GEOLOGY OF THE LA VERDE COPPER DEPOSITS, MICHOACAN, MEXICO

by

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Abstract

La Verde is in the state of Michoacán, 200 miles west of Mexico City. The deposits are on the Sierra del Marqués, an east-west-trending range nearly 4 miles long largely made up of quartz diorite intruded by acidic dikes and stocks. On what is called the East Hill there is one deposit in a quartz feldspar porphyry stock and three others in diorite breccia and crackle breccia adjoining it. Mineralization is chalcopyrite and bornite in varying proportions among and within the four orebodies, with only a very minor pyrite content. Hydrothermal alteration is present but generally weak. On the West Hill, centered a mile west of the East Hill orebodies, there is a single zone about 2,000 feet long and up to 800 feet wide, trending north-south. Mineralization is largely confined to steeply dipping, east-west-trending veins carrying pyrite, pyrrhotite, and chalcopyrite, and there are dozens of them. There is a selvage of intense silica-epidote-sericite alteration bordering these veins, but the diorite between them is only slightly altered and is nearly barren. Mineralization in both the East and West Hills extends to the greatest depths drilled up to 1,200 feet vertically below surface with no significant change in grade or character. Oxidation extends to varying depths up to about 200 feet, but there is no leached zone and no chalcocite blanket. The grade of the ore in the oxide and sulfide zones is about the same.

Introduction

There are many copper deposits known as La Verde in Mexico, but this one is located in the state of Michoacán, 320 km west of Mexico City and 220 km by highway inland from the Pacific Coast port of Lázaro Cárdenas (Fig. 1). La Verde was worked in a small way many decades ago, and some 50,000 tons of ore were mined underground from high-grade sections, hand sorted, and material grading 10 percent copper or better was shipped. The information on which this paper is largely based was developed in the course of exploration carried out in the years 1967-72, which included extensive tunneling, core and percussion drilling, bulk sampling, and geologic mapping of the surface and underground workings carried out by the senior author. Substantial ore reserves have been delineated at two locations. The concessions are held by Cia. Cuprífera La Verde, S.A., and a production decision awaits favorable conditions in the copper industry and an examination of the overall viability of the project.

Topographically, the location is in the valley of the Río Balsas, just south of the Central Volcanic Belt of Mexico. Several volcanic cones can be seen from the site, the closest about 3 km away. Locally, the deposits are on the Sierra del Marqués, an east-west-trending, arc-shaped range of hills 6 km long that rises to a peak elevation at Cerro Camacho of 730 m, 200 m above the plan elevation on the north side and 300 m above it on the south side. The property is unusual in that a paved highway, a branch line of the Na-

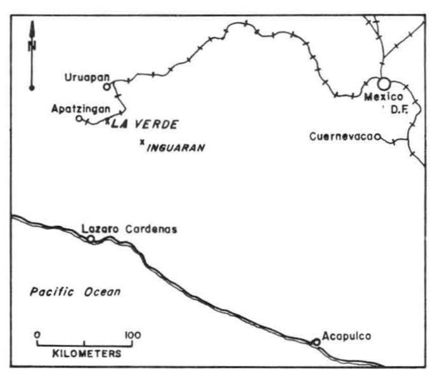

Fig. 1. Location map

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tional Railways of Mexico, major power lines, major power lines, and a river all pass through it.

Regional Geology

The host rocks are phases of the Huacana granodiorite-quartz diorite pluton, which is 70 km long and trends northwest. It is the northernmost member of a cluster of plutons in southern Michoacán, which in turn is one of a series of clusters extending up the west slope of the Sierra Madre Occidental into Sonora, many of which have associated copper deposits. There are four known porphyry copper deposits within the Huacana pluton where it is intruded by younger porphyries with associated igneous breccias, namely, La Verde, Inguarán, San Isidro, and Manga de Quimo.

This region of Mexico is characterized by basin-and-range topography trending east-southeast; the basins are filled with thick sequences of bedded conglomerate, thin sandstones and mudstones, and recent volcanic rocks. At La Verde, the absence of pebbles of intrusive rocks in the conglomerates and their presence in talus fans and old river fill cutting through the conglomerate point to the very recent unroofing of the pluton. Though age has not been radiometrically determined, this series of intrusive rocks is classed as Cretaceous on government geological maps; the andesitic lavas that cap many of the ranges are Tertiary.

La Verde Geology

The Sierra del Marqués in which the deposits occur is totally composed of intrusive rocks, mainly quartz diorite, for convenience called the La Verde intrusive complex. It is divided into two fundamentally different units known as the East and West Hills, the point of separation being at the center of the arc-shaped range (Fig. 2).

The East Hill unit is characterized by abundant aplite and quartz feldspar porphyry stocks intruding medium-grained quartz diorite and the development of large breccia zones which carry the bulk of the mineralization. Simple crosscutting relations suggest two phases of acid intrusion and related breccia development.

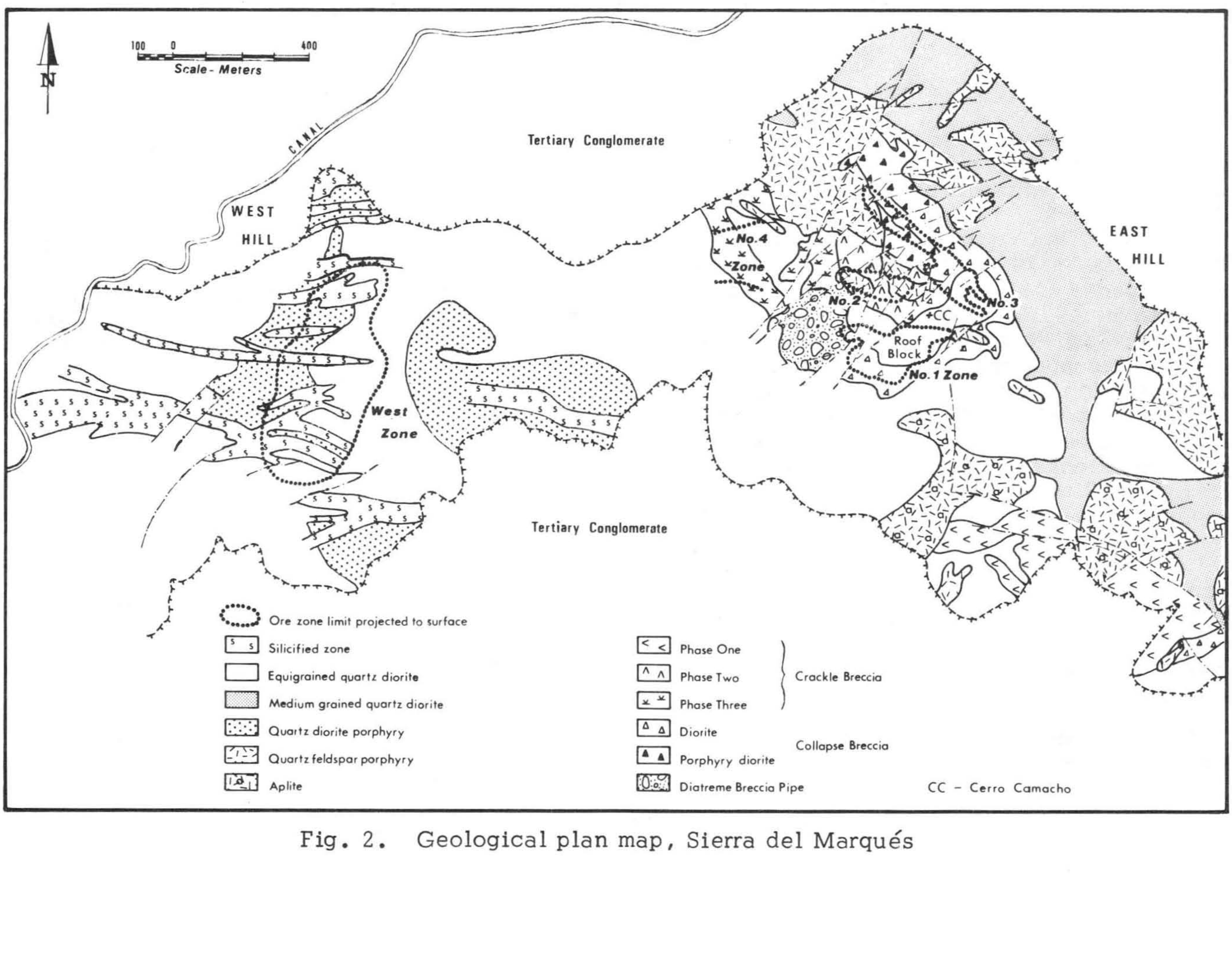

Fig. 2. Geological plan map, Sierra del Marqués

The West Hill unit is characterized by irregular bodies of quartz diorite porphyry in the medium-grained quartz diorite, and except for a few thin dikes in the diorite, acid intrusive rocks are absent. Mineralization is confined to replacement and fracture filling in sheeted vein systems of which the most important—the West Hill orebody—lies across the contact of one of the quartz diorite porphyry bodies.

The quartz diorites are massive grayish-green rocks composed mainly of oligoclase-andesine, hornblende, and quartz. In the medium-grained quartz diorite the feldspar is weakly sericitized and the hornblende partly chloritized throughout the Sierra del Marqués. Grain size is 2-5 mm, and quartz is interstitial. The quartz diorite porphyries are fresher in appearance, with phenocrysts of lilac-gray andesine and hornblende in a matrix of fine-grained feldspar (occasional potash feldspar), and quartz. Contacts of the quartz diorite porphyry and medium-grained quartz diorite are both gradational and sharp, never chilled, with little or no contact alteration.

The acid intrusive rocks are white, gray, and yellowish, both massive and strongly fractured. On the south slope of the East Hill they are predominantly aplites, with typical subgraphic and myrmekitic textures, and these appear to grade into quartz feldspar porphyries in some localities. The porphyries form stocks and irregular dikes in the center and north slope of the East Hill. They consist of 60 percent albite-oligoclase and 25 percent "bird's eye" quartz phenocrysts, with minor chlorite laths. Chilling and flow structures are common, and occasionally biotite develops in diorite and porphyry at the contacts of the stocks, while the centers tend toward equigrained textures.

The East Hill Complex

Two phases of acid intrusive rocks and three of breccias have been identified.

Phase One breccia is only developed in the southeast part of the Sierra del Marqués as an east-southeast-trending band of diorite crackle breccia 250 m wide with many large blocks of diorite. This breccia is thought to be early because it is intruded by aplite stocks and dikes of the first acid intrusive phase. Mineralization is weak or absent.

Phase Two breccias occur in an area 600 m in diameter centered on Cerro Camacho, and host two of the East Hill ore zones (Fig. 3). True breccias crop out as a band 30 to 150 m wide extending around the southern and northeastern slopes of the cerro. These breccias form a boat-shaped or elongate, inverted cone-shaped mass 500 m wide at surface, tapering to 200-250 m wide at a depth of 200 m. The sides of the cone dip 45-50 degrees toward the center except in the extreme northwest area where the breccia band is nearly vertical. The center of the cone is occupied by equigrained diorite crackle breccia and a "roof block" of unbrecciated diorite. Its lower contact is sharp, and the footwall is formed mainly of medium-grained quartz diorite. The upper contact is gradational, and massive quartz diorite grades downward into weakly then strongly crackle brecciated quartz diorite and finally coarse breccias. These have subangular to angular fragments of all quartz diorite phases, quartz feldspar porphyry, and minor aplite and quartz, 0.5 to 20 cm in diameter, in a cataclastic matrix of rock fragments and broken crystals of quartz, feldspar, and chlorite, which forms 10 to 40 percent of the volume of the breccia. Large blocks of unaltered diorite and porphyry and rare aplite up to several meters across occur in the breccia. Bands of distinctive lithologies with fragments of mainly porphyry, of diorite, or of mixed porphyry and diorite can be traced through it. Zones in which the fragments are mainly coarse (over 5 cm in diameter) or fine (1-5 cm in diameter) can also be identified, and dip toward the center of the cone, roughly parallel to its contacts. These facts, and also the texture of the breccia, its contact relationships, and conical form advocate formation by collapse. This would require a low-pressure volume to be developed at the apex of the cone into which the brecciating blocks subside. This space is occupied by a quartz feldspar porphyry intrusion (Fig. 4).

This porphyry of the second phase is best exposed on the adit level of the East Hill. Here it is elliptical in plan, 300 m long by up to 150 m wide, trending east-southeast. It is elliptical in cross section also and has the overall shape of a dike that has "ballooned" in the collapse breccia zone. No breccia xenoliths have been observed in the porphyry, but its southern half contains many inclusions of dioritic feldspar partly replaced by biotite and chlorite. It is speculated that intrusion occurred in two phases. A proto-intrusion was first emplaced passively and assimilated part of its diorite host. Magma pressure then dropped, resulting in the collapse of a cone of diorite around it, then subsiding diorite blocks squeezing new porphyry magma up into the breccia zone. The relaxation of magma pressure from the thin feeder dike into the larger tube would release large volumes of volatiles to lubricate breccia formation and "pump up the balloon."

Phase Three breccias form a band 700 by

Fig. 3. Plan of adit level, East Hill

300 m southwest of the Phase Two breccias, completing the ring of breccias around the Cerro Camacho. They consist of three units which crosscut or rebrecciate previously formed breccias and associated quartz feldspar porphyry. From southeast to northwest these are:

1. A breccia pipe about 200 m in diameter, with well-rounded fragments of all La Verde rock types in a matrix of pulverized rock and chlorite with abundant albite-oligoclase feldspar laths matching those in the quartz feldspar porphyry. The pipe is considered to be of diatreme origin formed by the injection of acid porphyry highly charged with volatiles. Two large blocks of andesite lava have been found in the pipe, indicating that it extended up into the covering volcanics which have since been stripped off by erosion.

2. A crackle breccia rim flanks the diatreme to the north; its matrix is essentially continuous with it. This crackle breccia clearly crosscuts the collapse breccia of Phase Two, its quartz feldspar porphyry intrusion, and its contained mineralization.

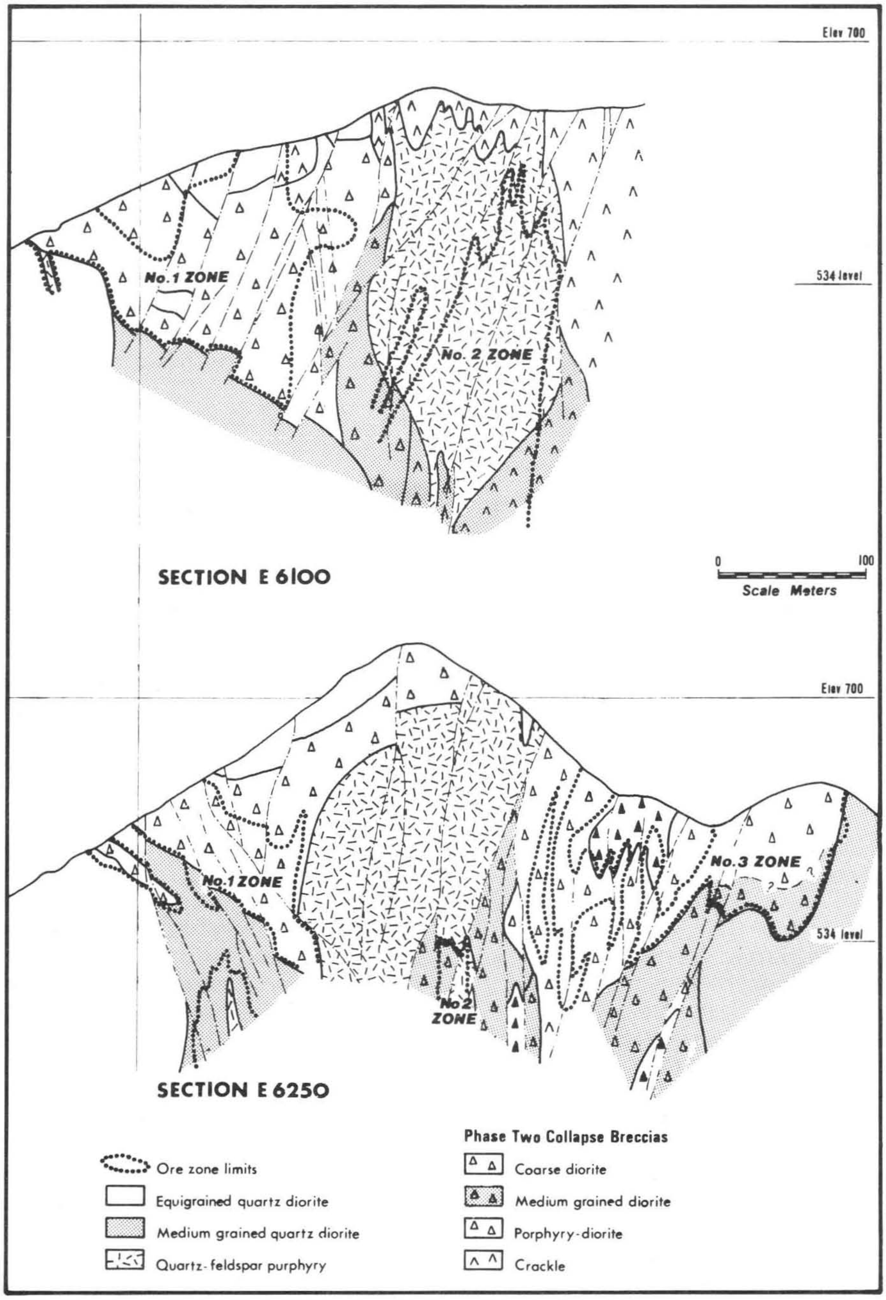

Fig. 4. Cross sections of East Hill ore zones, looking west

3. No. 4 orebody crackle breccia is northwest of the diatreme and appears to be of hydrothermal origin in that its matrix is formed wholly of sulfides and vein minerals.

Alteration and Mineralization of the East Hill Unit.

Phase One breccia shows intergrown pyrite-pyrrhotite with very minor chalcopyrite and arsenopyrite in quartz-calcite stringers and small vugs in the matrix of the breccia. These are the only breccias on the East Hill with significant pyrite, and they develop a thin gossan at surface. Acid intrusive rocks of this phase, mainly aplite, are almost barren.

Phase Two collapse breccia alteration consists of a strong pinkening of the feldspars in the fragments and matrix, extensive epidote and calcite replacement, and sericitization. Propylitization is often so strong as to obliterate breccia textures. There is no doubt that the matrix was the main channelway for solutions, as fragments larger than 20 cm in diameter almost always show a rind of pink alteration around fresh gray interiors.

Following propylitization, the breccias on the south and north sides of the Phase Two quartz feldspar porphyry intrusion were mineralized with bornite and chalcopyrite, minor tennantite and arsenopyrite, and traces of pyrite and molybdenite to form, respectively, the No. 1 and No. 3 orebodies. Sulfides occur as discontinuous stringers, fracture coatings, blebs, and fine disseminations throughout the matrix and fragments of the breccia. They frequently concentrate at fragment-matrix boundaries. On average, the bornite-chalcopyrite ratio is 2:1, but the distribution is uneven. The rim of the breccia cone in both No. 1 and No. 3 orebodies is usually chalcopyritic, with successive zones of mixed bornite-chalcopyrite and bornite toward the center of the cone. This zoning pattern is cut across by northeast-trending faults containing vuggy stringers of chalcopyrite and calcite and strongly sericitzed borders. The faults are only mineralized within the breccia, becoming barren when they pass out of it on strike. Mineralization is strongest in the outer rim of the breccia cone, with up to 5 percent sulfides, and cuts across the boundaries of the various Phase Two breccias, but sharply weakens to much below ore grade in the adjoining massive diorite.

Phase Two quartz feldspar porphyry contains near its northern contact a mineralized, sheeted vein structure known as No. 2 orebody. It trends parallel to the east-southeast-trending contact of the porphyry with collapse breccia, averaging 60 m wide. The zone consists of swarms of seams of copper sulfides, parallel and spaced one to a few centimeters apart, with selvages of silica-chlorite alteration with finely disseminated sulfides. The southern edge of the zone is mainly chalcopyrite, the center bornite-chalcopyrite, and the northern half bornite. Mineralization fades out in porphyry to the east and in breccia to the west and at depth.

Phase Three breccias all show development of greenish sericite, chlorite, and calcite in fragments, but to only a slight to moderate degree. Only a few minor lenses of ore occur in the diatreme and in its crackle breccia rim. Although the No. 4 crackle breccia extends through to surface, ore-grade mineralization begins only at 100 to 200 m below surface, where all interfragment space is occupied by bornite-chalcopyrite in a calcite-quartz-tourmaline gangue. No true matrix has been observed, and the breccia is considered to be of hydrothermal origin.

Following emplacement of the East Hill orebodies, slight silica-sericite alteration occurred along northeast and east-southeast fractures. This alteration is essentially barren of sulfides.

A series of northeast- to east-northeast-trending normal faults cuts through the East Hill orebodies. The major faults dip steeply southeast, and the conjugate set dips steeply northwest. The faults are in effect components of a small graben cutting northeast across the East Hill.

The West Hill Complex

On the West Hill three quartz diorite porphyry stocks intrude the equigrained quartz diorite. The westernmost stock, which is host to part of the ore zone, trends north-northeast. West of it the equigrained quartz diorite was affected by pervasive deuteric alteration over an area of several square kilometers in which feldspars and hornblende were replaced by microscopic aggregates of hematite-quartz-chlorite to form a reddish rock called "red diorite." Intrusive events terminated with the injection of a few dikes of aplite and quartz feldspar porphyry trending east-southeast.

The West Hill orebody is a north-north-east-trending zone 700 m long and 250 m wide straddling the contact of the westernmost quartz diorite porphyry stock with equigrained quartz diorite (Fig. 5). The zone includes three vein systems trending east-northeast, east-west, and east-southeast. Veins in the stock strike principally east-northeast; in the adjacent equigrained diorite east-south-east, and the east-west direction is common to both rocks. Individual vein zones thus describe a broad arc convex to the north, similar to that of the Sierra del Marqués as a whole. All veins are vertical or dip steeply south.

The veins contain pyrite, pyrrhotite, chalcopyrite, and minor arsenopyrite in a gangue of quartz, calcite, and tourmaline, with intense development of epidote, sericite, and quartz in the adjoining host diorite, so that its texture is totally destroyed. Individual sulfide veins are up to several meters wide, and vein zones are up to 100 m wide. Sulfides are almost entirely confined to the veins, and where they are widely spaced the host diorite away from the veins is little altered and almost barren. The vein zones are continuous and overall of remarkably uniform grade to the greatest depths drilled, although individual veins show great variations in width and grade over short distances on strike and dip. Overall, the pyrite content is about

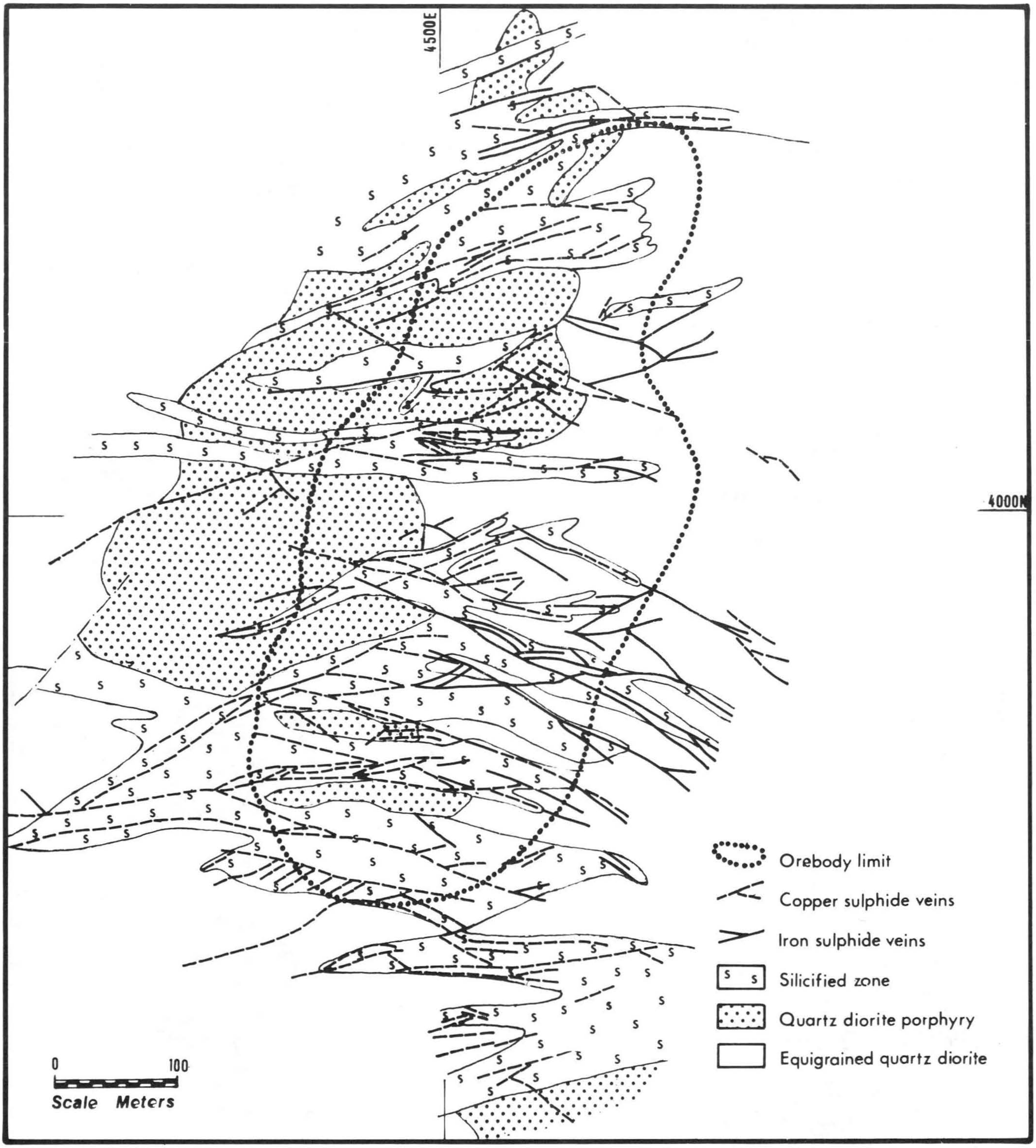

Fig. 5. Plan of West Hill orebody

3 percent and chalcopyrite 1.5% by weight. On strike to the east and west the sulfide veins simply fade out in the diorite. Wide zones of silica-epidote-sericite alteration are found in the diorite both east and west of the orebody but show only weak sulfide mineralization, except for minor pyrite and pyrrhotite in the red diorite.

No large acid intrusion crops out in the vicinity of the West Hill orebody, although it is speculated that one may occur at depth beneath it.

Exploration

Geological Mapping

Surface geology was mapped at a scale of 1:1000 for 4 km of strike length covering the central portion of the Sierra del Marqués. The topographic base at that scale was prepared from aerial photographs with a 2-m contour interval. All underground workings were mapped at 1:200.

Geochemical Survey

Soil samples were taken on north-south-bearing lines generally 100 m apart, at intervals of 25 m, and were assayed for copper only. All of the orebodies except No. 2, which does not crop out, are contained within the +500 ppm copper anomaly, and results can be contoured up to 4,000 ppm copper over the outcropping No. 1, No. 3, and the West Hill orebodies (Fig. 6).

Induced-polarization Survey

Extensive surveys in the time domain were carried out on the lines 100 m apart and showed almost the entire Sierra del Marques to be anomalous, with chargeabilities up to 30 milliseconds. Individual highs within the major anomaly are offset 100 to 200 m from the actual orebodies (Fig. 7).

Tunneling

A total of 3,386 m of tunnels were driven on both East and West Hills to provide geological data, bulk sampling material, and sites for underground drilling.

Drilling

Inclined holes were drilled on section lines 50 m apart, mainly bearing north-south. Several holes were drilled on each section, laid out generally so as to provide intersections at a spacing of not more than 50 m. A total of 48,559 m in 233 holes were core drilled, and 12,275 m in 279 holes by percussion drilling. Core recovery averaged 85 percent on the East Hill and 94 percent on the West Hill.

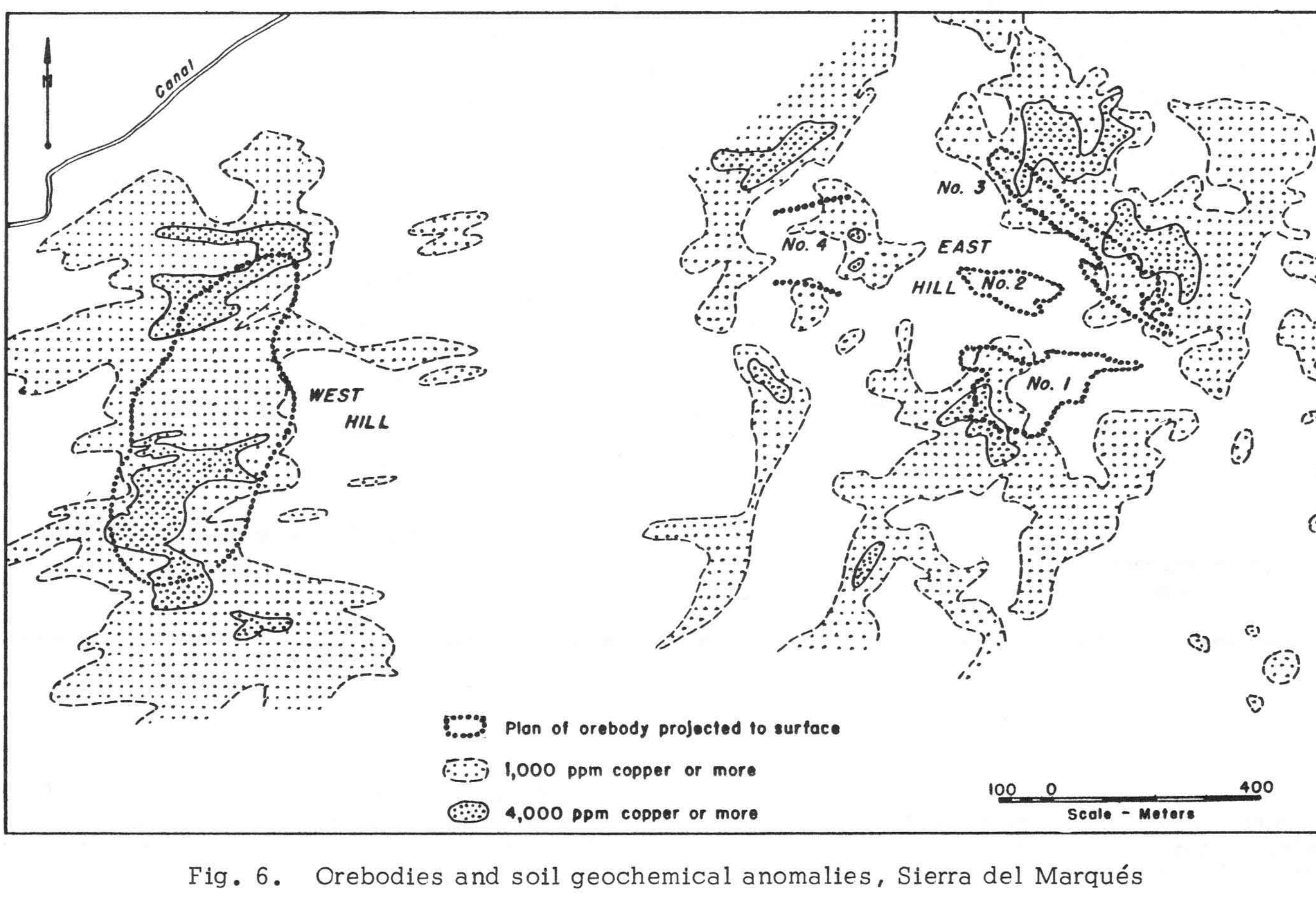

Fig. 6. Orebodies and soil geochemical anomalies, Sierra del Marqués

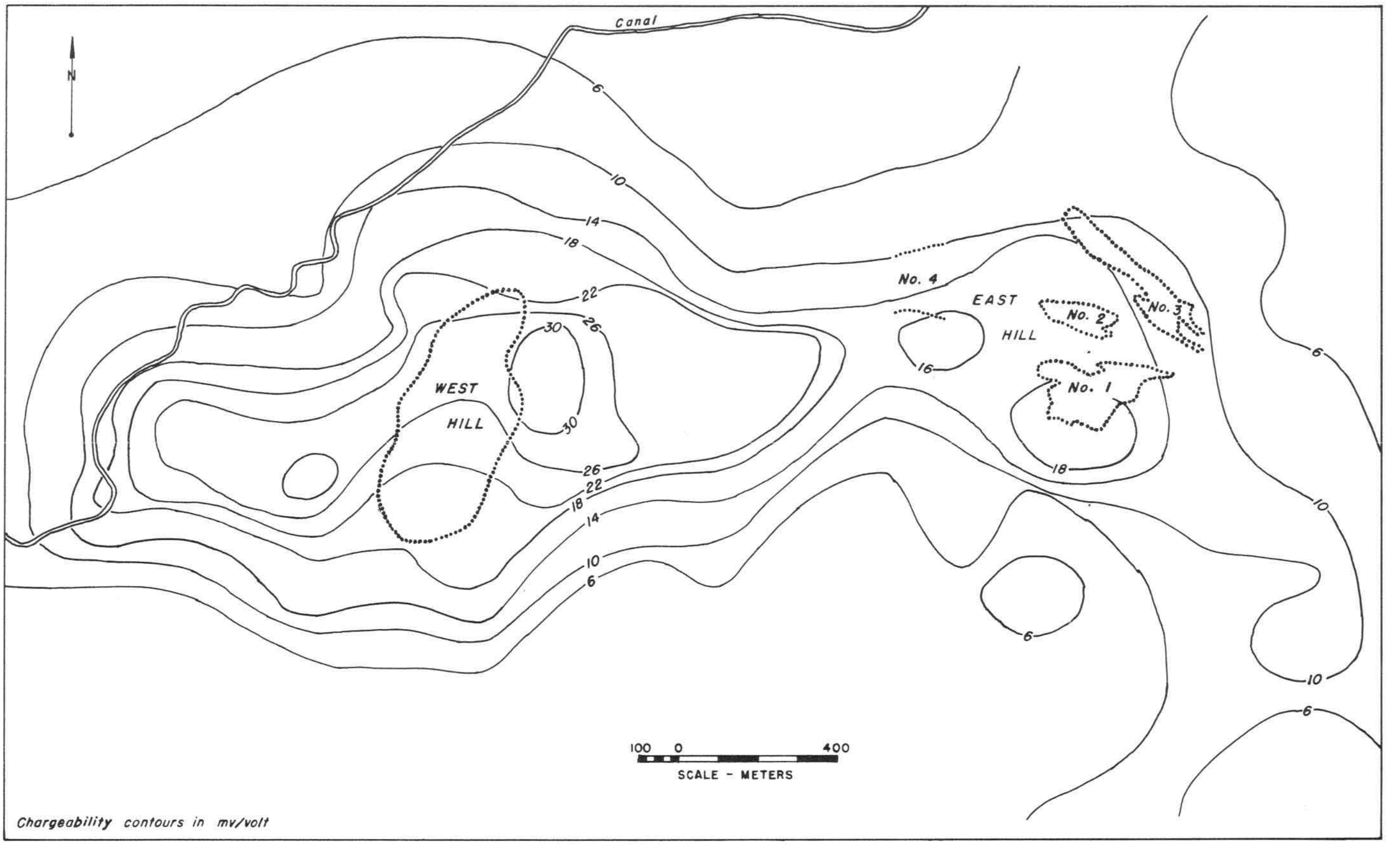

Fig. 7. Orebodies and induced-polarization anomalies

Sampling

Percussion drill holes were sampled at intervals of 2 m, core holes at varying intervals of up to 3 m, and face and car samples were taken from all tunnels driven. As a guide to the credibility of the various sampling methods, a total of 245 m of tunnel in various locations on both hills were driven on the line of a flat diamond drill hole and a flat percussion hole parallel to and a foot or so from the diamond drill hole, and the entire volume of rock, amounting to about 3,000 metric tons was put through a crushing and sampling plant, round by round, to provide a bulk sample. A comparison of the overall average results shows:

	East Hill	West Hill	Total
Meters driven	136	109	245
Average bulk sample, % Cu	0.99	0.54	0.79
Average car sample, % Cu	0.78	0.40	0.61
Average face sample, % Cu	0.93	0.46	0.72
Average core sample, % Cu	0.89	0.48	0.71

Core recovery averaged 73.7 percent for the East Hill drilling for the tunnel length sampled, 88.2 percent on the West Hill, and 80.1 percent overall. Only 5 out of 11 percussion holes were completed due to failure to penetrate faults, and the results are not comparable. They tended to produce erratically higher results than the bulk sample.

Acknowledgments

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