34. GEOPHYSICS AND GEOCHEMISTRY IN THE DISCOVERY AND DEVELOPMENT OF THE LA CARIDAD PORPHYRY COPPER DEPOSIT, SONORA, MEXICO

D.F. Coolbaugh
Consultant Industrias Peñoles, Mexico

Coolbaugh, D.F., Geophysics and Geochemistry in the discovery and development of the La Caridad porphyry copper deposit, Sonora, Mexico; in Geophysics and Geochemistry in the Search for Metallic Ores; Peter J. Hood, editor; Geological Survey of Canada, Economic Geology Report 31, p. 721-725, 1979.

Abstract

The discovery of La Caridad porphyry copper deposit in Sonora, Mexico was the result of planned mineral exploration which was carried out over a large potential area employing reconnaissance exploration methods of photogeology and geochemistry followed by semidetailed and detailed exploration methods of geophysics, geochemistry and geology. Intense hydrothermal alteration exposures in the district were visually observed from fixed-wing aircraft but before this area could be field checked anomalous copper and molybdenum values in stream sediments were found 18 km downstream in the drainage from the deposit. These anomalous values were followed upstream to the area of the La Caridad deposit. The stream sediment sampling was followed by more detailed soil and rock-chip sampling and reconnaissance geological mapping. Induced polarization surveys, geochemical studies and geological mapping were used to delimit the La Caridad deposit. Very low induced polarization and geochemical values were noted over the central part of the deposit due to deep leaching. Alteration and mineralization exhibit classic porphyry copper patterns. As a result of this exploration a deposit was delineated which contains in excess of 700 million metric tons with an average grade of 0.72% copper.

Résumé

La découverte du gisement du minerai porphyrique de cuivre de la Caridad à Sonora au Mexique, a été le résultat d'un projet d'exploration minière, réalisé dans une région ayant un grand potentiel minier. Les méthodes d'exploration de reconnaissance utilisées ont été la photogéologie et la géochimie, suivies d'une exploration géophysique, géochimique, et géologique détaillée et semi-détaillée. Dans le secteur on a observé d'un avion, à l'oeil nu, des affleurements présentant une altération hydrothermale intense; mais, avant d'en faire l'exploration au sol, on a trouvé des anomalies en cuivre et molybdène dans des dépôts fluviatiles à 18 km en aval du gisement. On a suivi ces anomalies en amont jusqu'à la région du gisement de la Caridad. L'échantillonnage des dépôts alluvionnaires a été suivi d'un échantillonnage plus détaillé des sols et de fragments de roches, et d'un levé géologique de reconnaissance. On a fait des levés de polarisation provoquée, des études géochimiques, et des levés géologiques pour délimiter le gisement de la Caridad. On a relevé de très faibles valeurs géochimiques et de polarisation provoquée au-dessus de la partie centrale du gisement à cause du profond lessivage. L'altération et la minéralisation sont typiques des minerais porphyriques cuprifères. Cette exploration a permis de délimiter un gisement contenant plus de 700 millions de tonnes métriques ayant une teneur moyenne en cuivre de 0.72%.

INTRODUCTION

Successful mine exploration requires sound planning and modern exploration techniques but it also requires perseverance and often the good fortune of being in the right place at the right time. The La Caridad mineral area had been known for over 70 years but, as with many mines, it was not 'discovered' until viewed under different economic conditions and different exploration philosophies. The La Caridad deposit is located in the State of Sonora, Mexico, approximately 120 km south of the international boundary between Mexico and the United States, at Douglas, Arizona (Fig. 34.1). The two nearest large copper deposits are Cananea, 105 km to the northwest and Bisbee, 128 km to the north. The Pilares mine, formerly operated by the Moctezuma Copper Company of Phelps Dodge Corporation, is located approximately 10 km to the west. Nacozari, Sonora, the nearest village is 15 km northwest of La Caridad.

The deposit is situated approximately 1825 m above sea level. The climate is semiarid with an annual rainfall of 38 cm. The topography is rugged and diversified.

The Cananea and Pilares copper mines were in operation over 80 years ago. In 1925, Alfred Wandke gave a description of the La Caridad Vieja mine which is located about 3 km northeast of the La Caridad porphyry deposit. Mineralization in the Vieja deposit occurs along a shear zone in quartz porphyry; a very small mining operation recovered some copper and a little silver (Wandke, 1925).

The Guadalupe mine, located in a pegmatite body on the flank of La Caridad, was exploited between 1954 and 1959. During this period 116 000 tons of ore containing 3.44% Cu and 0.43% Mo were mined.

During the period 1962-1967, the Mexican Government in conjunction with the United Nations undertook a joint mineral survey of selected zones in Mexico. The largest of these zones covered a 50 000 km^2 area in northern Sonora which included Cananea, Mexico's only large copper-producing mine, and the La Caridad deposit, which is the subject of this paper.

Subsequently a great amount of geochemical and geophysical work was carried out by the United Nations on the La Caridad deposit, and an excellent geological study of

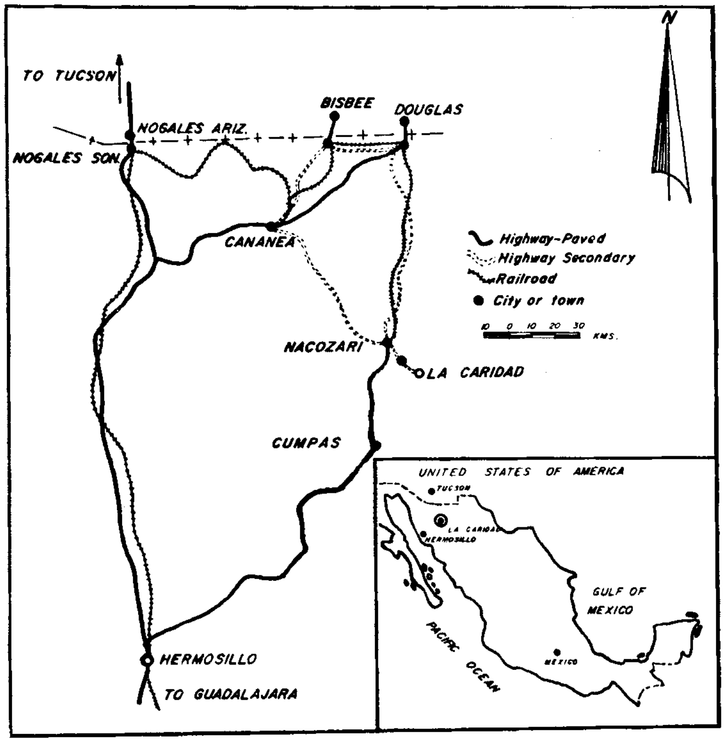

Figure 34.1. *Location of La Caridad Deposit.*

the deposit has been presented by Saegert et al. (1974). This paper, a discovery case history, will be confined primarily to the discovery methods, procedures and results and will not attempt to be a complete treatise.

METHOD OF EXPLORATION

Area Selection

Effective exploration is actually a process of selection and elimination. First the desired material must be selected and then the general area such as country or countries in which to explore must first be chosen. A selection of the area for reconnaissance surveys is made through library and similar studies by eliminating the areas with least potential. Reconnaissance surveys are carried out to eliminate the majority of the area and leave zones of greater potential to be studied by semidetailed and later detailed surveys.

The selection of the area for exploration that led to the La Caridad discovery was based on geological and economic decisions. The decision to explore for copper had been taken; also, it had been decided that the large bulk low-grade deposits were to be the exploration target.

Mexico is a mineral-rich country; however, in 1963 it only had one large copper-producing mine located at Cananea, Sonora. Immediately to the north of Cananea in the state of Arizona, U.S.A. are located the important copper mines of Bisbee, Pima, Mission, Esperanza, Twin Buttes and Ajo. Therefore, from an economic standpoint northern Sonora was a favourable area for exploration.

Northeastern Sonora is located along the north-south trending Wasatch-Jerome crustal lineament at or near its intersection with the northwest-trending Texas lineament. Correlation between these lineaments and the distribution of bulk low-grade copper deposits has been remarkable. Thus the foregoing favourable structural conditions and the fact that this area is known to contain many acid intrusive rocks of Laramide age, and the presence of existing mines, made the selection of northeastern Sonora as an area to explore for bulk low-grade copper deposits an easy decision.

Reconnaissance Exploration

The reconnaissance methods of exploration carried out in 1963-1965 included photogeology with aerial overflights by trained geologists and stream-sediment geochemical surveys.

The photogeological work was begun at about the same time as the other reconnaissance surveys. The results of this work could have been used more effectively had this work been completed before the other reconnaissance surveys were begun.

By using aerial photographs and topographic maps, aerial observation flights were planned and were flown along the sides of the mountain ranges in a fixed-wing aircraft with one photogeologist and two geologists observing geological features of interest such as alteration, mineralization, rock type and structure. These observations were plotted on photographs and topographic maps and were the basis, along with the photogeology and reconnaissance geochemistry, for the follow-up ground investigations.

Regional geochemical reconnaissance was carried out over the area utilizing stream-sediment sampling in tributaries to all major drainages and analyzing these samples for copper and for molybdenum by the cold extractable method (Hawkes, and Webb, 1962) which was used throughout this reconnaissance survey. Additional samples were taken where anomalous conditions were noted.

Geochemical Exploration

In late 1963 and early 1964, stream-sediment samples were taken from the arroyos (streams) entering the main drainage systems of northern Sonora within the zone of exploration of the Mexican-UN joint survey. This was a reconnaissance survey to locate areas for further exploration. Previously, geochemical stream sediment, soil and rock chip sampling over known copper deposits had demonstrated the feasibility of this type of survey in the area.

In early 1964, during the sampling of the arroyos emptying into the Rio Bavispe, anomalous values were noted in the arroyo Cruz de Cañada and in a few other streams. The method applied was to take three samples about 50 m apart where the arroyo emptied into the main drainage. The reason for three samples was that one sample might not prove reliable due to erratic results; however, three samples would constitute reasonable control. The values at the mouth

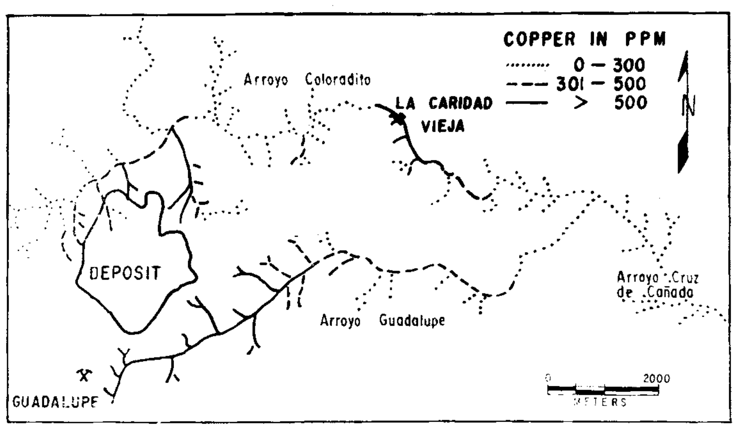

Figure 34.2. *Results of stream sediment sampling for copper, La Caridad, Sonora, Mexico (Lee and Osoria, 1964).*

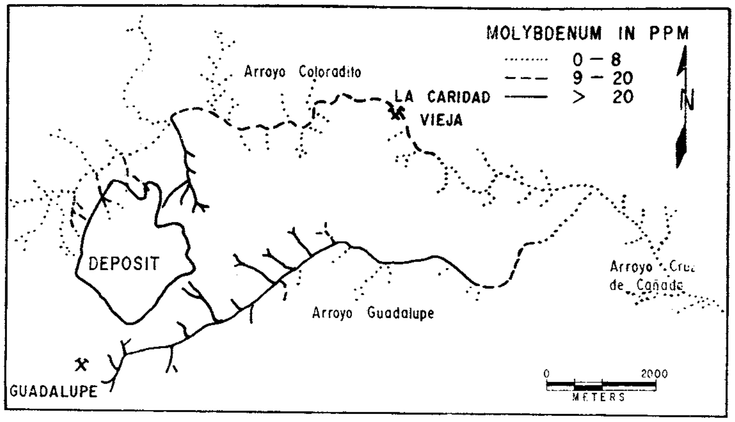

Figure 34.3. *Results of stream sediment sampling for molybdenum, La Caridad, Sonora, Mexico (Lee and Osoria, 1964).*

of the Cruz de Cañada arroyo ranged from 24 to 90 ppm copper and 2 to 15 ppm molybdenum in an area with a copper background of 20 ppm and a molybdenum background of 1.5 ppm (Lee and Osoria, 1965).

During this reconnaissance stream-sediment survey in a number of arroyos, of which Cruz de Cañada was only one, anomalous values were found. Although Cruz de Cañada gave one of the strongest anomalies, follow-up sampling was not undertaken for about four months. The follow-up consisted of sampling the arroyo upstream for approximately 3 km. The laboratory results of these samples showed them to be consistently anomalous at between three and five times background and these anomalous values were confined only to the main Cruz de Cañada drainage. Since the values were still anomalous, the field crew returned and sampled the Cruz de Cañada and the drainage entering it for another 7 km. Again values of copper and molybdenum gave values of between three and six times background with a few erratic higher values.

Since the arroyo Cruz de Cañada had proven to be anomalous over 10 km, the geochemical survey was quickly resumed. For the next 4 km upstream the values slowly increased to the junction of the arroyos Guadalupe and Coloradito (see Fig. 34.2). Both arroyos were anomalous and values increased more rapidly upstream. Following the arroyo Guadalupe, the values increased (to values more than 20 times background for copper and molybdenum) for another 7 km where the small abandoned copper-molybdenum workings of the Guadalupe Mine were found. This mine dump was the source of much of the downstream contamination; however, the drainage from the north into the arroyo Guadalupe had shown values of 5 to 30 times background in copper and molybdenum and the drainage from the south showed anomalous values in molybdenum up to 20 times background.

Values increased rapidly upstream in the arroyo Coloradito (to more than 20 times background for copper and molybdenum) for 4 km where the abandoned workings of the La Caridad Vieja mine, consisting of a few superficial workings, was found. Enargite, tetrahedrite and chalcocite were found. This mine had given rise to the heavy contamination downstream of copper and molybdenum. However, sampling was continued upstream from the workings and anomalous values equal to or sometimes even higher were encountered in the next 2 km.

The stream sediment sampling definitely located a large anomalous area that was not just related to the contamination of the two, previously unknown, abandoned small mine workings. Whether anomalous values would have been detected 18 km downstream from the now known La Caridad deposit without the contamination from these two old workings might be questionable, but this writer believes that anomalous values would have been encountered.

In July 1973, this drainage was resampled (Osoria, 1973) and the results were similar except higher values were obtained as the analyses were made by the atomic absorption method. The pH of the waters in the arroyos was between 5 and 6.

In order to maintain chronological sequence it is noted here that, while the reconnaissance geochemical studies were being conducted, this area was overflown and the prominent red hills lying approximately 3 km to the east of the La Caridad deposit were noted and plotted on aerial reconnaissance maps for later ground checking.

Induced polarization geophysical surveys were begun in late 1964 as soon as the La Caridad Vieja mine had been located and this work continued at the same time as the more detailed geochemical surveys were being made. The results of these surveys will be presented later. With the favourable geochemical results of stream sediments known, additional detailed stream sediment sampling in the local area was carried out leading to the closer determination of the location of the mineralized body (Figs. 34.2, 34.3).

Soil sample and rock chip sample surveys were also conducted during 1965-1966 to assist in determining the exact location of the deposit. Although this area is very steep and there is much talus on the slopes making true outcrops difficult to determine, and the soils were not well developed, samples were nevertheless taken of this material. Figures 34.4 and 34.5 show the results of the soil sample study. In Figure 34.4 it is easily seen that the surface over the mineralized zone gave much lower copper values than over the periphery; in fact, in the local region these values

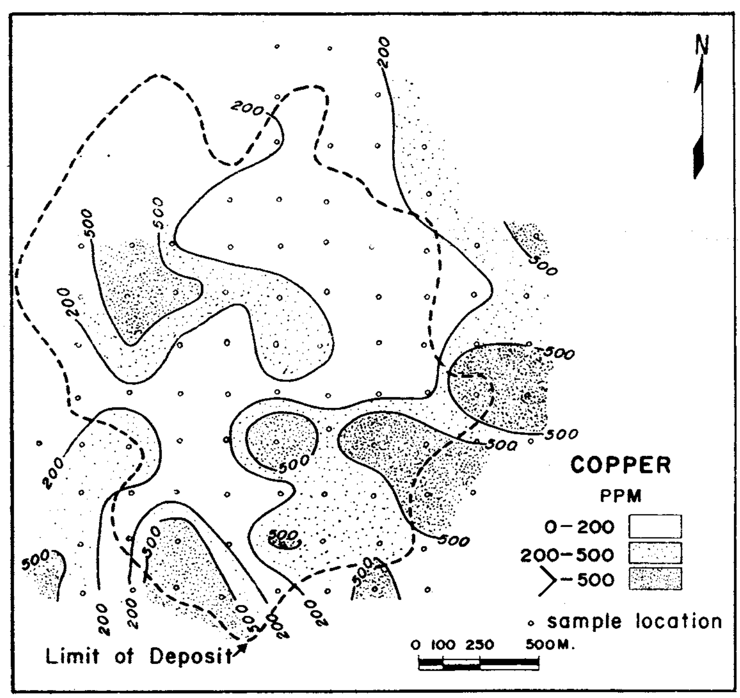

Figure 34.4. *Geochemical soil survey results for copper in parts per million, La Caridad deposit, Sonora, Mexico.*

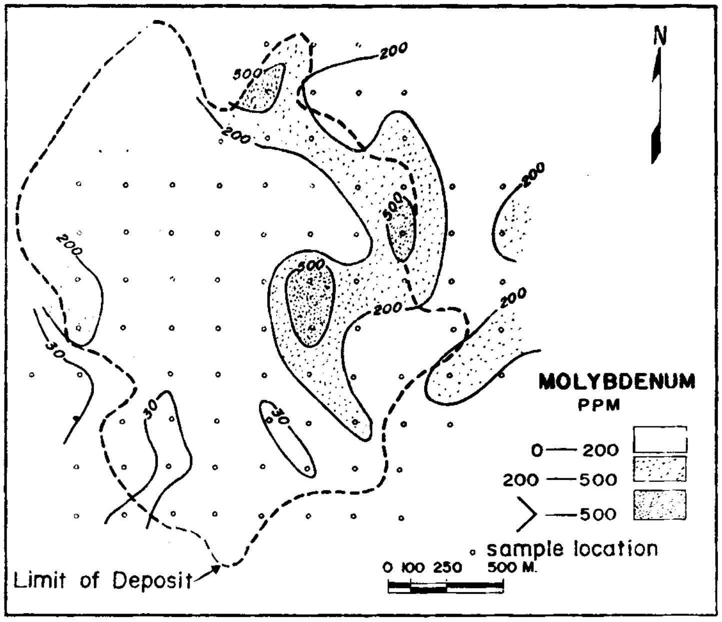

Figure 34.5. *Geochemical soil survey results for molybdenum in parts per million, La Caridad deposit, Sonora, Mexico.*

show as an anomalous low. This is easily explained since the rocks directly over the deposit have been leached of their copper which has been deposited in the supergene zone.

In Figure 34.5, higher values of molybdenum occur over parts of the deposit than in the surrounding area. This is due to the fact that the molybdenum has been retained and concentrated as molybdite in the leached capping. The anomaly indicated the higher molybdenum values in the deposit to be in the eastern part. The soil sample analyses were made by using the atomic absorption technique.

In 1976, the Mexican Geological Survey (Consejo de Recursos Minerales) in conjunction with the U.S. Geological Survey resampled the La Caridad drainage by collecting stream sediments and analyzed these using the cold extractable method. Their results correlated very well with the original survey. In this study zinc, silver and tungsten were also analyzed. The conclusions (Lee et al., 1976) were that copper and tungsten values were anomalous downstream to the Rio Bavispe; that molybdenum values were anomalous to the Rio Bavispe and as far as 13 km downstream in that river; that silver values were anomalous 10 km below the deposit and that zinc could not be considered a pathfinder element for the La Caridad deposit.

Geophysical Exploration

Induced polarization surveys were employed as a follow-up of the favourable stream sediment geochemical survey and were first conducted over the La Caridad Vieja mine area. Although widespread sulphide mineralization was not indicated, a shear zone in quartz monzonite gave values that indicate sulphides within a narrow zone. This zone was considered of minor importance and no drilling was planned.

An extension of the induced polarization survey lines to the south gave rather high readings over a granodiorite. These data suggested near-surface primary sulphides. A close examination of the surface of this granodiorite and an examination of a few prospect pits showed an abundance of pyrite, sufficient to account for the induced polarization anomaly. As the induced polarization survey was continued up the arroyo Guadalupe, anomalous values were recorded in the areas where the highest geochemical anomalies had been found. Here pyrite, chalcopyrite, chalcocite and molybdenite were sometimes observed at the surface. Anomalously low induced polarization values, that corresponded to the background or lower geochemical values for copper, were found over what is now known to be the leached zone above the La Caridad orebody. The area surrounding this leached zone contained the highest induced-polarization values.

This anomalous effect is very easy to understand if it is recognized that the deepest leaching penetrates to a depth of up to 225 m directly below the highest elevations. However, the thickness of this leached capping decreases on the flanks of the deposit, which are at a lower elevation, and sometimes sulphides outcrop at the lower elevations (Fig. 34.6). In the capping, the copper sulphides have been almost completely leached and, therefore, the geochemical values are low. The total volume of sulphides within the induced polarization area of influence is also decreased as the result of removal of sulphides from the capping. In addition, there is a pyrite halo around the deposit which enhanced the induced polarization values.

The induced polarization surveys were carried out using Seigel Associates Mark VG, 7KW, time domain equipment. The three electrode array was used with spacings of 100, 200 and in places, 300 m. Wenner expanding electrode arrays of up to 500 m spacing were also used in a few selected locations.

DESCRIPTION OF LA CARIDAD PORPHYRY COPPER DEPOSIT

Although this paper is a case history of the discovery and development of the La Caridad porphyry copper deposit, the account would not be complete without a description of the deposit.

The first hole was drilled in 1967 at La Caridad, and it encountered supergene mineralization with interesting copper and molybdenum values. The geochemical and geophysical studies had indicated a high probability for the occurrence of a bulk low-grade copper deposit and the first drillhole confirmed mineralization. Later drilling, based primarily on detailed geological studies, confirmed the existence of a major copper deposit.

There are no features of the La Caridad deposit which make it greatly different from other porphyry deposits. The ore is confined to the supergene enrichment zone where the predominant ore mineral is chalcocite. The underlying protore averages less than 0.25% Cu. The supergene blanket underlies a leached capping that varies in thickness from 0 to 255 m. No oxidized copper minerals are found in the capping.

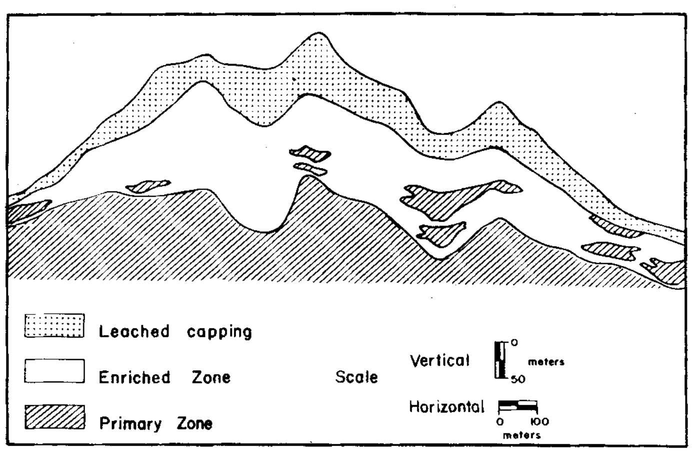

Figure 34.6. *Typical section through La Caridad deposit.*

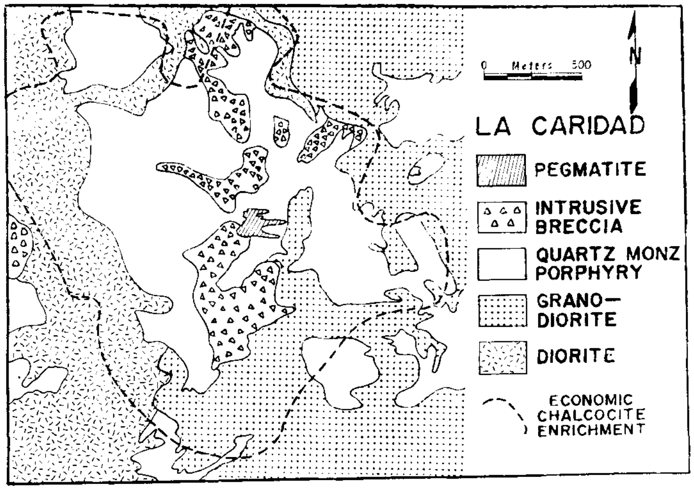

Figure 34.7. *Generalized bedrock geology (after – Saegart, Sell, Kilpatrick).*

Pre-mineral rock types found within the altered and mineralized area are diorite, granodiorite, quartz monzonite porphyry and pegmatites. Supergene copper mineralization is found in all these rock types (Fig. 34.7). Alteration in the central part of the deposit is phyllic with abundant sericite. This zone is surrounded by an irregular argillitic band which, in turn, is surrounded by a propylitic zone. Hypogene mineralization consists of pyrite, chalcopyrite and molybdenite. Supergene mineralization consists primarily of chalcocite. The chalcocite blanket has an average diameter of 1700 m and an average thickness of 90 m (Fig. 34.6). Both hypogene and supergene copper and molybdenum are disseminated in the igneous rocks, in fractures, in the cement of breccias or disseminated in pegmatites. Within both the breccias and pegmatites, the copper values are appreciably higher than in the surrounding rocks. A fairly large breccia pipe has been observed near the centre of the deposit. Small, randomly-spaced satellitic pipes are close to the main pipe, but the pipes are not restricted to any one rock type.

SUMMARY

A favourable bulk low-grade copper district was located in Sonora, Mexico in 1964. During the next two years, the most favourable area was investigated with the assistance of geochemical, geophysical and geological studies and, in 1967, the first hole drilled encountered very favourable mineralization and confirmed a porphyry copper discovery. During the next year limited additional drilling indicated a large deposit of favourable grade copper with values in molybdenum. In 1968, Asarco Mexicana, S.A. obtained exploration rights and drilling began which led to the delineation of an orebody in excess of 700 000 000 metric tons with an average of 0.72% copper (using a 0.4% copper cutoff) plus values in molybdenum. La Caridad is now owned by Mexicana de Cobre and production will begin in 1978 at the rate of 72 000 metric tons per day.

Although this discovery was the joint effort of various exploration disciplines, it can be stated that the reconnaissance geochemical survey was the first to pinpoint the favourable area. Both geochemical and induced polarization surveys were used to delineate the most favourable zone and were instrumental in choosing the location of the first drillhole which confirmed a discovery. Later development drilling was guided by information obtained by geological investigations.

A major orebody was discovered. How was it found? 1) First it was through planned regional reconnaissance exploration in a geologically favourable area, 2) through the use of modern exploration techniques, 3) through team effort of a dedicated group of exploration personnel who knew what they were looking for, and 4) a little bit of luck.

ACKNOWLEDGMENTS

The discovery and exploration of the La Caridad deposit have been by team effort. Special acknowledgment, however, should be given to the Mexican Government and the United Nations Development Program for the vision in initiating the project, to the dedicated Mexican engineers of the Consejo de Recursos Minerales, to the UN team of international experts, to the American Smelting and Refining Company consultants and to the management of Asarco Mexicana, S.A. and Mexicana de Cobre, S.A. for their vigorous approach to exploration and development.

REFERENCES

Chaffee, M.A., Lee Moreno, J.L., Caire, L.F., Mosier, E.L., and Frisken, J.G.
1976: Results of geochemical investigations comparing samples of stream sediment, panned concentrate, and vegetation in the vicinity of the Caridad porphyry copper deposit, northern Sonora, Mexico; U.S. Geol. Surv., Open File Rept. 76-559, 34 p.

Hawkes, H.E. and Webb, J.S.
1962: Geochemistry in mineral exploration; New York, Harper and Row.

Lee Moreno, J.L., Chafee, M.A., Mosier, E.L., and Frisken, J.G.
1976: Resultados de Investigaciones Geoquímicas en la Vecindad del Pórfido Cuprifero de La caridad, en el noreste de Sonora, Mexico, Comparando Muestras de Sedimentos de Arroyo, Concentrados de Batea y Vegetación; Geomimet No. 84, Nov./Dic.. 1976.

Lee Moreno, J.L., y Osoria H.
1965: Informe Preliminar sobre la Anomalía Geoquímica Cruz de Cañada; Informe CRNNR.

Osoria H.
1973: Exploración Geoquímica en La Caridad, Nacozari, Sonora, Mexico. Paper presented at the X Convention of the AIMMGM in Chihuahua, Chihuahua.

Saegart, W.E., Sell, J.D., Kilpatrick, B.E.
1974: Geology and mineralization of La Caridad Porphyry Copper Deposit, Sonora, Mexico; Econ. Geol., v. 67(7), p. 1069-1077.

Wandke, A.
1925: The Caridad mine, Sonora, Mexico; Econ. Geol., v. 20, p. 311-318.