples indicate that gold deposits lie under the thick blanket of soil on the ridges above the zone of mining. Three principal gold targets are outlined by gold and associated minerals in pan concentrates. The close relation of gold and copper anomalies suggests that copper may be useful as a pathfinder for gold elsewhere in the region.

Based on occurrences of gold or high concentrations of pyrite or chalcopyrite in pan concentrates and on analytical data, eight potential gold targets are outlined in the central massif. Reconnaissance of the surrounding region is warranted.

## INTRODUCTION

This report describes geological and geochemical studies of 400 $km^2$ in the Eastern Cordillera of Colombia, in the Departments of Santander and Norte de Santander (fig. 1). The study area (quadrangles 98-III-C, 110-I-A, and 110-I-C) is located in Zone III, the Bucaramanga region, and includes the gold districts of California and Vetas. Investigations carried out between October 197[illegible] and September 1973 dealt mainly with the two gold districts located in quadrangle 110-I-C. Reconnaissance studies of the crystalline rocks of the three quadrangles were partially completed.

The investigations described in this report were made by the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS) in collaboration with the U.S. Geological Survey. Several geologists from INGEOMINAS participated with the author in these studies: Jorge Mejia, Hernando Mendoza, Jaime Reyes, and Alonso Otero. Analyses were performed by the Subdireccion Investigaciones Químicas of INGEOMINAS, under the direction of Roberto Gaitán. The work was financed by the Government of Colombia

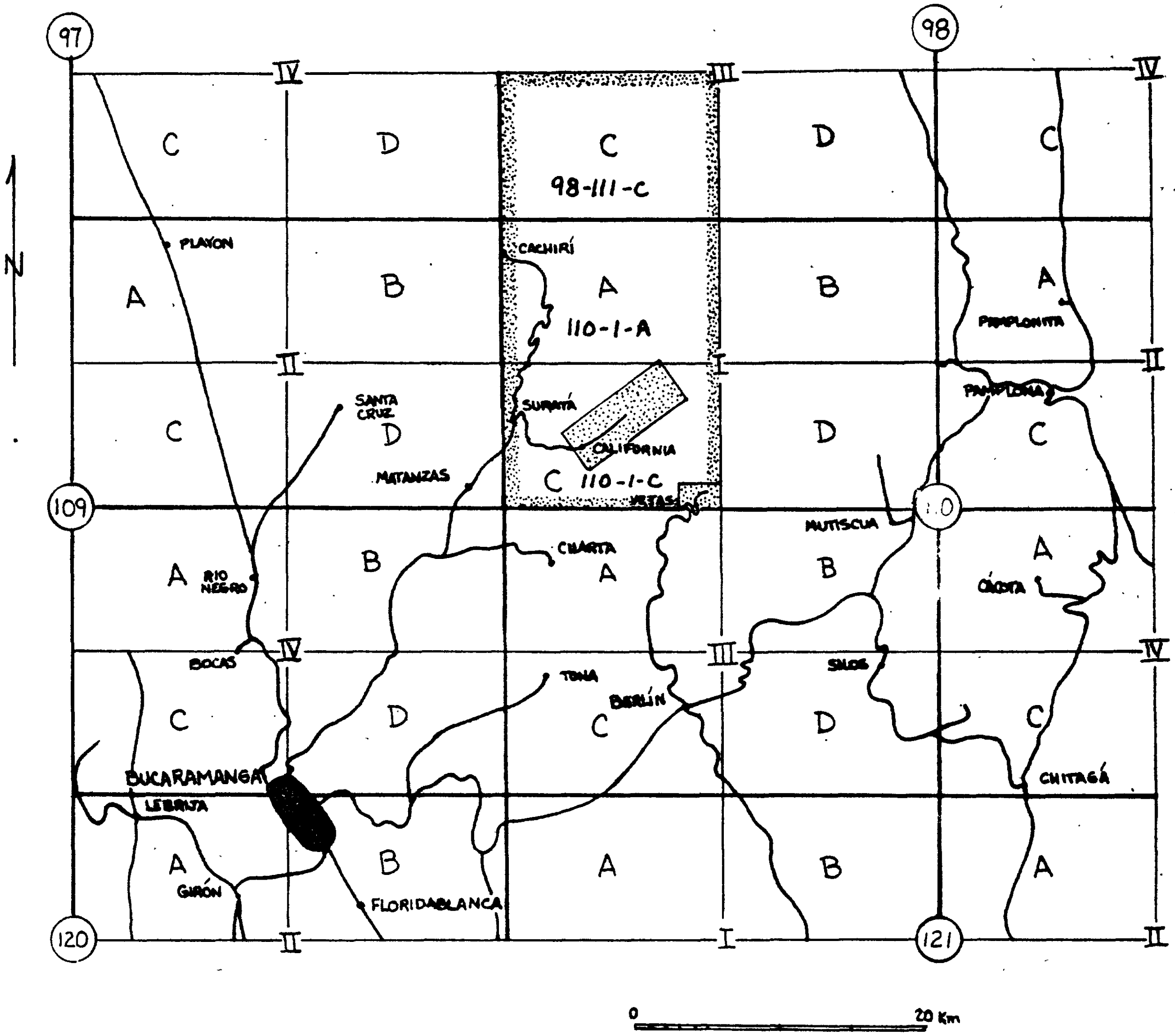


Figure 1. Index map showing location of the California and Vetas District, and quadrangles 98-III-c, 110-I-a, and 110-I-c , Colombia.

and the Agency for International Development, U.S. Department of State.

M. R. Brock, J. H. McCarthy, and H. V. Almimas, all members of the U.S.G.S., visited the writer in the field and shared their views on the geology and geochemistry of the area.

## Historical sketch and project outline

Metalliferous deposits have been explored in the central Santander Massif northeast of Bucaramanga since at least the middle 1500's (Wokittel, 1954). Primary interest has centered on the California and Vetas districts, which may have been the source of gold for many pre-Colombian artifacts (Duarte, 1966, p. 12). Geological investigations in these areas have been carried out only recently, for example, Bueno, 1955a, b; Duarte, 1966; Wokittel, 1954; Pagnacco, 1962; Ward and others, 1969, 1970, 1971.

The studies of Ward and others (1971) of the mineral deposits of the southern half of Zone III (Bucaramanga region) and their geologic maps of quadrangles H-12 and H-13 (scale 1:100,000; 1969, 1970) constitute the most important syntheses of regional geology and of knowledge of mineral deposits in the massif and adjoining regions. According to Ward and others (1971) the future potential of the gold districts of California and Vetas was dependent on an increase of the price of gold and consolidation of the small workings.

Recent (1972) gold and silver analyses of pan concentrates collected by geologists of INGEOMINAS from 600 $km^2$ of the central Santander Massif, including the California and Vetas districts, showed anomalous amounts of these two metals.

The suggestion of widespread gold mineralization in the massif coupled with the doubling of the price of gold on the international market in the fall of 1972 seemed to justify a reevaluation of the two gold districts as well as a geological and geochemical reconnaissance of the massif outside of the active mining areas.

This new study was to concentrate on a critical evaluation of the earlier geologic mapping, the gathering of more structural date related to the ore occurrences, the sampling of altered and mineralized rock between the known ore occurrences and stream sediment sampling. In addition, the causes for the estimated 30 to 40 percent loss of gold during the extraction process were to be investigated along with the prospects that a large low-grade deposit amenable to open-pit methods might be present in the gold districts or elsewhere in the study area.

This report describes the geology of the Vetas and California districts in detail, as these areas are the best known in the massif, and discusses other indications of mineralization in quadrangles 98-III-C, 110-I-A, and 110-1-C.

## General geology

Quadrangles 98-III-C, 110-I-A, and 110-I-C are underlain by rocks ranging in age from Precambrian to Upper Cretaceous, and possibly Tertiary (see fig. 2). The Precambrian Bucaramanga Gneiss (biotite gneiss containing zones of biotite schist, quartzo-feldspathic schist, and amphibolite) is believed to be overlain by the pre-Devonian Silgará Formation (silvery gray-green phyllite), although the nature of the contact between the two formations is not clear. The metamorphic rocks were intruded during the Triassic and Jurassic by massive pink to gray quartz monzonite and granodiorite and subordinate granite and quartz diorite. Disconformably overlying the crystalline rocks of the massif are Jurassic redbeds consisting of siltstone and conglomerate of the Jordán and Girón Formations, respectively, and locally, black shale of the Bocas Formation (Triassic ?). Block-faulting, uplift, and erosion occurred between deposition of the Girón Formation and a marine transgression in the Early Cretaceous, when the massif was covered by a miogeosynclinal sequence of sedimentary strata of variable thickness (on the order of several hundred meters in the central massif). Minor porphyry was intruded in the Cretaceous or Tertiary in the vicinity of California. The latest uplift began in late Tertiary, continued into Holocene, and was accompanied by much high-angle and thrust faulting.

VETAS DISTRICT

## Location and geological summary

The Vetas district (6 $km^2$; altitude 2,900-3,900 m) is 85 km by road northeast of the city of Bucaramanga. It is underlain principally by gneiss, schist, and amphibolite of the Precambrian Bucaramanga Gneiss (figs. 3, 4). These complexly deformed high-grade metamorphic rocks are intruded by quartz monzonite and quartz-rich alaskite ranging in composition from granodiorite to granite. The ages of the intrusive rocks are not known, but they are similar in composition to intrusions elsewhere in the massif which have been dated radiometrically as Jura-Triassic. About a third of the district is covered by Holocene deposits.

## Descriptions of the rocks

### Bucaramanga Gneiss

Bucaramanga Gneiss is divided into four map units: gneiss, biotite schist, quartzo-feldspathic schist, and migmatite. The gneiss is chiefly in the eastern half of the district, and the schists in the western half; minor amphibolite zones are present in the gneiss and biotite schist. Of the four map units, the gneiss seems to be the least resistent to weathering. However, the effects of differences in microclimate and in degree of alteration across the district are more important than lithology in determining erosional resistance.

### Migmatite

Zones of migmatite composed of Bucaramanga Gneiss, alaskite, and quartz monzonite occur on the periphery of the Mesozoic stocks described below. Most ot the igneous traction ot the migmatite resembles the alaskite. Quartz veins are common with in the migmatite.

The chief constituents of the fine- to medium-grained gneiss are quartz (20-30 percent), plagioclase (An $_{30-55}$) (40-50 percent), and biotite (5-15 percent). Potassium feldspar (25 percent max.), hornblende (10 percent max.), and epidote (10 percent max.) are locally abundant. Apatite, magnetite, pyrite, sphene, and zircon are generally present as accessory minerals. Allanite and muscovite are less common accessories. In places, especially on western Pozo del Rey Ridge, the plagioclase is much altered to sericite and clays, and the mafic minerals to chlorite.

Gneissic rocks in the schist are generally quartz-rich (35-75 percent) and locally contain abundant potassium feldspar (40 percent max.), biotite (10 percent max.), muscovite (10 percent max.), and iron oxides.

The generally fine to medium-grained biotite schist consists principally of quartz (generally 30-45 percent), biotite partly altered to chlorite (15-65 percent), muscovite-sericite (10-30 percent), and locally, albite-oligoclase (10 percent max.), and sillimanite (5-10 percent). Cordierite, garnet, magnetite, pyrite in veins, and zircon are also present.

The quartzo-feldspathic schist contains as much as 60 percent quartz, 10-40 percent muscovite, and up to 25 percent sericite altered from plagioclase, little of which remains. Potassium feldspar, in veins, comprises as much as 30 percent of the rock. Pyrite and chlorite each comprise as much as 10 percent of the schist. Epidote, iron oxides, and zircon are also present. Sulfur crystals are locally abundant in cavities.

Amphibolite zones in the gneiss consist chiefly of plagioclase ($An_{40-55}$) (30 percent), hornblende (30-45 percent), biotite (5-30 percent), and quartz (15 percent max.). The amphibolite in the schist has a similar composition, but the plagioclase grains have albitic rims.

The andesine-labradorite-bearing mineral assemblages in the gneiss and amphibolite and the presence of sillimanite in parts of the schist indicate that metamorphism in the Bucaramanga Gneiss attained at least the almadine-amphibolite facies (Turner and Verhoogen 1960, p. 544-553). Retrogressive metamorphism also occurred, as some minerals (albite, chlorite) more characteristic of the greenschist facies are present (Turner and Verhoogen 1960, p. 533-541). The low-grade metamorphic mineral assemblages (quartz-chlorite, muscovite-sericite) prevalent in the quartzo-feldspathic schist seem to be related to potassic alteration.

Relict myrmekitic textures identified in samples from the gneiss unit suggest that these gneisses were originally igneous rocks in which compositions range from quartz diorite to quartz monzonite. The schists, however, with their high content of alumina and silica are more likely to have been sedimentary rocks. The contact between the schist and the gneiss shown on figure 3 was probably originally an intrusive one.

A radiometric age date of 945±40 m.y. (hornblende gneiss) indicates that at least part of the Bucaramanga Gneiss is Precambrian (Goldsmith and others, 1971). In this report the gneiss is assigned to the Precambrian.

## Alaskite

The pale grayish white, fine-to medium-grained (grains 1.5 mm max) alaskite is generally poorly exposed in a zone around the quartz monzonite on Loma Pozo del Rey and near the northwest corner of the district. The latter body is part of an alaskite stock that extends about 3 km to the west of the district along the Rio Vetas (fig. 3). Numerous dikes of alaskite intrude the Bucaramanga Gneiss and are especially common in the migmatite. Some of the isolated alaskite dikes in the gneiss and schist are shown on the geologic map.

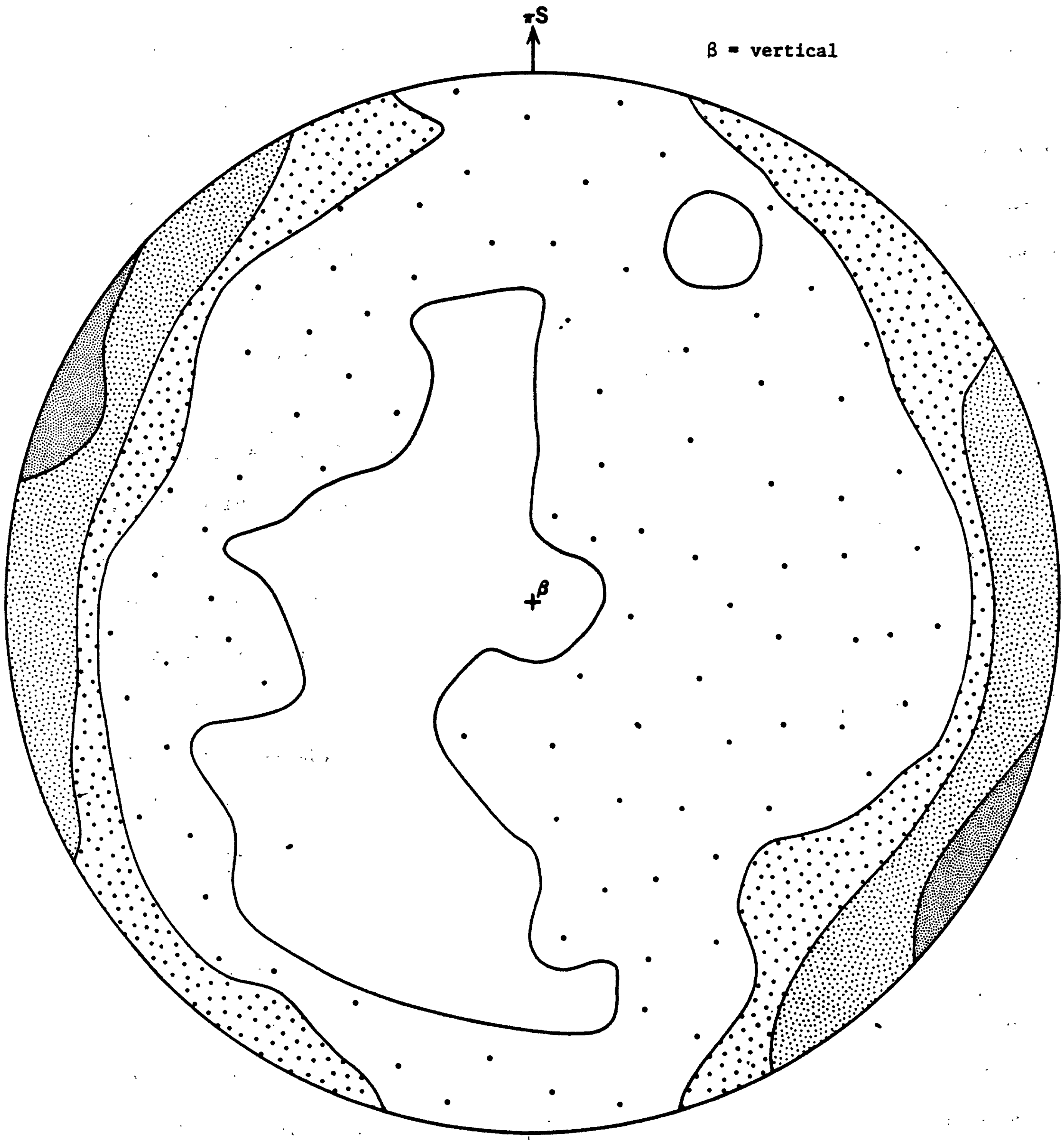


Figure 5. 96 poles to foliation in gneiss, Vetas District.
Contours, 2σ, 4σ, 8σ, and pole-free area.

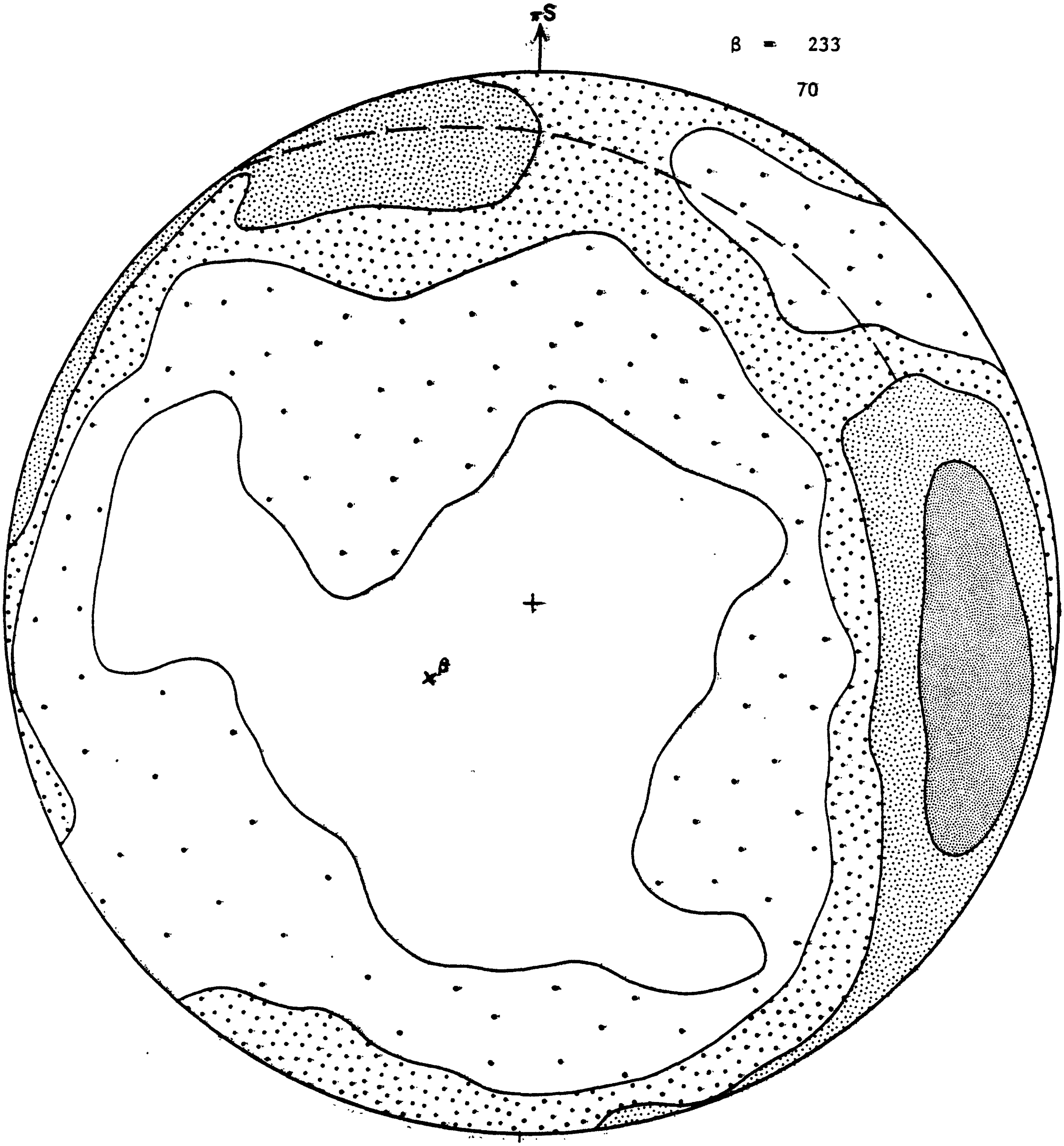


Figure 6. 125 poles to foliation in schist, Vetas District. Contours, 2σ, 4σ, 8σ, and pole-free area.

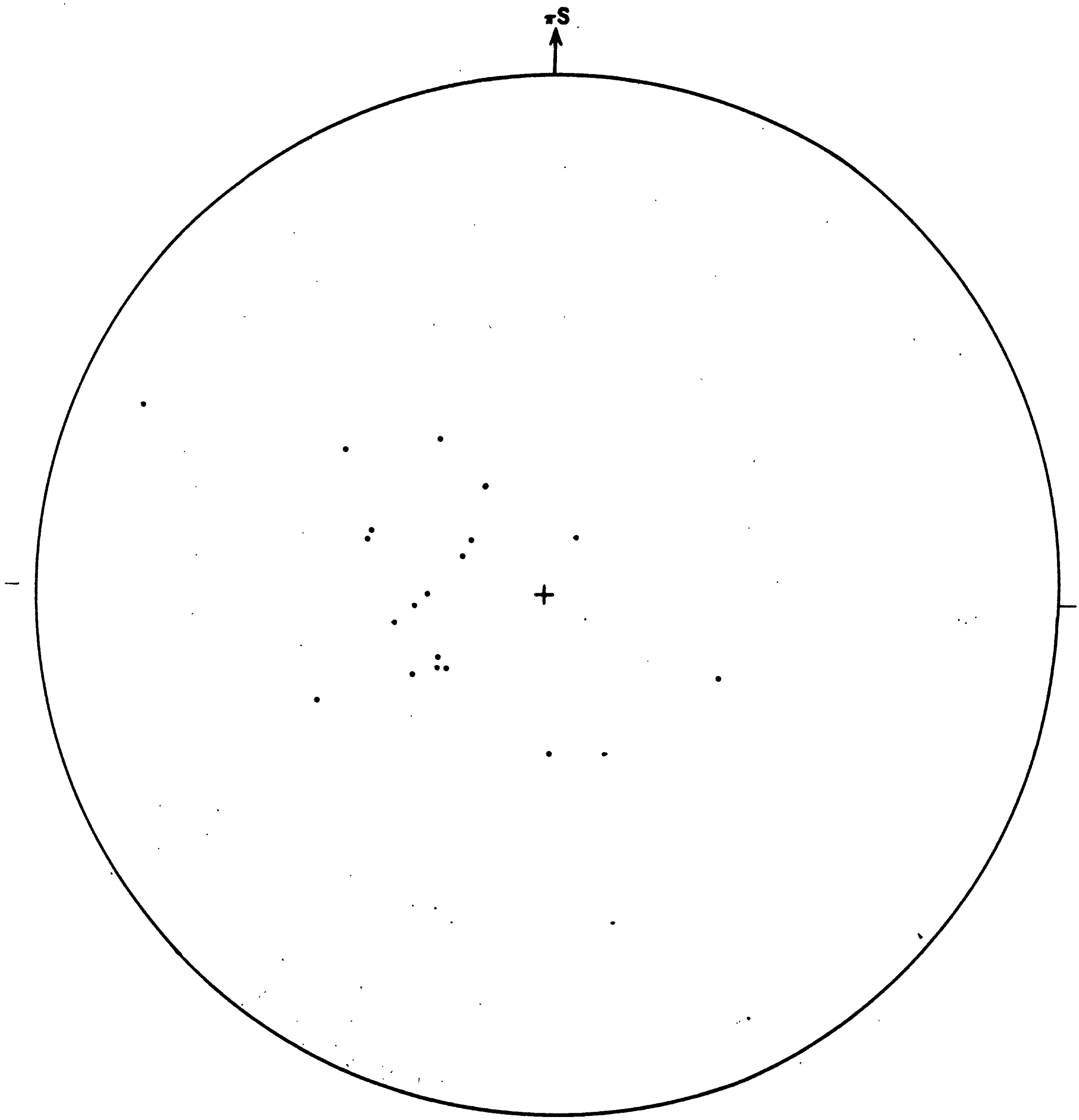


Figure 7. 19 minor fold axes in biotite schist, Vetas District.

The alaskite varies widely in composition: 15-50 percent quartz; 10-65 percent plagioclase ($An_{20-35}$); 10-60 percent potassium feldspar. Biotite (5 percent max), hornblende (5 percent max), and muscovite (10 percent max) are minor constituents. Apatite, clinozoisite, garnet, magnetite, pyrite, sphene, and zircon are accessories. Minor amounts of chlorite, hematite, and sericite in the rock are the result of alteration of the mafic minerals and plagioclase. Micrographic texture is present locally.

The alaskite unit includes a wide range of superficially similar rocks varying in composition from granodiorite to granite. Their ages are not known, but they coincide with the intrusive rocks designated Jura-Trias by Ward and others (1971, fig. 5) on the basis of their compositional similarity to radiometrically dated Jura-Trias intrusions in the massif. This age assignment is accepted here.

## Quartz monzonite

The medium- to coarse-grained light-gray and white speckled quartz monzonite and quartz monzonite porphyry occur as dikes and small stocks, generally poorly exposed. The largest one, predominantly porphyritic, is on Pozo del Rey Ridge 3/4 km northeast of Vetas. This stock is exceptionally well exposed along the ridge line and on the west flank of the ridge where hydraulic mining was done. Part of another stock of unknown size is exposed 1/4 km southwest of Vetas (near the edge of the geologic map fig. 4). Several quartz monzonite porphyry dikes a few meters wide are also present in the gneiss and schist. One quartz monsonite dike 10 meters wide is mapped near the mine, La Elsi, northwest of Vetas.

The rock is composed mostly of quartz (15-35 percent), plagioclase ($An_{25-40}$) (25-40 percent), potassium feldspar (15-35 percent), and as much as 15 percent biotite. Apatite, garnet, magnetite, muscovite, pyrite, and zircon are also present. The rock is locally much altered, expecially on western Loma Pozo del Rey; plagioclase is replaced by sericite, biotite is replaced by chlorite, and hematitic and argillic alteration are extensive.

Proportions of phenocrysts to groundmass in the porphyritic phases vary from 1:5 to 3:2. The phenocrysts are as much as 1 1/2 cm across. In places the plagioclase phenocrysts are partly saussuritized.

Most samples collected from this unit are quartz monzonite; a few of them are granodiorite. Two lines of evidence suggest that the quartz monzonite may be related to the alaskite: (1) the ranges of composition of the two units overlap; (2) on Loma Pozo del Rey the zone of fine-grained alaskite surrounds the coarser-grained porphyritic quartz monzonite. On Loma Pozo del Rey at least, the alaskite may be the chilled margin of the quartz monzonite stock. The quartz monzonite was designated as Jura-Trias by Ward and others (1971, fig. 5), and is so designated here.

## Holocene deposits

Possibly as much as 30 percent of the Vetas District is covered by Holocene deposits--mostly stream gravels and terraces, fanglomerate, and landslide debris. A glacial lateral moraine occurs along the southeast side of Q. El Salado.

Structure

The oldest structural feature in the district is the foliation in the Bucaramanga Gneiss. The foliation consists chiefly of compositional banding in the gneiss and preferred orientation of mica in the schist. Generally it is vertical or steeply dipping. It strikes mainly northeast in the gneiss and north in the schist. In detail, however, the foliation in both the gneiss and the schist outline narrow girdles about a vertical (gneiss) or steeply plunging ($70^{\circ}$ SW, schist) axis, $\pi S$ (figs. 5, 6). Minor folds in the schist are tight "similar" folds. Most of them plunge steeply to the west and southwest, close to the $\pi S$ axis in the schist (fig. 7). This relationship suggests that the schist contains macroscopic folds which plunge steeply or are vertical, and that $\pi S$ is equivalent to $\beta$. Similarly, the gneiss, with its $\pi S$ axis subparallel to the one in the schist, probably also contains vertically plunging macroscopic folds (and $\pi S = \beta$). Over the district as a whole the minor folds and the $\pi S$ or $\beta$ axes seem moderately homogeneous.

A few minor fold axes diverge widely from near parallelism with the $\beta$ axes, but the significance of this difference is not clear from the scanty structural data.

The Precambrian and Mesozoic rocks have been much faulted along vertical and steeply dipping fault zones, some of which are breccia zones as much as 5 m wide. No pre-Mesozoic faulting has been positively identified. Post-Jurassic faulting is common, or at least obvious, and is best developed in the north and west parts of the district where several north-trending faults and a steeply dipping northwest-trending fault are truncated by the fault zone along Quebrada El Volcan.

A prominent joint set dipping $30^\circ$-$60^\circ$ northeast and north-northeast is present on Loma Pozo del Rey and to the east of the ridge, but is not developed in the western part of the district. A zone 400m wide of closely spaced quartz veins which dip parallel or subparallel to these joints occurs in the quartz monzonite, alaskite, and schist along the crest of Loma Pozo del Rey.

## Description of the ore deposits

Most of the gold is in white to dark-gray brecciated aphanitic quartz vein material and light to dark-gray and greenish-gray phyllonite. The dark-gray coloring is due to a sooty material which may be, at least in part, graphite, although the material has not yet been positively identified.[1] Less commonly the gold is found in pyritiferous gneiss and porphyry. Several minerals are associated with the gold. Pyrite and chalcopyrite are very common in and near the ore zones. In the high-grade ore they occur as fine grains less than 1 mm across. In other rocks the pyrite with minor chalcopyrite, much of it coarser then 1 mm, fills fractures and comprises veins as much as 2 cm thick, within medium-to coarse-grained gray- and white-banded quartz veins. Other minerals are less common, such as: blue fluorite, white and clear barite, and sphalerite at the Volcan Mine; molybdenite (?) said to have been collected near the Volcan Mine from a vein in the headwall of the Quebrada Reina de Oro canyon in which the mine is located; and wire silver and proustite (?) at the San Bartolo Mine.

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[1] Two samples of the sooty ore, analyzed in the Denver laboratory of the U.S. Geological Survey, contained 0.5 percent and 6.1 percent, respectively, carbon. Both mercury and gold were more abundant in the sample containing more carbon (1.5 vs. 8 ppm Hg; 26 vs. 300 ppm Au).

Structural controls appear to be very important in localization of the ore deposits. Most of the tunnels shown on the geologic map (fig. 4) were excavated along the ore zones and, therefore, the trends of the tunnels show that the general trends of the ore veins are (1) west northwest, and (2) north northeast. The west-northwest-trending group includes the San Bartolo, Tosca, and El Arco Mines, the workings of which follow breccia zones with quartz veins. These zones are subparallel to faults mapped in the area. The north-northeast-trending mineralized zones at La Elsi, Trompeteros and La Colombo are subparallel to the foliation in the gneiss and to minor fault zones which are subparallel to the foliation. In the vicinity of the Volcan Mine, the north-northeast-trending tunnels and trenches are along fault zones mapped in the schist.

## Element distribution

The concentrations of gold, silver, molybdenum, copper, barium, arsenic, zinc, lead, and manganese from rock (selected and channel samples), stream sediment samples and panned concentrates are plotted in figures 8-15. Gold analyses were done by atomic absorption methods. The other elements were analyzed spectrographically. All analytical work was done at the INGEOMINAS Laboratory in Bogota.2/

### Gold

Most of the rock samples containing anomalous gold values ($\geq$0.5 ppm) are from localities in or near active mines or old excavations (fig. 8).

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2/Complete analytical data on which fig. 8-15 are based, was not available to the author, hence a more detailed and meaningful description of the element distribution cannot be presented.

Anomalous gold concentrations were also found at two localities not closely associated with mining: on Pozo del Rey Ridge 1 km east of Vetas (between 0.5 and 1 ppm) and at a site 300 m northeast of Pozo del Rey (≥20ppm). Several other gold-rich samples were taken from the altered zone exposed along the Vetas-Volcan road. These selected rock samples were located: (1) 50 m south of Cañaverales (between 1 and 5 ppm), 250 m northeast of the Arco mineralized zone (≥20ppm); (2) 100 m west of the Monumento de la Virgen and 100 m northeast of Cañaverales (both samples between 0.5 and 1 ppm).

Gold in anomalous amounts was also found in stream sediment samples. Between 1 and 5 ppm gold occurs in fine sediment from an unnamed stream west of and subparallel to Quebrada de Vetas and in several seasonal creeks of western Loma Pozo del Rey. Most of the pan concentrates were of insufficient weight for atomic absorption analysis; one of them, however, from a stream draining the Cañaverales-Buenavista area, contained ≥20 ppm gold. Other pan concentr tes taken from the same area contained from 1 to 5 fine-sand-sized grains of gold (microscopic examination). The other high gold concentrations in stream sediment from within the district in Quebrada de Vetas, Quebrada San Antonio, and Quebrada El Volcan result from recent mining activity, and reflect the high gold loss during the recovery process.

Both rock and stream sediment samples from the altered zone on the western slope of the Pozo del Rey Ridge, especially in the Cañaverales-Buenavista area, contain anomalous amounts of gold. These results are consistent with the fact that the western slope was formerly the site of hydraulic mining of the intensely altered rock. However, samples from some of the old workings still contain significant concentrations of gold (≥20 ppm in a rock at a site 250 m west of Pozo del Rey). The San Bartolo Mine is the only active mine on the western slope of the ridge.

## Silver

Silver, like gold, is highest in samples taken in or near mines (fig. 9). High concentrations of silver are found in rocks along the Vetas-Volcan road, 250 m northeast of the Arco mineralized zone (≥100ppm), and in sediments from streams draining the western slope of the Pozo del Rey Ridge. A pan concentrate from a drainage on the northeast flank of the ridge, (south of El Paraiso) contained between 10 and 30 ppm silver. No mining is known to have taken place upstream from the sample site, but a rock sample containing ≥20ppm Au was taken from the same basin.

## Molybdenum

Molybdenum is generally present in amounts less than 50 ppm in the rocks of the district (fig. 10). In the vicinity of the Volcan Mine several samples contained between 100 and 500 ppm Mo. High values(locally to ≥500 ppm)were determined in samples selected from the altered zone along the Vetas-Volcan road. The highest values are near San Bartolo Mine and at localitites 200 m northeast and 75 m south of Cañaverales. The high molybdenum concentrations from the altered rocks along the road and from rocks in the mineralized area around the Volcan Mine may be coincidental. However, a geographical correlation of high molybdenum and high gold may exist, and molybdenum might be used as a pathfinder for gold in the massif.

## Copper

Between 100 and 500 ppm copper are commonly found in the rocks throughout the district (fig. 11). Higher copper concentrations are rarely found. The copper concentrations in the stream sediments in the area are of the same order of magnitude and probably reflect these rock values.

## Barium

Concentrations of barium $\geq$500 ppm are relatively common in the rocks (fig. 12). Higher concentrations occur locally in the altered rocks in the western third of the district. The fine stream sediments contain concentrations of about the same order of magnitude as the rocks. The pan concentrate containing the highest amount of barium (also barite-rich) was taken 250 m west of Falda Grande, from a stream which drains the relatively gold-rich basin 250 m northeast of the Arco mineralized zone.

## Arsenic and zinc

Arsenic and zinc are present in detectable amounts (>200 ppm) at or close to mines (fig. 13). Arsenic also occurs in rocks from a few sites near the crest of Loma Pozo del Rey.

## Lead

Concentrations of lead are generally low (<50 ppm) over the eastern half of the district and locally somewhat higher in the western half (fig. 14).

## Manganese

Relatively high ($\geq$1000 ppm) concentrations of manganese are much more common in rocks in the western half of the district than in the eastern half (fig. 15). This variation may be due to lithological differences.

Exceptionally high manganese values (>5000 ppm) occur in the rocks at or near mines. The pan concentrate taken south of El Paraiso contained >5000 ppm manganese, an anomalous amount of silver, and >20 ppm Au. The sample was taken from an unexploited basin.

## General conclusions and suggestions

The location of economic mineralization in the Vetas District is strongly controlled by faults. As no new mineralized breccia zones have been uncovered, the discovery of new deposits in the district does not seem likely. However, additional geochemical studies might be used to look for more subtle anomalies that could indicate mineralization below the relatively barren surficial rock.

The broad zone of alteration on the west side of Loma Pozo del Rey should be studied more closely with regard to its potential for a large low-grade gold deposit (fig. 3). Although this zone was exploited for many years, only the upper 25 m or less of the rock was removed and, locally, tunneling has penetrated somewhat deeper along high-grade veins in the rock. The anomalous amounts of gold in stream sediments derived from these altered rocks can be viewed either as contamination from the old workings or as indications that significant amounts of gold may still be available for extraction by modern methods.

Additional studies in the Vetas District should include drilling of several holes below the weathered surface of the altered zone exposed along the Vetas-Volcan road. Some holes should definitely be collared in the Cañaverales-Buenavista area, where anomalous gold concentrations were encountered. The holes need not be deeper than 100 m (although a few deeper holes are recommended), as low-grade gold ore must be near the surface to be economically extractable.

## Gold recovery

At Vetas the gold is recovered in two main steps: (1) crushed ore is sluiced and panned for visible gold; (2) the ore, crushed to sand-sized grains, is placed in cyanide percolation tanks and the gold is precipitated from the cyanide solution. An estimated 60-70 percent of the gold is recovered in this way.[3/]

Although the recovery process itself could be improved, the chemistry of the ore should also be studied to determine whether cyanicides are present in high concentration in the ore. Some of the elements that reduce the effectiveness of the cyanide extraction process, such as Cu, As, and Sb are present in the ore, but not in exceptionally high concentrations. However, carbon, another cyanicide, is present in the ore in amounts as high as 6 percent. The carbon content of the ores should be examined further in order to determine the role of carbon in the gold extraction. Perhaps different recovery methods would be more efficient at Vetas.

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[3/] At the Volcan Mine the mill tailings were saved in hopes of finding a way of recovering the gold that they contain. As of 1969 the 90,000 tons of sandy and finer tailings gave assay values of 26 g/ton Au and 44 g/ton Ag for the muds and 18 g/ton Au and 38 g/ton Ag for the sands (Ward and others, 1971, p. 39). Attempts in 1972 and 1973 to concentrate the gold-bearing pyrite (300 ppm Au) and reprocess it failed to recover additional gold.

Dark-gray mud washing down Q. El Volcan from the mill and tailings pile assays 52 ppm Au and 132 ppm Ag at a site 300 m west of the tailings pile. A sand sample from the dump at the San Bartolo Mine contained 33 ppm Au and 14 ppm Ag.

Bueno (1966, p. 57) and Duarte (<u>in</u> publications of Univ. Industrial de Santander) have suggested that the ore be roasted before cyanide extraction. Adoption of this method will require: (1) consolidation of the ore from several small workings in order to make a roasting plant economically feasible; (2) disposal of poisonous sulfurous wastes that must either be safely dissipated in the atmosphere or converted to sulfuric acid as a by-product.

At the Carlin Gold Mine, Nevada, U.S.A., chlorination of the high carbon gold ore neutralizes the effect of the carbon in the cyanide extraction process. Application of this technique to the Vetas ores may be helpful.

## CALIFORNIA DISTRICT

### Location and geologic summary

The California District (24 $km^2$; altitude 1950-3500 m) takes its name from the town of California, 55 km by road northeast of Bucaramanga (fig. 3). The district is underlain chiefly by igneous and metamorphic rocks, poorly exposed except within a few hundred meters of the main canyon bottoms (Quebradas La Baja, Angostura, and Páex). The metamorphic rocks, probably Bucaramanga Gneiss, host many small dikes, and for this reason are mapped as migmatite. Quartz monzonite underlies more than half the district and contains xenoliths of quartz diorite. The Lower Cretaceous Tambor Formation (sandstone) and Rosa Blanca Formation (limestone) overlie these crystalline rocks disconformably. Porphyry dikes intruded the cyrstalline rocks of the massif and the Tambor Formation.

## Description of rock units

### Migmatite

The metamorphic fraction of the migmatite is chiefly medium-grained banded gneiss. Its major constituents are quartz (15-20 percent), albite-oligoclase (45-60 percent), potassium feldspar (20 percent max), and biotite (10-25 percent). Locally hornblende is an important constituent (10 percent). Allanite, apatite, ilmenite, magnetite, muscovite, pyrite, sphene, and zircon are accessories. Epidote occurs in veinlets and as discrete grains disseminated in the gneiss.

The gneiss is dioritic to granodioritic in composition, somewhat more mafic than the gneiss in the Vetas District. Here, as at Vetas, the gneiss probably was metamorphosed in the almandine amphibolite facies before undergoing retrogressive metamorphism. The gneiss at California is most likely part of the Bucaramanga Gneiss and, so, is assigned a Precambrian age. The dikes in the migmatite are quartz diorite and quartz monzonite which are described below.

### Quartz diorite

The massive medium-grained quartz diorite occurs as irregularly shaped xenoliths within the quartz monzonite and as dikes in the migmatite. One quartz diorite body in the district is part of a large stock that lies southeast of California (fig. 3).

The principal constituents are quartz (10-15 percent), plagioclase, $An_{30-40}$ (40-60 percent), biotite (45 percent max), and hornblende (15 percent max). Allanite, apatite, chalcopyrite, epidote, ilmenite, magnetite, potassium feldspar, pyrite, sphene, and zircon are accessories.

The quartz diorite is commonly intruded by quartz monzonite dikes, and so is the older of the two igneous rocks. Ward and others (1970, fig. 4) have assigned the quartz diorite to the Triassic. This age designation is accepted here.

## Quartz monzonite

The quartz monzonite stock, which underlies about 50 percent of the district, includes leucocratic, fine- to medium-grained rocks, generally poor in mafic minerals. Thin-section examination indicates that the stock includes both quartz monzonite and granodiorite phases.

The quartz monzonite phase consists chiefly of quartz (15 percent), plagioclase, $An_{10}$ (30-50 percent), and potassium feldspar (30-45 percent). Muscovite is abundant in many samples (10 percent max), and biotite is a minor constituent (5 percent). Apatite, epidote, magnetite, sphene, and zircon are accessories. The granodiorite phase is principally quartz (15 percent), plagioclase, $An_{30}$ (50-65 percent), potassium feldspar (10-15 percent) and biotite (5-15 percent). Muscovite is locally a minor constituent (5 percent max). Ilmenite and pyrite are present in addition to the same accessories as in the quartz monzonite. The granodiorite comprises a minor part of the stock.

The quartz monzonite stock was given a Jura-Trias age by Ward and others (1971, fig. 4, 1970) because of its similarity to radiometrically dated Jura-Trias rocks in the massif. This age assignment is accepted here.

## Cretaceous sedimentary rocks

Lower Cretaceous miogeosynclinal rocks disconformably overlie the crystalline rocks of the massif. In the California District these sedimentary rocks include the Tambor Formation, principally a fine- to medium-grained quartzite, but with minor shale, and the younger Rosa Blanca Formation, a thick-bedded limestone, locally bioclastic, with minor black shale zones.

A block of massive and banded, pale-gray, medium-grained quartzite occurs in the Quebrada Chorrerón area. Subangular to subrounded quartz grains containing minute opaque inclusions (magnetite?) comprise 50-95 percent of the rock. Some of them have undergone granulation and have weak to strong undulatory extinction. Others have sutured grain boundaries. Some samples contain other kinds of detrital grains (10 percent max), including: laminated muscovite schist; fine-grained siliceous sedimentary rock (chert?); pellets of glauconite partly altered to limonite; sphene; and zircon. The detrital fragments are set in a matrix, comprising up to 45 percent of the rock, of fine-grained detrital quartz, micro to cryptocrystalline quartz, and aggregates of sericite and muscovite stained red and yellow brown by iron oxides. Locally, the rock contains as much as 20 percent white mica concentrated in irregular bands.

As the nature of the contacts of this quartzite with the quartz monzonite are not clear, doubt may exist whether the quartzite is related to the Cretaceous sedimentary rocks or is a part of the Bucaramanga Gneiss engulfed by the quartz monzonite. However, inasmuch as no similar quartzite has been found in the Bucaramanga Gneiss and as few detrital grain outlines and glauconite pellets would survive metamorphism (and tectonism?) in the amphibolite facies, the quartzite is most likely a Cretaceous sedimentary rock that has been faulted into contact with the quartz monzonite.

### Porphyry

Porphyry dikes, generally less than 100 m thick, crop out throughout the district. A few thicker ones (300 m max) are exposed along Quebradas La Baja and Chorrerón.

The rock is massive, with 35-65 percent phenocrysts as much as 2 cm across in a light- or dark-gray, fine-grained matrix of quartzo-feldspathic material and black mineral grains. The feldspar phenocrysts, chiefly andesine, comprise 20-35 percent of the rock and are accompanied by lesser amounts of quartz (5-25 percent), biotite (10 percent max) and locally hornblende (10 percent max) in the coarse-grained phase. Epidote and muscovite are minor constituents. Apatite, chalcopyrite, ilmenite, magnetite, pyrite, sphene, and zircon are also present. No estimate of the potassium feldspar content has been made because of the intense alteration of the feldspars to sericite and clay in most samples. However, based on estimates of the feldspar composition, some samples were identified at the petrography laboratory in Bogotá as dacite, andesite, and trachyte. The porphyry is post-Lower Cretaceous, as a porphyry dike intrudes shaly beds in the Tambor Formation. 4/

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4/ Boulders of porphyry in the upper part of Quebradas Ramada Vieja near the Rosa Blanca Formation must have come from other porphyry dikes that cut the Lower Cretaceous sedimentary rocks.

## Structure

The oldest structural feature in the California District is the foliation of the banded gneiss in the migmatite. In general, it is vertical or steeply dipping and strikes north-northeast, but also exhibits other orientations. For the district as a whole, the poles to the foliation form a girdle, the pole of which plunges 85° W. (fig. 16). This $\pi S$ axis is subparallel to the ones in the gneiss and schist in the Vetas District and is consistent with identification of the gneissic rocks in the California District with the Bucaramanga Gneiss. Furthermore, the similarity in the $\pi S$ axes ($\approx \beta$ axes) across 8 km of the massif suggests that the fabric of large parts of the Bucaramanga Gneiss is homogeneous with regard to this linear fabric element.

The prevalent northeast strike of the foliation in the gneiss seems to have exerted a partial control over the orientation of a few later structures: 1) the contact between the migmatite and the quartz monzonite which trends generally northeastward; 2) a steep northeast-trending fault that cuts through the migmatite and younger rocks on the northwestern edge of the district.

Post-Lower Cretaceous tectonism may have reactivated pre-existing faults in the massif, but certainly resulted in thrust faulting and folding within the Cretaceous sedimentary rocks. The Tambor Formation is thrust over the Rosa Blanca Formation in the west corner of the district. Beds of the upper plate of this thrust are folded into a syncline, the axis of which plunges gently to the south (fig. 17).

Intense fracturing is pervasive in the crystalline rocks. However, no statistically significant pattern of preferred orientation of the minor faults and joints was found.

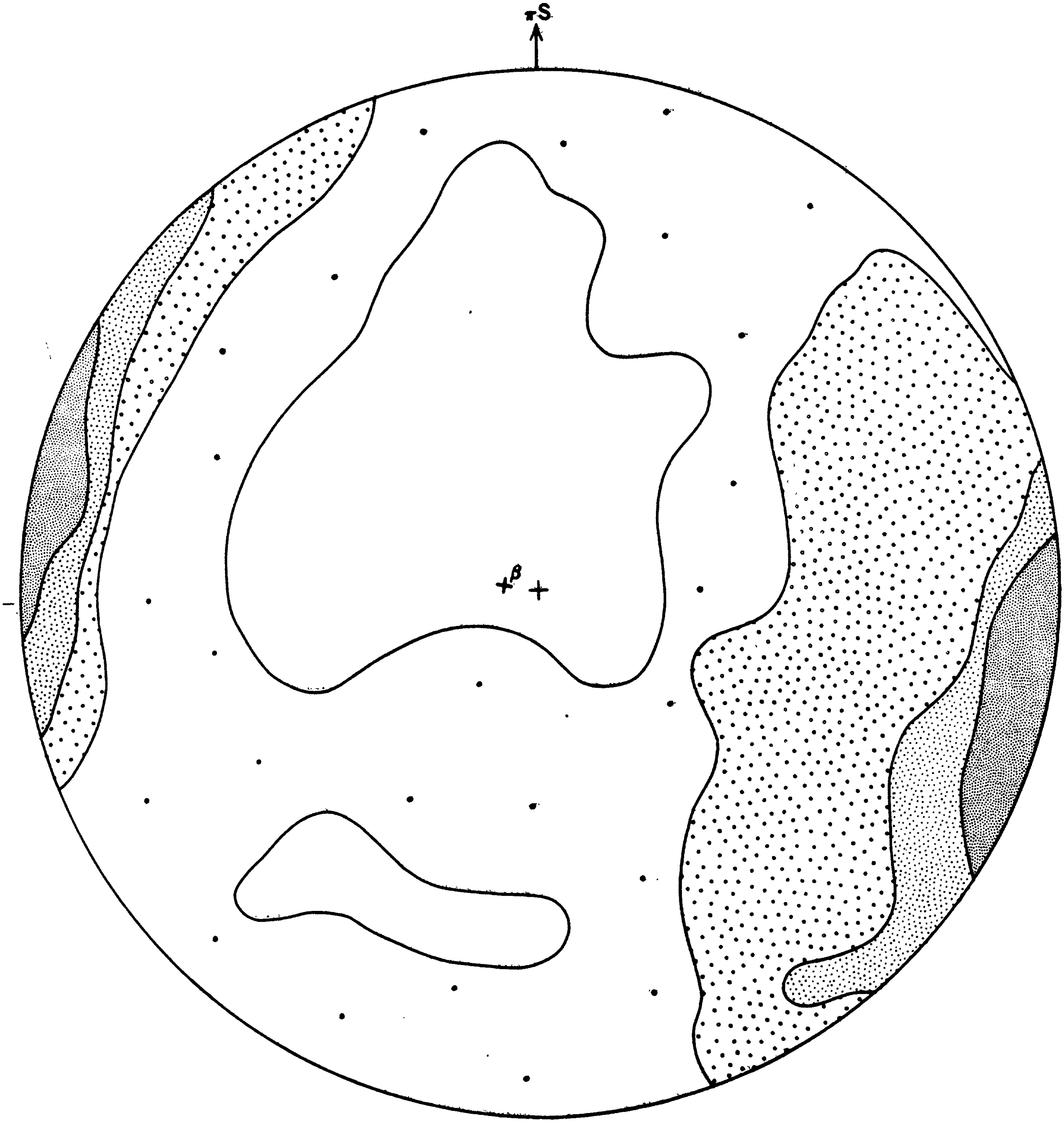


Figure 16. 68 poles to foliation, California District. Contours, 2σ, 4σ, 6σ, and pole-free area.

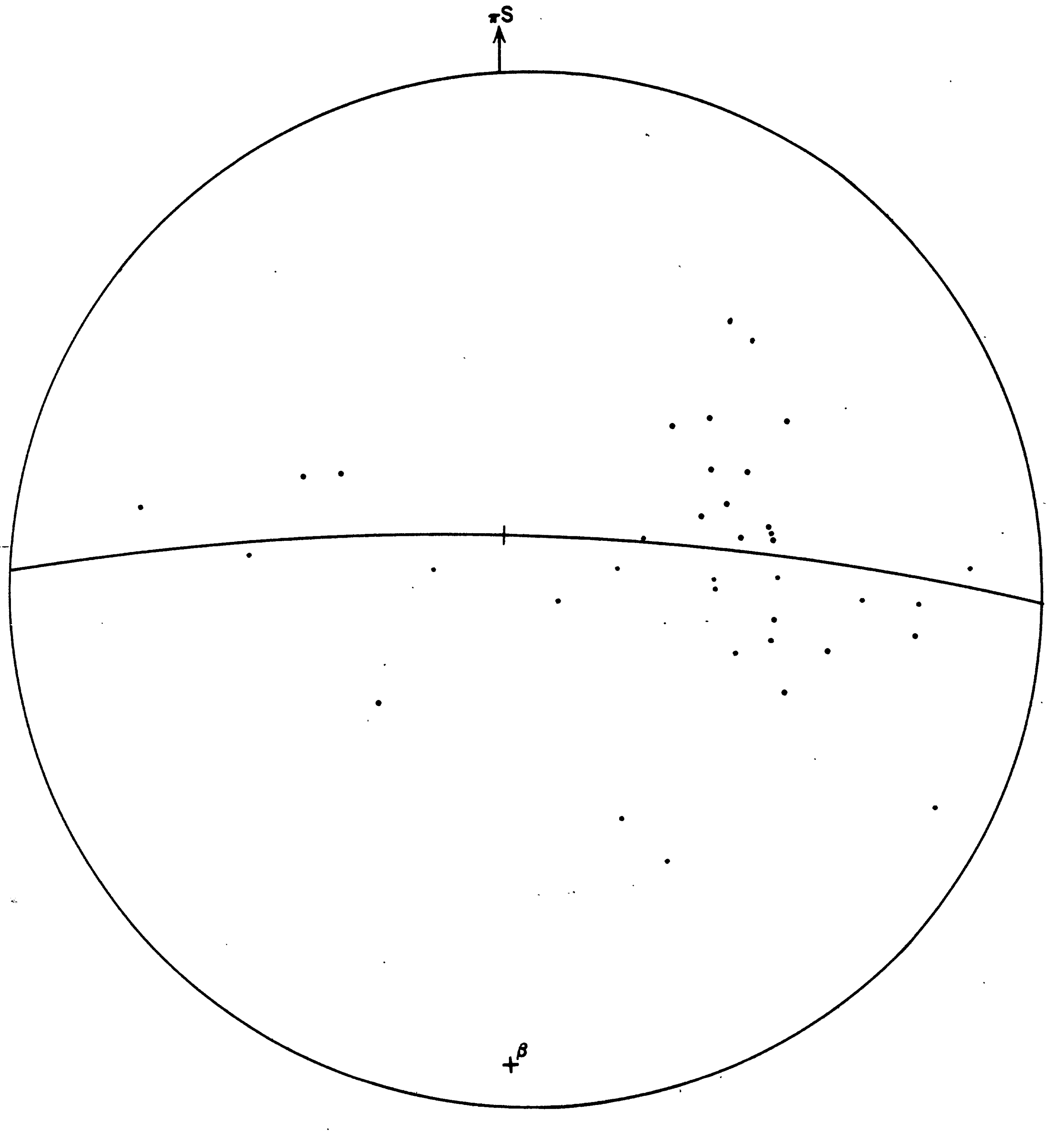


Figure 17. 37 poles to bedding in Cretaceous rocks, California District.

## Alteration

Sericitization, silicification (including quartz vein formation), chloritization and argillic and hematitic alteration are common throughout the district, especially in association with gold mineralization. The alteration is most intensely developed in the quartz monzonite, where the rock is much fractured. Zones in which the alteration is especially intense are in the headwaters of Quebrada Chorrerón in the area of the San Celestino and San Antonio mines and in the vicinity of La Angostura and La Alta, which also contains many mine workings (fig. 3). Other zones of brecciation and alteration may be present below the thick soil cover on the flanks of the ridges.

## Description of the ore deposits

The ore in the California District is of three kinds: (1) quartz veins and brecciated quartz; (2) silicified porphyry breccia; (3) argillically altered quartz monzonite with hematite veins.

The quartz veins are white and light gray, fine to medium grained or aphanitic, and may be brecciated or have numerous vugs. The fine-grained quartz veins contain fine- to medium-grained pyrite and thin veins of dark-gray aphanitic siliceous material, much like the ore in the Vetas District. This same kind of aphanitic material cements the quartz breccia. Medium-grained quartz veins have pyrite cubes commonly exceeding 1 mm. Locally, as at the Mascota Mine, these veins also contain numerous veins and nodules of pyrite, chalcopyrite, and bornite several centimeters across.

Some of the quartz veins are porous. The irregularly shaped vugs are of two kinds. The vugs lined with subhedral quartz are generally partly filled with a black sooty material (graphite?) and stained with malachite and chrysocolla. The dark-gray to black rocks of this kind, common at the San Antonio Mine, are highly radioactive (radioactivity level estimated qualitatively with a geiger counter).

Other cavities, formed in quartz veins by solution along vertical or steeply dipping minor fracture zones, are commonly stained red from hematite and may contain nodules of pyrite. In local parlance these veins are called "caracha," and, although they vary widely in gold content, are generally considered to be of low gold potential.

Silicified porphyry breccia is mined only at the San Celestino Mine. The angular fragments of the silicified porphyry are cemented with a black aphanitic siliceous material like the dark veins and siliceous cement in the brecciated quartz at the nearby San Antonio Mine.

The argillically altered quartz monzonite contains unoxidized pyrite grains up to 1 mm across. Locally, the quartz monzonite has been altered to a gray saprolitic paste. Hematite veins as much as a few meters wide in the altered quartz monzonite are especially rich in gold. These kinds of ore are typical of the Asturias Mine and the workings to the northeast of Quebrada Páex.

The ore in the porphyry breccia indicates that at least some of the gold mineralization is post-Lower Cretaceous or Tertiary, as the porphyry is of that age.

## Results of geochemical sampling

Soils were sampled every 100 m (88 locations) at the base of the ridges flanking Quebradas La Baja, Angostura, and Páez, in order to test the hypothesis that gold-bearing veins lie beneath the thick soil mantle on the ridges. Care was taken to avoid localities below mines. The B soil horizon was the one most commonly sampled. At most sites where more than one soil horizon was sampled, the B horizon had the largest gold content (see table 1).

Gold was found at 90 percent of the sample sites, and gold concentrations were 0.5 ppm or more (6.4 ppm max) at 28 percent of the sample sites. The highest concentration was obtained below Buenavista, near Quebrada Aserradero (fig. 3). No mines are known on the ridge above that sample site.

Unfortunately, all the sample localities do not appear on the sample locality map of the California District (master copy at the Bucaramanga office of INGEOMINAS), and the field maps on which some of them were located have been lost. However, the hypothesis that unexposed gold veins flank the zone of mining is substantiated by the results of the soil sampling.

The results of microscope examination of 46 pan concentrates from the California District are included in figure 18. Fine sand-sized gold grains were found in 14 concentrates from 13 streams, and were accompanied by azurite, barite, chalcopyrite, hematite pseudormophous after pyrite or chalcopyrite, malachite, and pyrite. The heavy minerals in at least two of these samples were probably derived from the panning of crushed ore.

Table 1

Soil Samples from the California District
Analysis: Atomic absorption for gold
(Limit of detection for gold, 0.05 ppm)

| No. IGM | Field No. | ppm. Au | Remarks |
|---|---|---|---|
| 73529-S | Je C 266 | *1/ | |
| 73530 | 145 A | .12 | Three soil |
| 73531a | 145 B | .24 | horizons |
| 73532 | 145 C | .07 | sampled |
| 73533 | 146 S | .26 | |
| 73534 | 147 A | .09 | Three soil |
| 73535 | 147 B | * | horizons |
| 73536 | 147 C | .07 | sampled |
| 73537 | 150 S | .17 | |
| 73538 | 151 S | .13 | |
| 73539 S | 155 A | .13 | Three Soil |
| 73540 | 155 B | .46 | horizons |
| 73541 | 155 C | .10 | sampled |
| 73542 | 174 S | .54 | |
| 73543 | 175 S | .08 | |
| 73544 | 176 S | * | |
| 73545 | 178 S | .05 | |
| 73546 | 182 S | .67 | |
| 73547 | 183 S | .09 | |
| 73548 | 184 S | .39 | |
| 73549 S | 185 S | .10 | |

| No. IGM | Field No. | ppm. Au | Remarks |
|---|---|---|---|
| 73550 | JE C 186 S | .24 | |
| 73551 | 187 A | .18 | Two soil |
| 73552 | 187 B | .30 | horizons sampled |
| 73553 | 188 S | * | |
| 73554 | 205 S | .08 | |
| 73555 | 206 S | * | |
| 73556 | 207 S | .11 | |
| 73557 | 208 S | .05 | |
| 73558 | 209 S | .16 | |
| 73559 | 211 S | .33 | |
| 73560 | 212 A | 1.12 | Two soil |
| 73561 | 212 B | 1.08 | horizons sampled |
| 73562 | 213 S | .12 | |
| 73563 S | 214 S | .17 | |
| 73564 S | 215 S | .46 | |
| 73565 | 216 S | 1.52 | |
| 73566 | 217 S | .92 | |
| 73567 | 218 S | .28 | |
| 73568 | 219 S | .22 | |
| 73569 | 220 S | .80 | |
| 73570 S | 221 S | .17 | |
| 73571 S | 223 S | .05 | |
| 73572 | 225 A | * | Two soil |
| 73573 | 225 B | .11 | horizons sampled |

| No. IGM | Field No. | ppm. Au | Remarks |
|---|---|---|---|
| 73574 | 226 S | .06 | |
| 73575 | 227 S | .08 | |
| 73576 | 229 S | .10 | |
| 73577 | 230 A | .17 | Two soil |
| 73578 S | 230 B | .54 | horizons sampled |
| 73579 | 231 S | .58 | |
| 73580 | 232 A | * | Two soil |
| 73581 | 232 B | .25 | horizons sampled |
| 73582 | 233 S | .05 | |
| 73583 | 235 S | * | |
| 73584 | 247 S | .22 | |
| 73585 | 248 S | .43 | |
| 73586 | 255 S | * | |
| 73587 | 259 S | .86 | |
| 73588 S | 260 S | 1.01 | |
| 73589 S | JE C 261 S | * | |
| 73590 | 265 S | .08 | |
| 73592 | EM 882 | .87 | |
| 73593 | 883 | .75 | |
| 73594 | 884 | * | |
| 73595 | 885 | .10 | |
| 73596 | 887 | * | |

| No. IGM | Field No. | ppm. Au | Remarks |
|---|---|---|---|
| 73597 | 888 | .75 | |
| 73598 | 890 | .14 | |
| 73599 | 891 | .08 | |
| 73600 | 894 | .07 | |
| 73601 | 895 | .20 | |
| 73602 | 896 | .68 | |
| 73603 | 897 | .72 | |
| 73604 | 898 | .08 | |
| 73605 | 899 | .10 | |
| 73606 | 900 | .18 | |
| 73607 | 850 | 3.75 | |
| 73608 | 851 | .69 | |
| 73609 | 852 | .83 | |
| 73610 | 853 | 6.38 | |
| 73611 | 855 | 3.61 | |
| 73612 | 856 | .08 | |
| 73613 | 858 | .09 | |
| 73614 S | 859 | .50 | |
| 73615 S | HM 861 | .89 | |

| No. IGM | Field No. | ppm. Au | Remarks |
|---|---|---|---|
| 73616 | 863 | .34 | |
| 73617 | 865 | .26 | |
| 73618 | 866 | 1.71 | |
| 73619 | 867 | .64 | |
| 73624 | 873 | .08 | |
| 73625 | 874 | .28 | |
| 73626 | 875 | * | |
| 73627 | 876 | .20 | |
| 73628 | 877 | .16 | |
| 73629 | 878 | .10 | |
| 73630 | 879 | .14 | |
| 73631 | 880 | * | |
| 73632 | 881 | .12 | |

1/ Sample insufficient for analysis.

Altogether 11 of the streams from which gold-bearing pan concentrates were taken drain basins with no known gold mines and no inferred contamination by exotic material. These basins can be viewed as gold targets. The largests of these potential targets in the California District are:

Quebrada Chorrerón; the combined basins of Canada Zeppelin and Quebrada Agualimpia; the combined basins of Quebrada Las Animas, Quebrada Aserradero, and an unnamed stream (fig. 18).

The presence of gold in the pan concentrate from Quebrada Ramada Vieja, a stream draining a basin underlain by Lower Cretaceous and possibly younger rocks, indicates that at least some of the gold mineralization must have occurred in Cretaceous or Tertiary rocks.

The copper concentrations of fine stream sediments from the district were compared with copper values in all fine sediment samples from quadrangle 110-I-C. Anomalously high concentrations of copper (background 50 ppm, threshhold 200 ppm for quadrangle 110-I-C) were found in the vicinity of the San Antonio and San Celestino gold mines (200-300 ppm) and in Quebradas Chorrerón and Aserradero ($\geq$1000 ppm).[5]

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[5] Anomaly maps and analytical data are not available. The San Celestino-San Antonio area was studied by the Nippon Mining Co., Ltd., and though estimated to contain 46,000 tons of ore averaging 1.24 percent copper (Ward and others, 1971, p. 39), was considered to be subeconomic.

The possible association of gold and copper in the California District suggests that areas anomalously high in copper should also be studied for their gold potential. The basins of Quebradas Chorrerón and Aserradero, with the highest copper concentrations in fine stream sediment, also contain gold in pan concentrates and are prime mineral targets.

## Conclusions

1. Much of the ore in the California District is fine- to medium-grained pyritiferous quartz veins and quartz breccia with black sooty material (graphite?), much like the ore in the Vetas District. At California the gold is also present in altered porphyry breccia and argillically altered quartz monzonite with hematite veins.

2. The age of at least some of the mineralization is post-Lower Cretaceous.

3. Soil samples indicate that gold mineralization of unknown extent underlies the thick blanket of soil on the ridges flanking the principal zone of mining near the canyon bottoms of Quebradas La Baja, Angostura, and Páez.

4. Pan concentrates outline three principal gold targets: (a) the basin of Quebradas Agualimpia and associated streams; (b) the basin of Quebrada Chorrerón; (c) the basin of Quebrada Aserradero and adjacent streams (fig. 18).

5. If gold and copper anomalies are related in the California District, copper may be useful as a pathfinder for gold mineralization elsewhere in the massif.

## QUADRANGLES 98-III-C, 110-I-A, and 110-I-C

Quadrangles 98-III-C, 110-I-A, and 110-I-C cover 450 $km^2$ of the central Santander Massif, including the Vetas and California Districts (fig. 1). Part of the area outside of the gold districts was studied during a reconnaissance in which stream sediments were sampled (fine sediment and pan concentrates). Areas covered were along Rio Vetas and some of its major tributaries (Quebradas Mangora and La Plata), the creeks draining the ridge of Alto El Popo, south of California, and the headwaters of Quebradas La Cabrera and Rio Arboledas. A few pan concentrates from the Rio Suratá were found in the office at Bucaramanga and examined under the microscope along with the newly collected samples.

The Vetas and California Districts, already described, include 30 $km^2$ of the central massif, mostly in quadrangle 100-I-C. Little more of the geology of the crystalline rocks was mapped in detail during this study.

### Geology

The general geology of quadrangles 98-III-C, 110-I-A, and 110-I-C is shown in figure 2. Some of the contacts were taken from the geologic map of quadrangle H-13 (Ward and others, 1970).

The eastern two-thirds of the area is underlain by crystalline rocks: Precambrian Bucaramanga Gneiss, Triassic quartz diorite, Jura-Trias quartz monzonite and alaskite, and post-Lower Cretaceous monzonite porphyry. In the Vetas area the Bucaramanga Gneiss contains schist units. At California the gneiss hosts many dikes of quartz diorite and quartz monzonite and is mapped as migmatite.

In quadrangle 110-I-C several large stocks (quartz diorite, alaskite, quartz monzonite porphyry) intrude thc gneiss, but few intrusions have been mapped in the Bucaramanga Gneiss north of the California District.

Along the west edge of the study area the pre-Devonian Silgara Formation, a silvery gray-green phyllite, is intruded by the quartz diorite and quartz monzonite. The Silgara Formation is separated from the Bucaramanga Gneiss by a trough of Mesozoic sedimentary rocks and the relationship between the two rock units is not known from this part of the massif. Elsewhere, however, the Silgara Formation is believed to overlie the Bucaramanga Gneiss and to be older than the Devonian Floresta Formation (not exposed in the study area).

The Jura-Trias sedimentary rocks which overlie both the Bucaramanga Gneiss and the Silgará Formation include the Triassic(?) Bocas Fromation, (black shale) and Jurassic red beds (Jordán Formation, siltstone; Girón Formation, conglomerate). On the geologic map of quadrangle H-13 (Ward and others, 1970) only the Girón Formation is shown resting on the metamorphic rocks, but in the field the post-Paleozoic and pre-Cretaceous sedimentary rocks also include strata typical of the Bocas and Jordán Formations.

The Cretaceous sedimentary rocks, ranging in age from Lower to Upper Cretaceous, lie disconformably on the crystalline rocks and the earlier Mesozoic sedimentary rocks. The Cretaceous strata include the Tambor, Rosa Blanca, Paja, Tablazo, Simití, La Luna, and Umir Formations, listed in order of age.[6/]

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[6/] These stratigraphic units were defined in the Magdalena Basin and have been extended to the east of the basin into the massif as far as the study area. About 20 km east of California, a different stratigraphic nomenclature, taken from the Maracaibo Basin, is used for similar Cretaceous strata.

Indications of mineralization

The occurrence in pan concentrates of gold, or in a few cases, high concentrations of pyrite or chalcopyrite, were used as criteria for delineating potential gold targets in the massif. Of the 85 samples from outside the California District, only one sample (from Quebrada Guasamán) was probably contaminated by material from a drainage other than the drainage it purported to sample.

The target areas, shown in figure 18 by dotted lines, delineate areas which merit additional geochemical and geological study. The basins of principal interest are listed below.

Quadrangle 98-III-C:

The headwaters of Quebradas Chorrerón and Cinera, on Páramo de Cinera.

Quadrangle 110-I-A:

Upper Quebrada Vadorreal and the lower parts of Quebradas La Resumida and Monsalve.

Quadrangle 110-I-C:

The basins of Quebradas Martiño, Venaderos, and El Pozo

The south flank of Cuchilla Violetal

The basins of Quebradas El Arado and Malpaso

The basins of Quebradas La Botija and La Chorrera, on the north flank of Páramo Rico (and perhaps also Páramo Rico, south of the quadrangle)

Upper Quebrada Salado and its tributaries (including part of quadrangle 110-I-D)

In the Vetas District the acidity of stream water is related to decomposition of sulfide minerals and to degree of gold mineralization, and may be useful as a supplementary guide to gold mineralization elsewhere in the massif. In the study area the waters are mostly neutral or somewhat basic, as in areas underlain by the Cretaceous sedimentary rocks. However, in Quebrada Mangora and its tributaries on the south flank of Cuchilla Violetal, the pH of the stream waters is 5 to 6. This area is also noted for the occurrences of gold in the pan concentrates (fig. 18) and for the extensive argillic and hematitic alteration, silicification, and brecciation in the porphyry. The geological and geochemical characteristics strongly indicate that the area is extensive mineralized. This area connects with the mineralized basin of Quebradas Chorrerón in the California District, and is a prime target for more detailed geochemical study.

## Recommendations

The stippled boundaries on figure 18 outline the areas known or suspected to have gold mineralization. All these targets should be studied in more detail, beginning with the prime target areas listed above.

A pan concentrate taken from Quebradas de Vetas at a site above the town of Vetas contained 200 ppm gold (spectrographic analysis). The drainage basin (12 $km^2$) above the sample site is south of the study area (in quadrangle 110-III-A). No mines are located in the basin, nor have the geology and geochemistry of the basin been studied. A reconnaissance of this target area is recommended, as it adjoins the Vetas District.

Other mineralized areas are probably present in the massif. Additional reconnaissance should be made of the hitherto unsampled crystalline rocks of the study area and of the adjacent quadrangles to the south (110-III-A), east (98-III-D, 110-I-B, 110-I-D) and north (98-III-A).

Additional geochemical investigations should also focus on the copper potential of the massif.

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