35.

EXPLORATION OF THE REAL DE ANGELES SILVER-LEAD-ZINC SULPHIDE DEPOSIT, ZACATECAS, MEXICO

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Abstract

In the Real de Angeles district of Zacatecas, Mexico, galena, sphalerite, and silver ore minerals occur with pyrrhotite, pyrite and arsenopyrite in narrow fault veins and fractures, as disseminated grains, and along bedding planes. The asymmetrical, funnel-shaped body measures 500 x 400 m in plan near surface and extends to a known depth of 300 m. The host rock is composed of moderately warped, interbedded and gradational carbonaceous greywacke, sandstone, and shale of the Upper Cretaceous Caracol Formation. The mineral deposit outcrops in places but is largely overlain by a cover of caliche, numerous mine dumps, and the stone ruins of the village of the Real de Angeles. Conventional ground geophysical methods, including induced polarization, magnetic and resistivity surveys, were employed during the exploration diamond drilling program as a means to better determine the lateral and depth limits of the large deposit. Generally, the ore minerals are not chargeable nor are they naturally magnetic. However, the associated gangue sulphide minerals are chargeable and/or magnetic. The body could therefore be outlined by its high chargeability, low resistivity, and high magnetism, thereby reducing the number of drillholes required in the exploration program.

Résumé

Dans le district de Real de Angeles à Zacatecas, au Mexique, des minerais de galène, sphalérite et argent accompagnent la pyrrhotine, la pyrite et l'arsénopyrite dans des veines faillées étroites et dans des fractures, sous forme de particules dissiminées, ainsi que le long des plans de stratification. Le corps asymétrique, de forme conique, a pour dimensions 500 m par 400 m dans un plan proche de la surface, et se prolonge jusqu'à une profondeur connue de 300 m. La roche favorable est composée d'une grauwacke charbonneuse, de grès, et d'une argile litée de la formation de caracol du Crétacé supérieur; ces roches sont modérément plissées, sont stratifiées en alternance répétée, et granoclassées. Le gîte minéral affleure en certains endroits, mais est en grande partie recouvert d'une croûte calcaire, de nombreux déblais de mine, et des pierres provenant des ruines du village de Real de Angeles. Les méthodes géophysiques au sol conventionnelles, en particulier les levés de polarisation induite, magnétiques et de résistivité, ont été employées au cours du programme d'exploration par forage au diamant, pour mieux déterminer les limites latérales et en profondeur du vaste gisement. Généralement, le minérai n'est ni chargeable ni naturellement magnétique. Cependant, les minéraux sulfureux associés qui constituent la gangue sont chargeables ou magnétiques, ou bien les deux à la fois. Par conséquent, on pourrait délimiter le corps grâce à sa forte capacité de polarisation, sa faible résistivité et son magnétisme élevé, ce qui permettrait de réduire ainsi le nombre de trous de forage nécessaires au programme d'exploration.

LOCATION

The Real de Angeles silver-lead-zinc mineral district is located on a regional, semiarid central plateau near the geographic centre of Mexico, in the southeast part of the State of Zacatecas, about midway between the cities of Zacatecas and San Luis Potosí (Fig. 35.1), and lies at an elevation of 2300 m above sea level. The mines and mining village of Real de Angeles, whose ruins cover the top of the mineralized hill, were reportedly established by the Spanish late in the 16th century.

THE PURPOSE OF THE GEOPHYSICAL STUDIES

Explomin S.A. de C.V. obtained the mineral rights over the Real de Angeles mineral district between late 1973 and mid-1974. Geophysical surveys were conducted over the district and a large surrounding area for the purpose of better defining the limits of the Real deposit in three dimensions, to search for extensions thereof, and to investigate the ore potential under the nearby proposed millsite, mine dump and tailings disposal areas. This work was carried out in 1975 while surface diamond core drilling and geological mapping were in progress. The geophysical work consisted of ground magnetometer, resistivity, and induced polarization (IP) surveys. A VLF-EM survey was attempted but proved ineffective.

The known portion of the Real deposit is largely covered by rock debris of numerous small shaft mine workings, the stone ruins of the village, and a caliche capping several metres thick. Other than by blind drilling and/or dewatering more than 30 very old mine shafts and drifts, the lateral and vertical extent of the mineral body and the surrounding mineral potential could not be determined easily. It was hoped that the geophysical responses of the gangue sulphide minerals closely associated with the ore minerals, could lead indirectly to a better definition of the limits of the silver-lead-zinc mineral body, prospect for blind, unknown orebodies and provide guidance to the drilling program.

Figure 35.1. Location map of the Real de Angeles mining district, Zacatecas, Mexico.

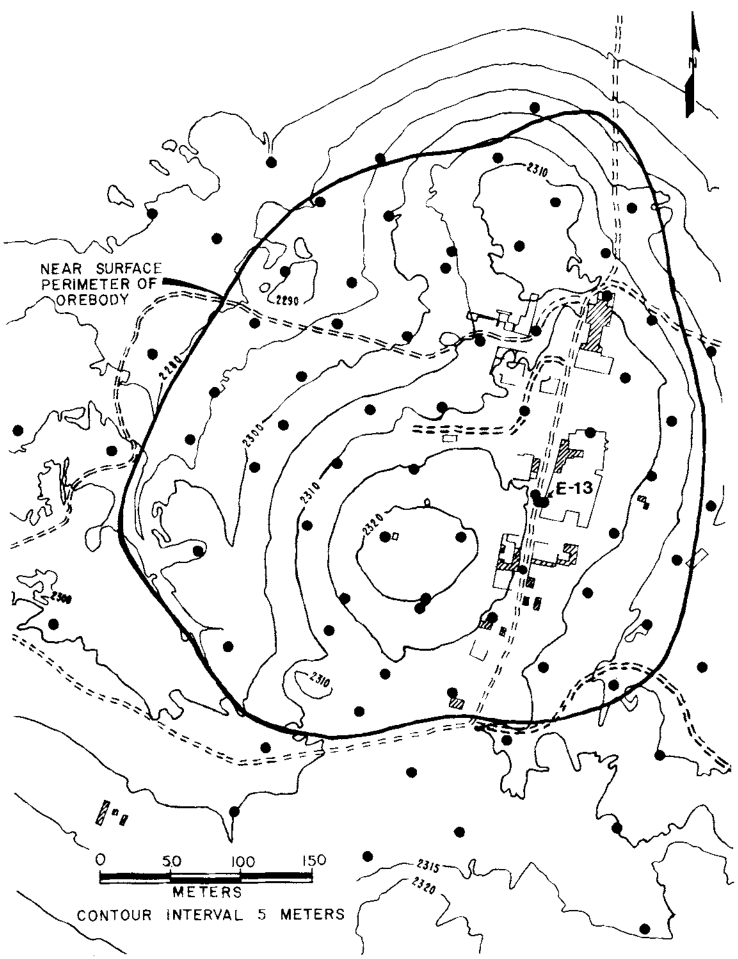

Figure 35.2. Topographic map of the Real de Angeles mineral area, orebody outline, drillhole location, and village ruins. Note location of DDH E-13.

GEOLOGICAL STRUCTURE OF THE MINERAL DEPOSIT

The Real sulphide deposit has sharply defined lateral limits, beyond which both ore and barren sulphides diminish rapidly. The mineral deposit near the ground surface measures 500 m by 400 m (Fig. 35.2). The body is asymmetrically funnel-shaped and plunges steeply to the southwest. Continuous sulphide mineralization is indicated in one sulphide drillhole to a depth of 362 m or a vertical depth of 332 m. Overburden consists of up to 15 m of mine waste rock, rock rubble of the village, and a caliche layer which is in turn successively underlain by a leached capping 5 to 10 m thick and a transition zone of mixed sulphides and oxides 25 m thick.

The sulphide body, as shown in Figure 35.3, is hosted by fine grained shallow-marine clastic rocks of the Caracol Formation of Late Cretaceous age, which consists of thin bedded, lenticular, interbedded, and intercalated sandstone, greywacke, siltstone, shale and argillite. This flysch-type stratigraphy is characteristic of the host rock. Crossbedding and slumping are observed.

Two older calcareous units, the Cuesta del Cura and Indidura formations, are exposed in the small hill immediately south of the mineral deposit, where they are overthrust above the Caracol Formation. Based on top determinations the Caracol Formation is right side up in the immediate vicinity of the mineral deposit.

MINERALOGY

Ore, associated gangue sulphide, and nonmetallic hypogene minerals occur generally as separate, discrete, small- to medium-size grains disseminated in the clayey matrix of the sedimentary rocks, as fillings and aggregates in fractures, joints, and bedding planes, and as vein matter along narrow, discontinuous faults. Galena, the iron-bearing variety of sphalerite (marmatite), and freibergite are the ore minerals. Galena and freibergite carry important amounts of silver. Pyrite, low-temperature pyrrhotite, arsenopyrite and marcasite are the gangue sulphides. They are closely associated spatially with the silver-lead-zinc mineralization.

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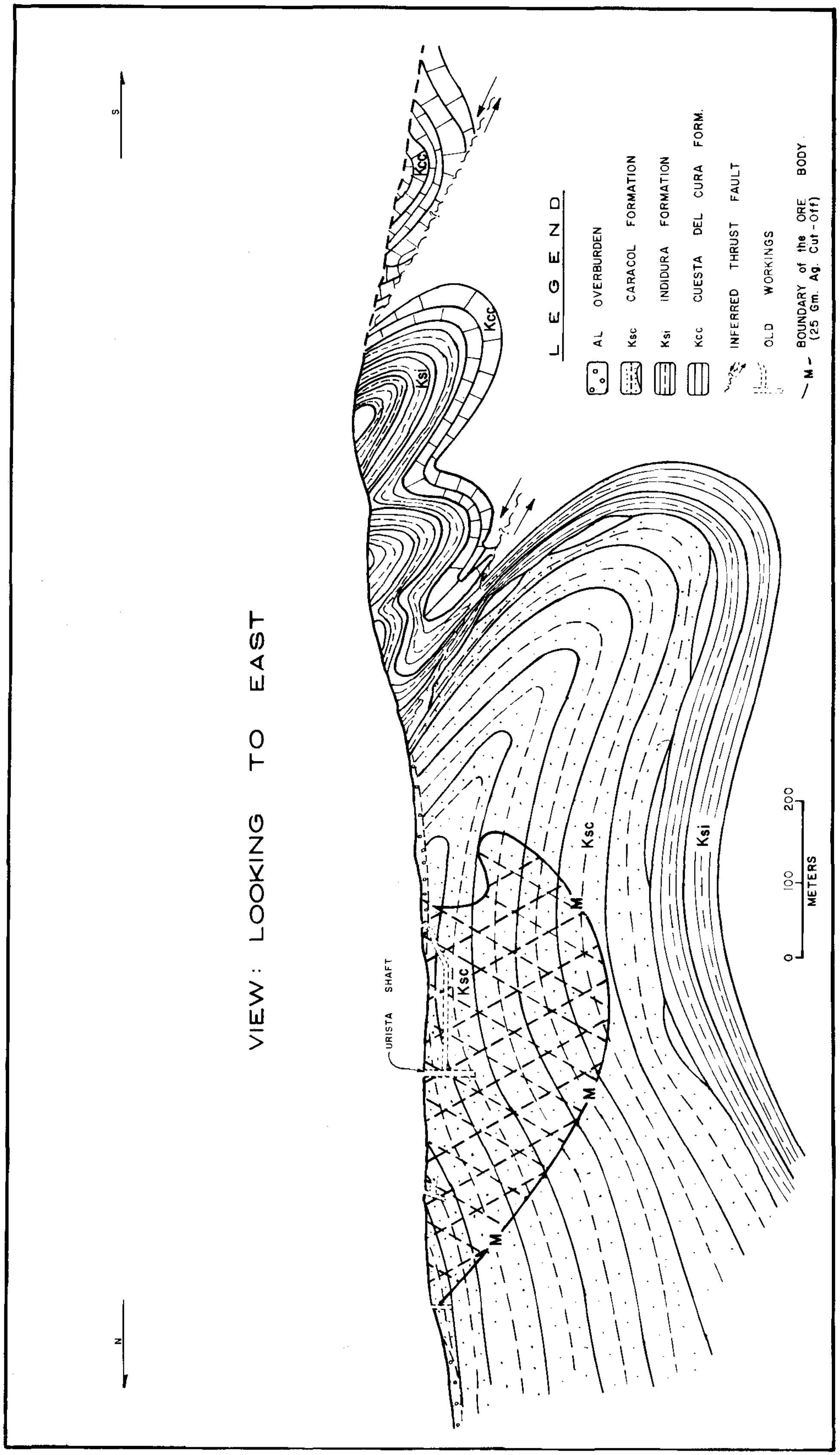

Figure 35.3. *North-south geological cross-section through Real orebody.*

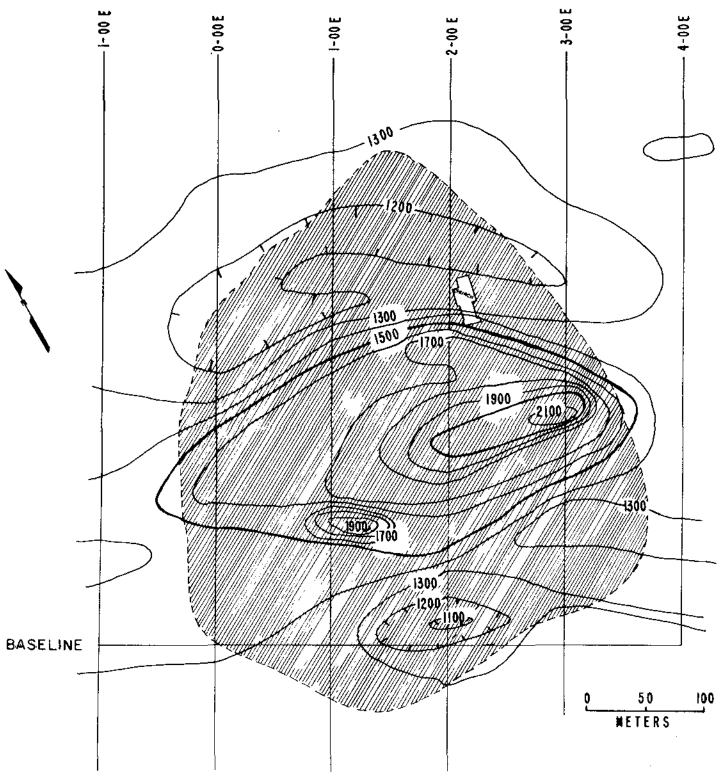

Figure 35.4. *Ground vertical-field magnetic anomaly map; contour interval is 100 gamma. Real orebody is indicated by shaded area.*

Syngenetic, diagenetic and hydrothermal processes have been proposed by various geologists for the origin of the Real de Angeles deposit. In our opinion, evidence for hydrothermal deposition prevails. No intrusive rocks are known in the vicinity. Dr. G.L. Cumming of the Department of Physics at the University of Alberta (Canada) (pers. comm.) has determined isotopically that the galena in the deposit is probably less than 25 million years old.

Pyrrhotite is distributed through the whole mineral body, averaging about 5% by volume but locally may exceed 10%. No magnetite was detected in the ore. Total sulphide content is about 5-15% by volume, of which less than 3% corresponds to the ore minerals galena and sphalerite. The volume of sulphides decreases rapidly outside the deposit to one per cent or less with pyrite becoming the dominant sulphide mineral.

GROUND GEOPHYSICAL SURVEYS

Ground Magnetometer Survey

A hand-held, vertical-field magnetometer was used in an attempt to determine whether the magnetic pyrrhotite associated with the ore minerals would give a detectable, meaningful magnetic response. A favourable response was obtained on the initial test line across the Real deposit, so five additional lines spaced 100 m apart were surveyed. Readings were taken at 20 m intervals on each line. The results contoured in Figure 35.4 show a good correlation of the magnetic anomaly with the sulphide body. The anomaly consists of an 800 gamma high flanked on the north by a 150 gamma low and trends west-northwesterly within the mineral area. This direction conforms fairly well to the strike orientation and position of the major set of fault veins that cut the disseminated body. The high concentration of pyrrhotite contained in those veins, therefore, is most likely the cause for the anomaly. The fact that this central core also defines the zone where the mineral body lies closest to the surface is undoubtedly an important factor.

The well-developed arcuate 250 gamma low located along the northern margin of the Real deposit is a direct consequence of the relatively shallow inclination of the earth's magnetic field (I = 50°N) intersecting a fairly steeply dipping magnetic body. The characteristics of the anomaly in profile change along strike. The shape is smooth and broad at the west end, suggesting a deeper source. At the east end, the anomaly is characterized by a sharp, positive peak, bounded by two sharp but weaker positive lows. Actually the ore zone has limited depth extent and is centred directly under the positive magnetic high.

The magnetic data obtained from this survey show that the magnetic response from pyrrhotite could be used to determine the location and approximate areal extent of the Real silver-lead-zinc orebody. It should be mentioned that no magnetic anomaly was indicated by a ground survey over an area of anomalous electrical conductivity encountered about 1200 m northeast of the Real deposit and another located 1000 m southwest. These areas will be referred to in more detail under Induced Polarization Survey.

Induced Polarization Survey

A portable time-domain unit (Scintrex IPC-7 and IPR-8) and a three electrode (pole-dipole) array were used in the induced polarization survey. The transmitter had a maximum output of 5000 volts and five amperes, and the receiver was set for a pulse duration of 1.5 s and an integration time of 0.3 s, which conforms to the mean value of the curve. Seven parallel lines spaced 300 m apart and one transverse line, totalling in all 15 km of traverse, were surveyed in an area of about 2.2 x 2.0 km. Readings were taken along the lines using electrode spacings of 50, 100, and 200 m, and in selected segments at 300 and 400 m spacings. The remote electrode in each case was placed off to the south side of the line (see Fig. 35.5, 35.6, 35.7, and 35.8).

Because caliche is a very poor electrical conductor, electrical contact problems were expected. Fortunately, these did not materialize and currents sufficiently high to generate voltages above the strong SP noise level were achieved in all but a few cases. However, some deviation from the regular electrode spacings had to be made when rock dumps and rock rubble and buildings of the village were encountered.

Figure 35.5 shows the chargeability and apparent resistivity pseudosections obtained on traverse line 20N heading S 62° E looking northeast, and Figure 35.6 is a line (23E) at right angles to the former. Location of the traverse lines is shown on Figures 35.7 and 35.8. The relative position of the orebody on each traverse line is also shown.

The field work and data interpretation were done by the Mexican Government Consejo de Recursos Minerales. In both cases, the IP data are plotted on vertical pseudosections according to the Consejo de Recursos Minerales practice of using the centre of the three-electrode array as the data point co-ordinate, vertically below which are plotted the IP readings at scaled distances equal to the electrode spacing and then contoured. This representation should not be taken as an electrical section of the underlying ground; rather, it is a convenient schematic plot of results from various electrode spacings on a simple visual format. The Consejo has found this schematic procedure satisfactory for their purposes in Mexico.

It can be readily seen in Figure 35.5 that the chargeability within the orebody of as much as seven times background; i.e., 20 vs. 3 millivolts, particularly near the surface, and that the apparent resistivity low of 20 ohm-metres, or less than one tenth of background resistivity, are spatially related to the orebody.

Figure 35.6 shows an IP and apparent resistivity pseudosection on line 23E, as viewed looking N 62° W. Again, the coincident chargeability high and resistivity low are directly related to the sulphide body.

The strength of these electrical responses, in particular, the resistivity anomaly, is quite surprising given the low overall metallic sulphide content in the orebody. Some observers were skeptical about the results obtained by the IP survey, thinking that graphite shale layers might have been responsible, in spite of the fact that the graphite seems to have been leached out by the hydrothermal solutions and subsequent emplacement of the sulphide minerals. This uncertainty was settled by the results of laboratory tests on mineralized core of drillhole E-13, located just east of the centre of the mineralized area (Fig. 35.2). The results are shown in Table 35.1. There is a strong IP effect in the stockwork mineralized sample at 100.5 m, which has only 4% sulphide by volume. Evidently a very high degree of interconnected sulphide stringers reduces the resistivity of these rocks. Such stringers are quite common in the Real de Angeles ore.

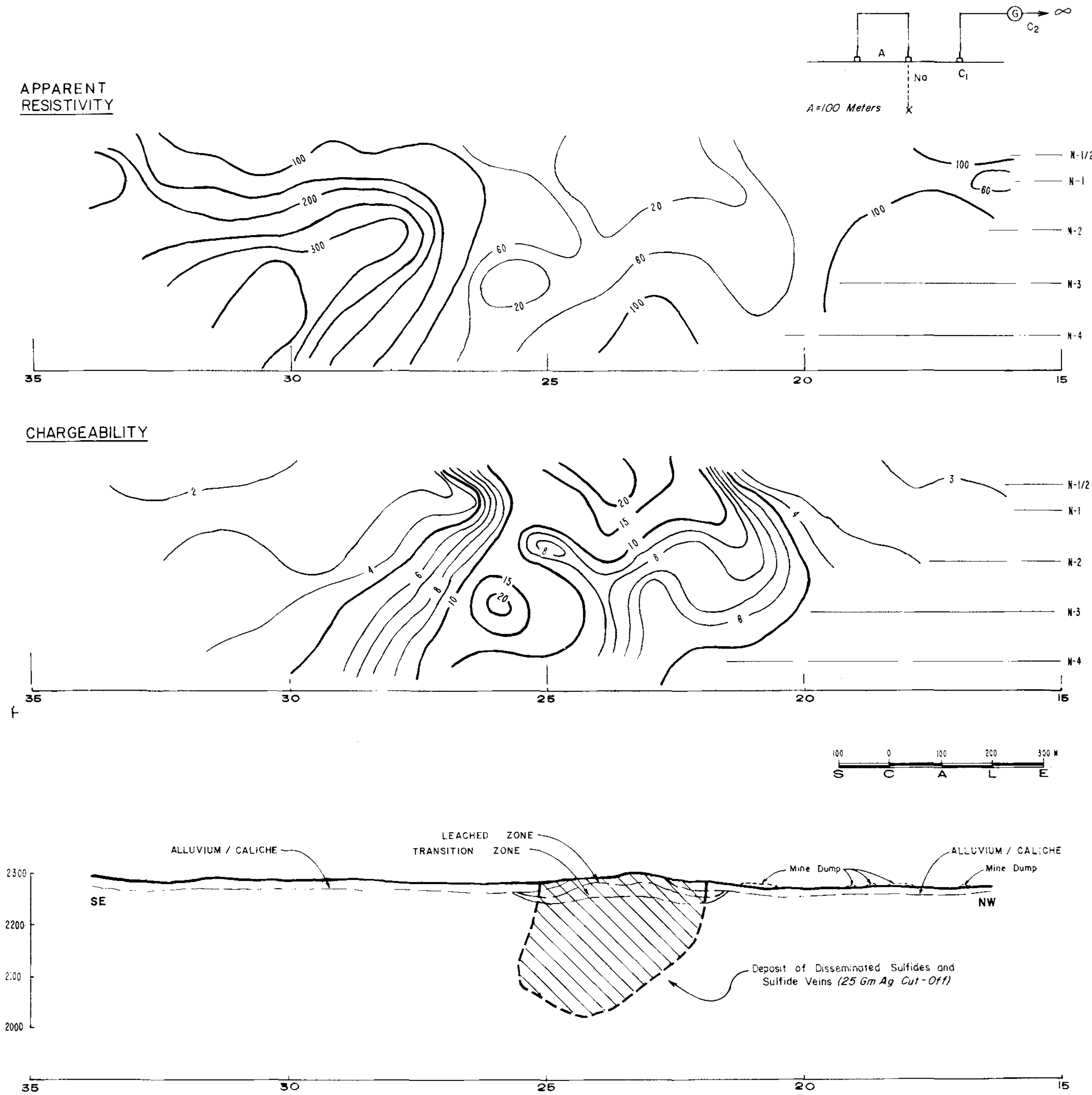

Figure 35.5. *Vertical IP and apparent resistivity pseudo-sections on line 20 N oriented N28°E.*

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Figure 35.7 shows a resistivity contour plan produced from readings taken of the same area surveyed by IP at 100 m electrode spacings; the contour interval is 20 ohm-metres. The orebody outline is shown superimposed on the resistivity results for comparison purposes. The low resistivity anomaly coincides with the known location and nearsurface outline of the mineral body.

A chargeability contour map (Fig. 35.8) based on readings of the same 100-metre electrode spacings as before shows a similar coincidence of a strong chargeability anomaly high with the Real orebody. Another anomaly with moderate chargeabilities of 6 to 10 milliseconds was encountered about 1200 m northeast of the Real de Angeles body. Unlike the Real deposit, this later anomaly is not accompanied by a resistivity low or magnetic response. Several holes drilled in this anomaly to depths of 150 m encountered only weakly pyritized Caracol rocks. The small chargeability anomaly 1000 m southwest of the Real orebody has no corresponding apparent resistivity or magnetic anomaly. This anomaly was not drilled (Fig. 35.8).

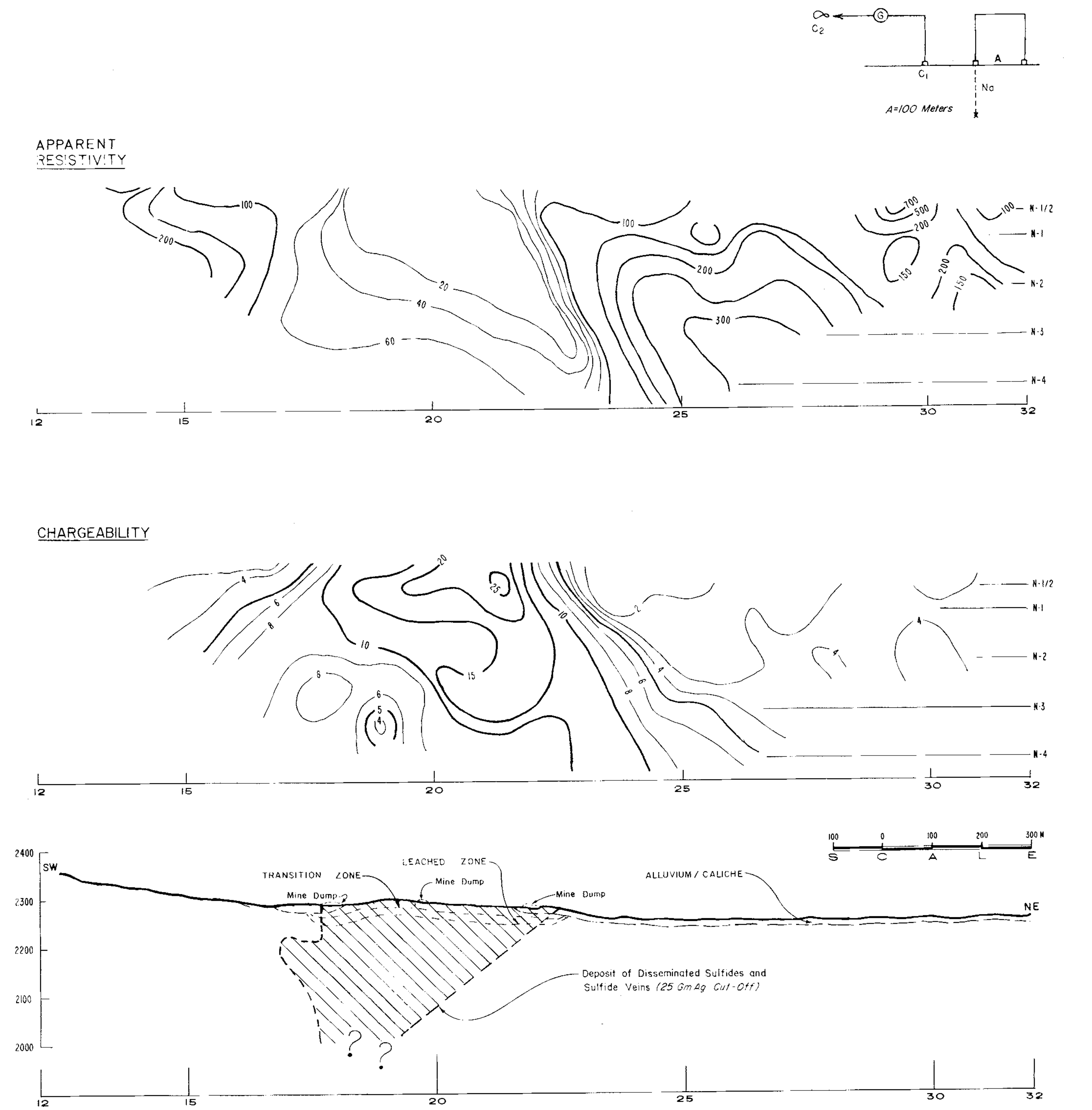

Figure 35.6. *IP and apparent resistivity pseudo-sections on line 23 E oriented N62°W.*

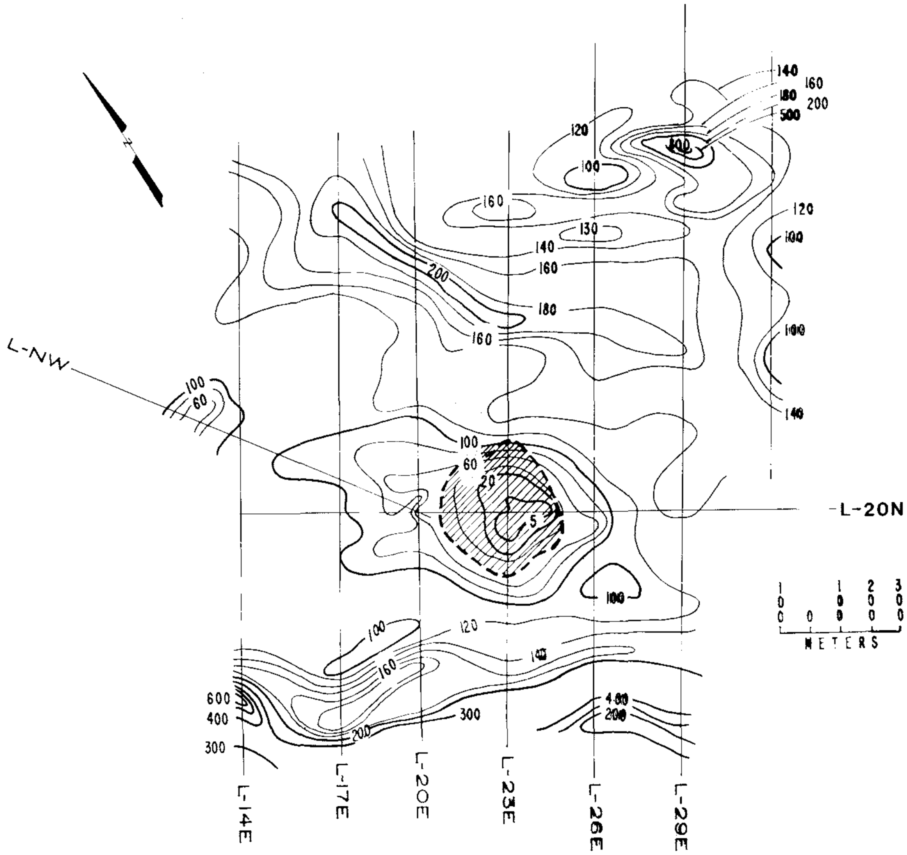

Figure 35.7. *Apparent resistivity contour map; electrode spacing is 100 m; contour units are millivolts; Real orebody is shown by shaded area.*

Table 35.1

Chargeability and mineralogical description of samples in drillhole E-13, Real de Angeles orebody

Specimen Depth (M)	% PFE	Chargeability Milliseconds	ASSAYS			Hole Interval (M)	Description
			%Pb	%Zn	Gm.Ag.		
88.5	12.7	50	1.95	1.40	180	87- 90	Diss Py, Po, Sl, Gn, in grey 1 mm sandy matrix. 4% vol. sulphides. Spec. quite magnetic.
100.5	48	200	4.0	2.50	167	99-102	Same as above but network of 2-5 mm Gn, Po, Sl grains. Numerous hairlike veinlets. Whole rock wkly. magnetic, but Po sections strongly magnetic.
139.5	50	200	1.95	1.35	77	138-141	15 mm wide Po, Sl, Gn, $CaCO_3$ veinlet in fine grain arenite. No diss. sulphides. Only large magnetic Po grains.

(Abbrev.: Py (Pyrite), Po (Pyrrhotite), Sl (Sphalerite), Gn (Galena)).

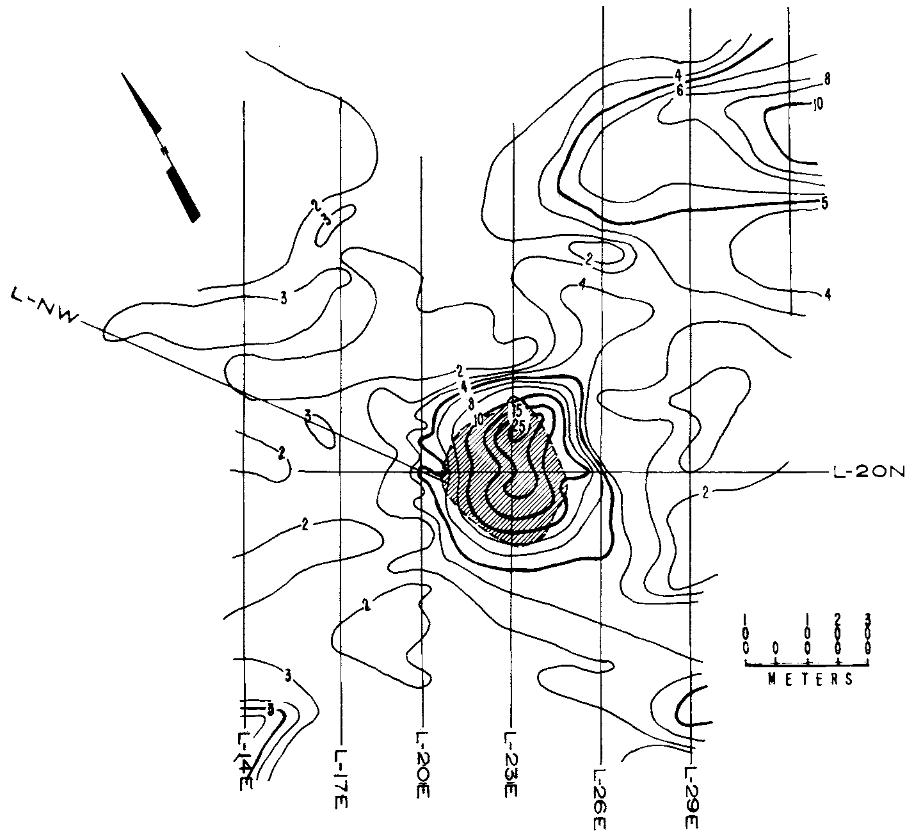

Figure 35.8. *Chargeability contour map; electrode spacing is 100 m; contour units are ohm-metres; Real orebody is shown by shaded area.*

Ground Electromagnetic Survey

A ground VLF-electromagnetic survey was attempted in the hope that massive sulphide veins and bedded layers of massive sulphides could be detected. The VLF signals from the transmitters at Seattle and Washington, USA, and Balboa, Panama were utilized. The survey proved ineffective because the orebody is not conductive enough to give a readable response.

DIAMOND DRILLING

EXPLOMIN and a previous exploration company together drilled a total of 13 123 m in 78 surface holes, a large majority of which were oriented S 28°W at angles of minus 45 to 75°. Hole depths ranged from 41 to 366 m, and, in the latter instance continuous sulphide mineralization was encountered to a hole depth of 362 m. Core size was principally NXWL. Also, two holes totalling 254 m were drilled to test the satellite geophysical anomaly located northeast of the Real de Angeles deposit.

MINERAL RESERVES

As a result of the foregoing development and exploration work, the Real de Angeles silver-lead-zinc deposit appears amenable to low-cost open pit mining methods because of its physical shape, low waste-to-ore ratio, and the uniform distribution of ore minerals therein. Ore reserves have been calculated at 51.1 million metric tons grading 78.4 g (2.5 oz.) silver per ton, and about 1% each of lead and zinc, using a 25 g silver cut-off. Recoverable amounts of cadmium and copper are also present. At the time of writing (September, 1977), a final decision to bring the deposit into production was awaiting further economic evaluations.

CONCLUSIONS

Ground geophysical surveys co-ordinated with core drilling and geological mapping were carried out in an attempt to use the magnetic and electrical properties of the more abundant gangue sulphide minerals as a guide to determine indirectly the limits of the Real de Angeles silver-lead-zinc orebody and to prospect for other blind orebodies under a caliche cover. The geophysical survey was a qualified success in correctly delineating extent of the Real de Angeles orebody. No additional orebodies were discovered as a result of this survey.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to the Banco de Comercio, Comision de Fomento Minero, and Placer Development Ltd., the shareholders of Explomin S.A. de C.V. for permission to present this paper on the Real de Angeles mining property. The data used in this case history were drawn from technical reports written by staff geophysicists of the Mexican Consejo de Recursos Minerales while under contract to Explomin, and from technical input of the exploration staffs of both Explomin and Placer. The efforts of our colleagues and the Mexican Government geophysicists are gratefully acknowledged. Also, we wish to thank R.A. Rivera and R.K. Warren for their critical review of the technical data covered in this paper.