APPLICATION OF X-RAY DIFFRACTION ALTERATION AND GEOCHEMICAL TECHNIQUES AT SAN MANUEL, ARIZONA

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Abstract

Alteration zoning at the San Manuel-Kalamazoo porphyry deposit near San Manuel, Arizona has been evaluated by the X-ray diffraction method of monomineralic contouring. Over 350 drill and draft samples from the San Manuel segment have been analyzed by X-ray diffraction for major alteration minerals, including sericite, quartz, pyrite, K-feldspar, plagioclase, chlorite, etc., followed by plotting and contouring of XRD data.

Contouring of alteration data indicates that the San Manuel orebody is bound by concentric zones of alteration assemblages that outline the general shape of the ore zone. Alteration zones include: (a) external zones that surround the orebody as concentric outer envelopes of sericitization, silicification and pyritization, and (b) internal zones of high plagioclase-low K-feldspar (locally high biotite) that make up the porphyry core of the deposit, and (c) K-feldspar-rich zones that usually coincide with the orebody, but are occasionally discordant to the ore and alteration zones.

Monomineralic contouring for each type of alteration corroborates the general conclusion that the San Manuel orebody is terminated circumferentially and at the east end by closed contours, but remains open to the west and on top, where the Kalamazoo segment is believed to have been removed.

Résumé

On a étudié les auréoles d'altération du gisement porphyrique de San Manuel-Kalamazoo, situé près de San Manuel (Arizona), par la méthode consistant à tracer les contours lithogéochimiques de chaque élément identifié par diffraction X. On a analysé plus de 350 échantillons de surface ou recueillis par forage dans le secteur de San Manuel, par la méthode de diffraction X, afin d'identifier les principaux minéraux d'altération: séricite, quartz, pyrite, K-feldspath, plagioclase, chlorite, etc.; on a ensuite reporté les résultats et tracé les contours lithogéochimiques qui correspondent aux minéraux d'altération.

Le tracé des contours montre que le corps minéralisé de San Manuel est délimité par des auréoles concentriques d'altération, qui donnent la configuration générale de la zone minéralisée. Les auréoles d'altération sont constituées (a) des zones externes qui enveloppent le corps minéralisé, à savoir les auréoles concentriques, de séricitisation, de silicification et de pyritisation et (b) les zones internes riches en plagioclase et pauvres en K-feldspath (avec localement une forte concentration de biotite), qui forment le noyau porphyrique du gisement et (c) les zones riches en K-feldspath, qui coïncident habituellement avec le corps minéralisé, mais ne concordent pas toujours avec les zones minéralisées ni avec les auréoles d'altération.

Le tracé géolithochimique correspondant à chaque minéral indicateur pour toutes les phases d'altération, confirme la conclusion générale à laquelle on était parvenu à savoir que le corps minéralisé de San Manuel est bordé à l'est par des contours fermés, mais des contours ouverts à l'ouest et à son sommet, le segment de Kalamazoo ayant probablement été érodé.

INTRODUCTION

In recent years, Newmont Exploration Limited (NEL) has developed a quantitative method for the measurement of alteration minerals in altered wall rock. This method, termed monomineralic contouring, has been successfully demonstrated in the evaluation of various mineralized prospects (Hausen and Kerr, 1971; Hausen, 1973), and applied to the detailed investigation of alteration trends at the San Manuel porphyry copper deposit, San Manuel, Arizona.

This alteration study correlates pervasive wall rock alteration with copper mineralization at San Manuel, and provides a test case for the contouring of XRD alteration data around mineralized centres in a large porphyry copper deposit. Techniques of monomineralic contouring are described from a case history aspect at San Manuel, and as a state-of-the-art development in mineral exploration, supplementing conventional methods of geochemistry and geophysics.

HISTORY AND DEVELOPMENT

Magma Copper Company, a wholly owned subsidiary of Newmont Mining Corporation, operates one of the world's largest underground copper production facilities at San Manuel, Arizona. The San Manuel copper deposit is in the desert valley of the San Pedro River between the Santa Catalina and Galiuro mountains, about 35 miles northeast of Tucson, in the Old Hat District, Pinal County, Arizona (Fig. 36.1).

Early exploration at San Manuel included drilling by the U.S. Bureau of Mines in 1944, which established the existence of the copper deposit (Schwartz, 1953). The Bureau discontinued work in 1945 when the Magma Copper Company obtained an option on the property. Development churn drilling was continued by Magma from 1945 to 1947, conforming to the original Bureau of Mines' drill pattern. By 1947, approximately 120 million tons of ore averaging 0.8 per

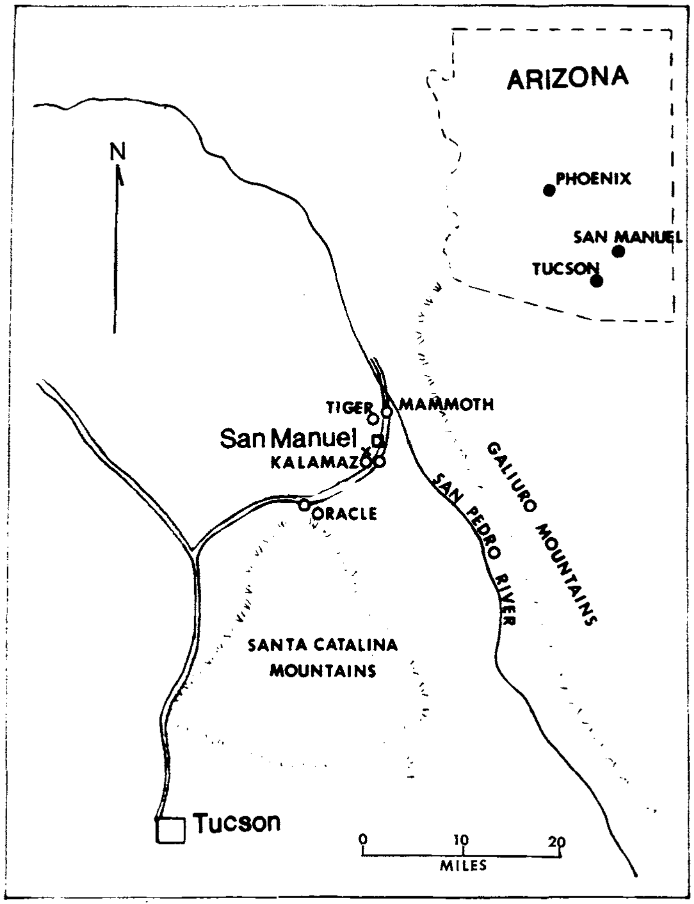

Figure 36.1. *Location map of San Manuel area, Arizona.*

cent copper (Steele and Rubly, 1947) were blocked out. This resulted in the development of the San Manuel underground block-caving mine which has a current production capacity of about 60 000 tons per day.

An exploration project west of the San Manuel deposit was initiated by Quintana Minerals Corporation in 1967, resulting in the discovery of the down-faulted segment of the San Manuel orebody. The project was based on the concept by J.D. Lowell (Lowell, 1968) that the original orebody was cylindrical with concentric alteration zoning, the orebody being first tilted approximately 70°, then bisected by the flat San Manuel normal fault into the lower plate San Manuel segment and the upper plate Kalamazoo segment. Reserves of the combined San Manuel-Kalamazoo orebody are reported at approximately a billion tons of 0.75 per cent copper (Dayton, 1972).

According to Lowell (op. cit.), the Kalamazoo orebody has the shape of an overturned canoe, complementing the upturned San Manuel ore shell to the east. Development drilling was guided by geology and mineral zone symmetry extrapolated from the San Manuel deposit.

Recent geochemical investigations by Chaffee (1976) on drill samples from Kalamazoo indicated that sulphur and selenium offer considerable promise as pathfinder elements. According to L.A. Thomas (pers. comm.), the inner edge of the selenium anomaly at San Manuel and Kalamazoo is essentially coincident with the inner edge of the ore shell. The outer edge of anomalous selenium is significantly outside of the ore zone, extending for distances up to 1000 feet (305 m), or more, into the outer pyritic-sericitic zones of altered wall rock.

GEOLOGIC BACKGROUND

Most of the San Manuel area is underlain by Gila Conglomerate, consisting of coarse boulder conglomerate to fine marly silt, representing late fanglomerates and playa (or lake) deposits, respectively.

The Cloudburst Formation of late Cretaceous or early Tertiary age consists of more than 6000 feet (1800 m) of intercalated fanglomerates and propylitized latite flows which unconformably underlie the Gila Conglomerate, and overlie the Precambrian granitic rocks of the area.

A large area of volcanic rocks (basalt flows, flow breccias, and agglomerate) occurs north and northwest of Tiger; these appear to lie below the main beds of the Gila Conglomerate. Dykes and irregular masses of rhyolite, which cut all formations older than the Gila, are also found over a wide area.

Precambrian basement rocks comprise mostly Oracle quartz monzonite and an older granodiorite. Leucocratic rocks (aplite and alaskite) appear to be related but slightly later than the Oracle quartz monzonite. The crosscutting relations of late diabase dykes suggest partly Precambrian and partly Cretaceous age (Creasey, 1965).

Laramide porphyry intrusives ranging from dacite, granodiorite, and latite to monzonite occur as small irregularly-shaped masses and dykes in the Oracle quartz monzonite, and are the principal host rock for the disseminated copper ores of the San Manuel deposit.

The San Manuel deposit is situated within a central concentration of Laramide intrusives. Much of the orebody lies within the porphyry intrusives and along highly brecciated contacts with the Oracle quartz monzonite. The deposit is roughly 2000 to 3000 feet (600 to 900 m) in overall diameter, more than 6000 feet (1800 m) in length, and is developed in multiple, rod-shaped injections of porphyry that interfinger with lenticular slices or fragments of Oracle quartz monzonite. Most of the elongate Oracle fragments and porphyry plugs have a similar orientation and are parallel to the cylindrical axis of the ore shell.

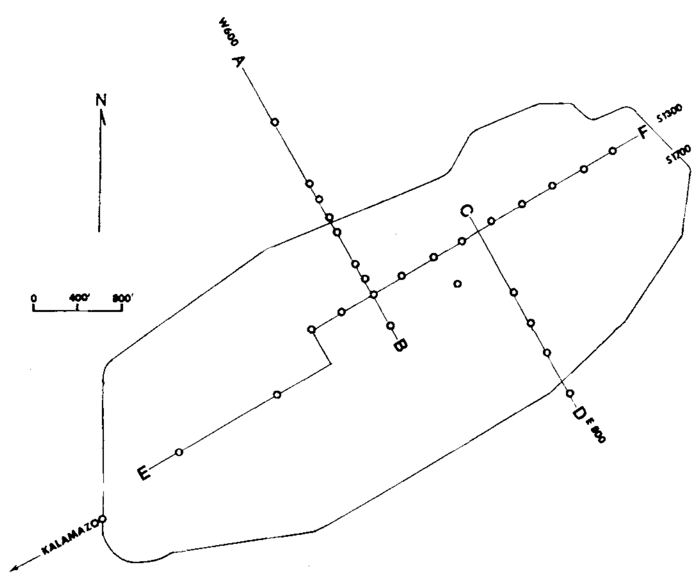

Figure 36.2. *San Manuel plan map, sections AB, CD, and EF.*

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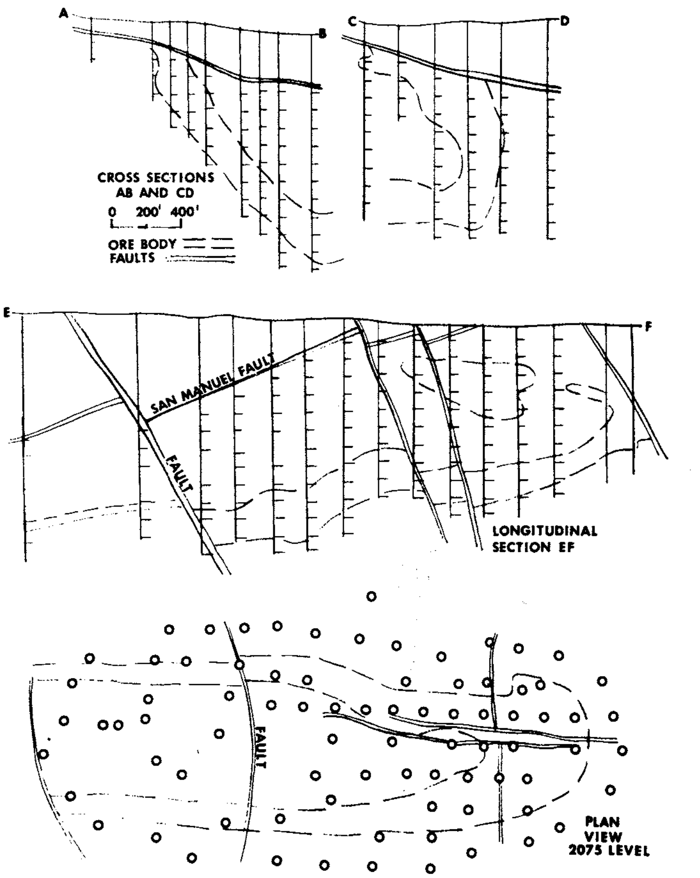

Figure 36.3. *Sampling patterns along sections in San Manuel deposit.*

Rock types in the ore zone are commonly heterogeneous and hybrid in appearance, often consisting of mixtures of porphyry and Oracle quartz monzonite. Such mixtures have been highly sheared, K-feldspathized and recrystallized, and appear to represent hydrothermally-healed shear zones. Hybrid zones, consisting mostly of Oracle quartz monzonite, appear to have been remobilized during shearing and multi-injections of porphyry; these zones probably represent major avenues of hydrothermal solution movement during the period of mineralization.

LOCATION AND DESCRIPTION OF SAMPLING

Whole rock samples from the San Manuel orebody were obtained along several sections, including two cross-sections, one longitudinal section, and one horizontal section through the 2075 level of the mine (Fig. 36.2). Most of the samples were collected from churn drill cuttings obtained in the 1940s and retained in storage for over 30 years. The irreplaceable nature of these samples cannot be overstated, since they provide the means for reconstructing the original alteration zoning of the deposit. The deposit has since been block-caved to a major degree and is inaccessible to sampling.

Ten-foot (3 m) samples were composited every 200 feet (60 m) along equivalent horizons (elevations) from each drillhole through the longitudinal and cross-sections (Fig. 36.3). Samples from the Plan view (2075 level) were also selected from churn drill cuttings, and supplemented by additional chip samples collected by hand from locations in haulage drifts at this level where no previous churn drilling existed (Fig. 36.3). The grid spacing of sampling at this level was between 200-500 feet (60-150 m).

Most of the churn drill pulps were received in a sufficiently pulverized condition for direct analysis by X-ray diffraction.

FEATURES OF MINERALIZATION

The semi-elliptical shape of the San Manuel orebody in cross-section is outlined by the 0.6 per cent Cu contour. The 0.3 and 0.1 per cent Cu contours show the distribution of lower grade copper mineralization around the orebody.

The orebody outlined in cross-sections (Fig. 36.4) is distributed about equally between the Oracle quartz monzonite on the west and the Laramide porphyry on the east.

If the two halves were brought into juxtaposition, the orebody would appear as a tilted U-shaped configuration, with the open portion of the "U" oriented upwards toward the west.

Contours of copper mineralization are generally smooth and uniformly spaced, indicative of gradational decreases away from the ore zone (Fig. 36.5). The eastern perimeter of the deposit shows a relatively wide zone of low grade copper mineralization (0.1-0.2 per cent) persisting for an indeterminate distance. This greater thickness of low grade copper dissemination is related in part to the sharp flexure (greatest curvature) of the ore shell, and in part to the porphyry host rock which commonly carries low grade copper mineralization.

The orebody in longitudinal section (defined by the 0.6 per cent Cu contour) appears for the most part as a planar-shaped layer (Fig. 36.4), plunging gently towards the southwest, locally segmented by steeply-dipping normal faults to the east, and largely terminated by the Hangover Fault on the west. Copper mineralization continues on the west side

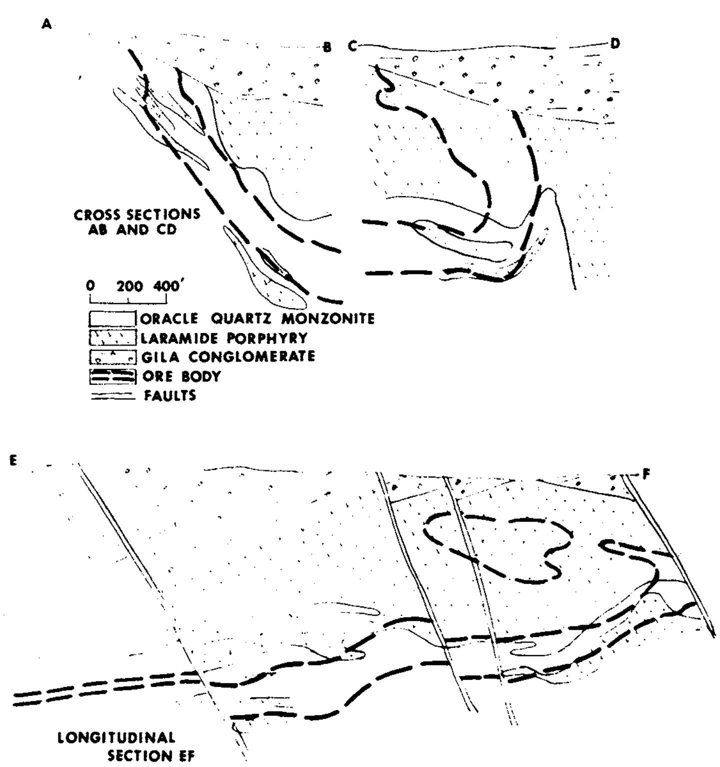

Figure 36.4. *Geologic cross-sections of San Manuel deposit.*

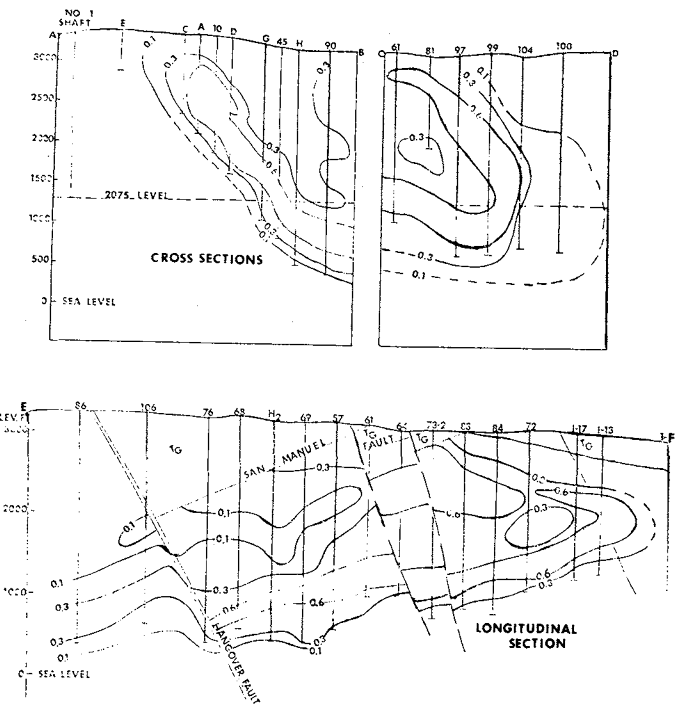

Figure 36.5. *Per cent copper distribution in San Manuel sections.*

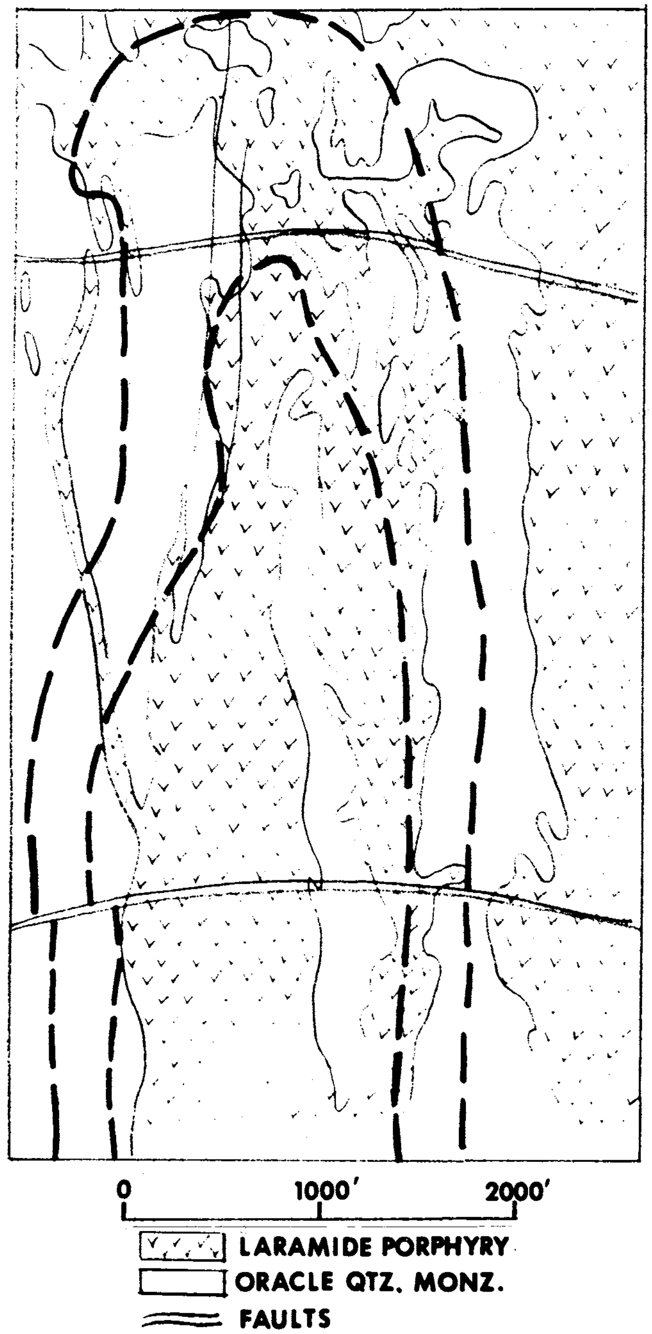

Figure 36.6. *Geologic plan of 2075 level.*

of the fault, but at lower grades and at higher elevations. The orebody throughout much of its extent follows the contact between the Oracle quartz monzonite and the Laramide porphyry.

A major flexure in the orebody occurs at the eastern end, where the zone of high copper values (>0.6 per cent Cu) swings upward and rolls back towards the east at higher elevations (Fig. 36.4, 36.5). This upper ore zone is largely oxidized and variable in thickness and continuity.

The San Manuel orebody follows an irregular intertongued contact in the horizontal section through the 2075 level of the mine (Fig. 36.6). The orebody at this level (defined by the 0.6 per cent contour) has a horseshoe-shaped configuration, with the open end oriented toward the Kalamazoo Block to the southwest. Copper contours are uniformly spaced, indicative of gradational changes in copper values away from the ore zone.

TECHNIQUES OF X-RAY DIFFRACTION ANALYSIS

X-ray diffraction analysis provides a direct measure of most major alteration features, including sericitization, K-feldspathization, silicification, and pyritization, and more qualitatively of chloritization, kaolinization, and carbonatization. The use of such facies terms as "potassic" and "propylitic" are thus supplemented by mineralogic terms such as "K-feldspathic", "sericitic", "chloritic", "pyritic", etc., which relate directly to the distribution of their mineralogic equivalents, e.g., K-feldspar, sericite, chlorite, pyrite, etc., as alteration replacements in wall rocks.

A transistorized Norelco X-ray diffractometer with a wide range goniometer, a curved graphite crystal monochromator, and a transistorized Honeywell recorder was utilized in obtaining X-ray diffraction patterns for this investigation. Pulp samples were pulverized to nominal 200 mesh at San Manuel, and scanned from 2 through 40 degrees, 2θ, at a scanning speed of 2 degrees per minute, using Cu Kα radiation. Samples were continuously scanned and rotated at an operating voltage of 40 kv and 25 ma at a sensitivity of 1000 cps. Sensitivity and alignment were checked periodically, using a standard quartz mount, to insure minimum instrumental deviation.

Special care was taken to prepare sample surfaces that were relatively reproducible under X-ray analysis. Preferred orientation of mineral grains is the source of largest error, and is minimized by fine grinding and random packing. Random orientation is approached by impressing the surface with a grid design similar to that described by Peters (1970), which is called simply a Peters grid.

Sample holders were one-inch (2.54 cm) in diameter and recessed 0.020 inch (0.051 cm) with a 0.020 inch (0.051 cm) thick rim to retain about 1/2 gram of pulverized sample.

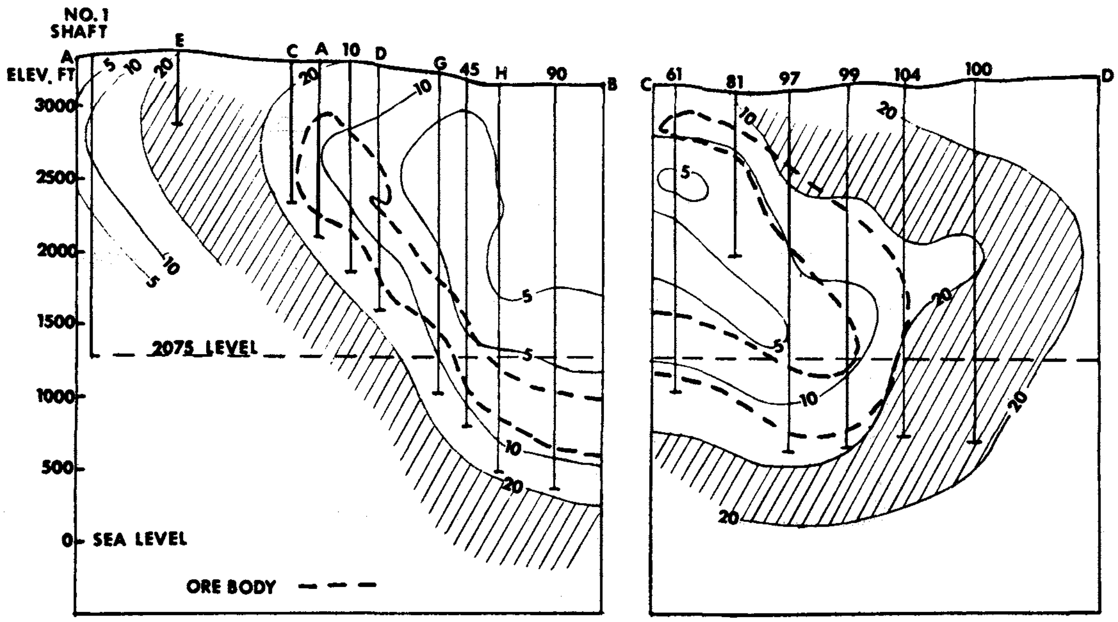

Figure 36.7. *Sericitization: per cent sericite distribution in cross-sections AB and CD.*

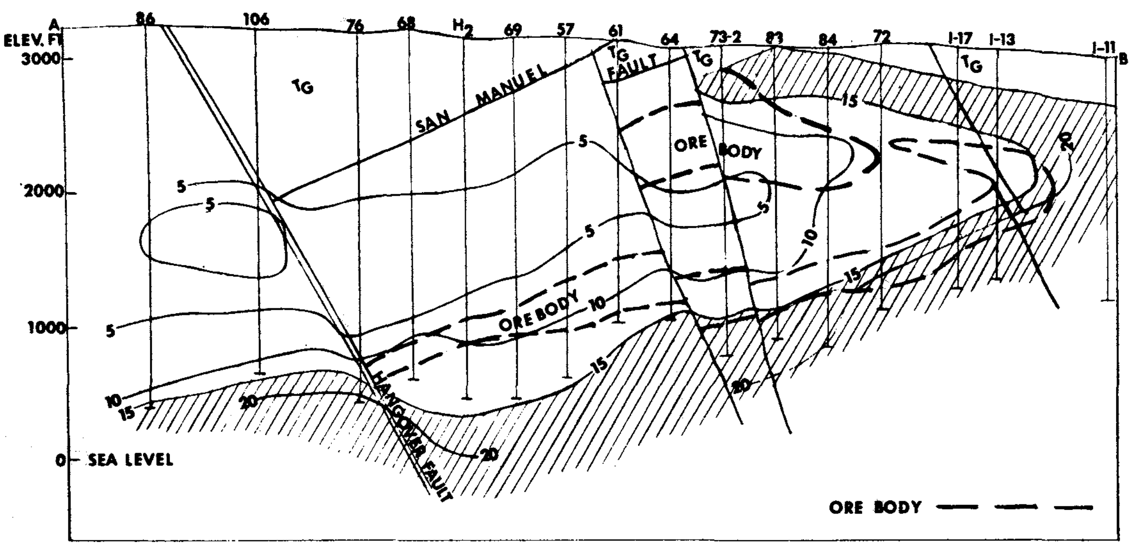

Figure 36.8. *Per cent sericite distribution longitudinal section EF.*

The sample, when ready for scanning, was placed in a Philips rotating flat specimen holder, Type No. 52413, and rotated continuously during analysis.

Peak intensities for characteristic reflections of each mineral were calculated into weight percentages by means of computer processing, using standard curves for each mineral and normalizing to 100 per cent. The mineralogic composition for each sample was calculated in the same manner, to provide semiquantitative weight percentages for quartz, plagioclase, K-feldspar, sericite, chlorite, calcite, pyrite, amphiboles, etc.

For quartz, peak intensities for only the 100 (4.26Å) reflection were measured as a guide to silicification. Only one peak was required for reproducible analyses, because of the refinements in use of a rotating sample holder and Peters grid.

For pyrite, peak intensities for the 200 (2.71Å) reflection were measured as a guide to pyritization. This peak has no apparent interferences, other than the 104 spacing for hematite near 2.68Å, and shows good reproducibility using a Peters grid and a rotating sample holder.

For sericite, peak intensities for two reflections, including the 004 (4.97Å), and 110 (4.47Å) spacings, corresponding to $2M_1$ muscovite, were measured, integrated, and converted into estimated percentages as a guide to sericitic alteration. Coarse grained micas including biotite were estimated largely from the 001 (10.0Å) spacing, to which some intensities are contributed by sericite and illite.

In the evaluation of K-feldspathic alteration, a ratio method was used, whereby the intensity of the 050 spacing for K-feldspar (3.24Å) is divided by that of plagioclase (3.18Å), and expressed as a quotient.

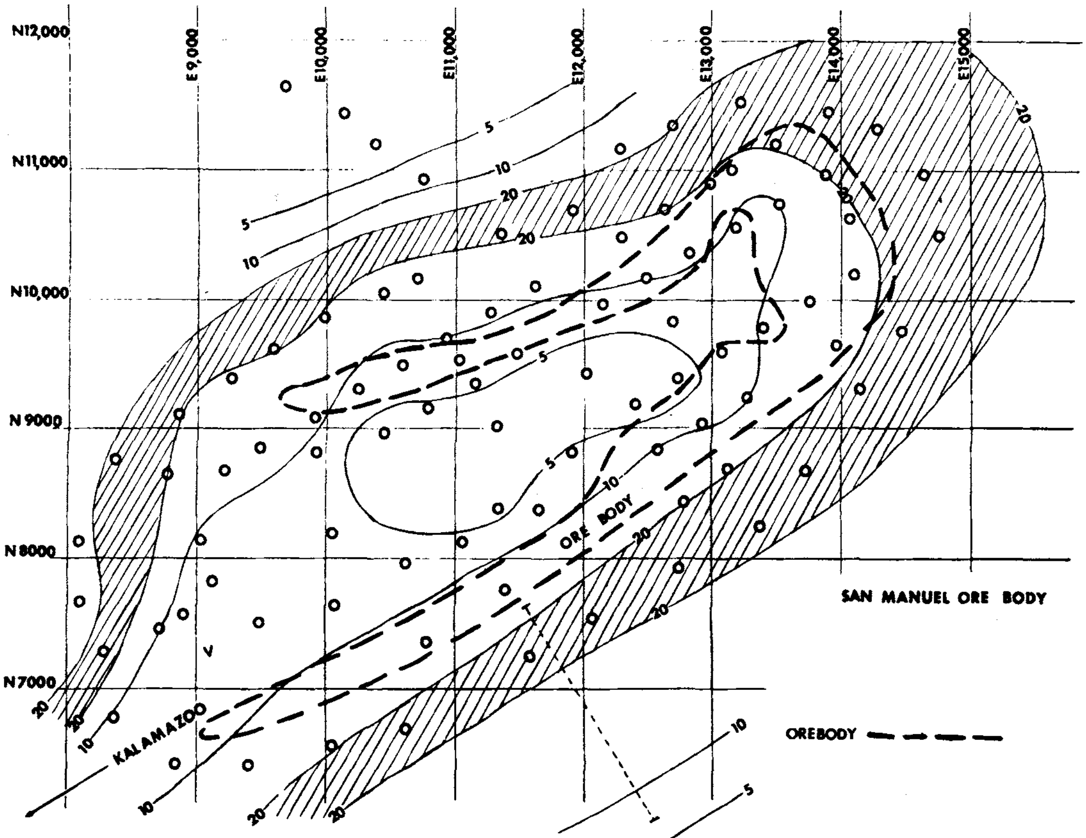

Figure 36.9. *Sericitization: per cent sericite distribution horizontal section 2075 level.*

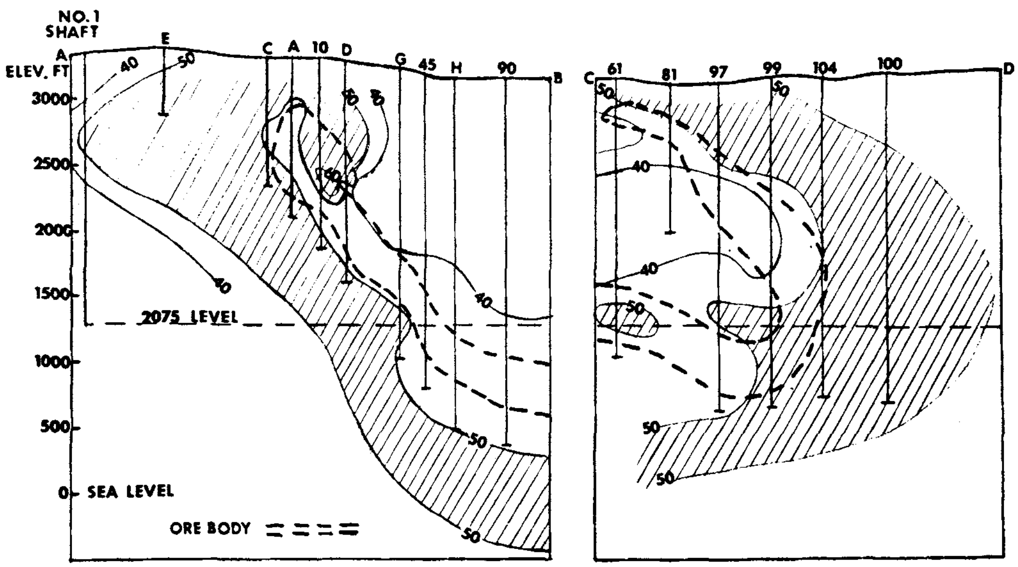

Figure 36.10. *Silicification: per cent quartz distribution in cross-sections AB and CD.*

On the basis of repetitive mineral analyses, the XRD data obtained by the methods described are considered sufficiently precise (although semi-quantitative) for contouring alteration data and evaluating mineralizing trends in mineral exploration.

Coefficients of variation have been compared for deviations of 1, 2, and 3 sigma, representing, respectively, the 65, 95, and 99.7 percentage confidence levels. Of the minerals tested, quartz shows the lowest variation, ranging between 5 and 10 per cent for one sigma, and averaging near 7 per cent for all of the sets ($n = 60$). Coarse micas show the highest variation, averaging near 15.6 per cent for all of the sets. Plagioclase shows relatively close precision (averaging near 8.5 per cent for one sigma), whereas sericite, chlorite, and calcite tend to group between 13 to 15 per cent.

The occasional large deviations in XRD analysis are usually attributed to preferred orientation of cleavage flakes, a feature that is often a problem in analyzing feldspars and sericitic micas. The problem is more serious using a flat pack instead of a gridded pack. However, major alteration trends are usually discernible in spite of higher deviations, because of the multiplicity of data points in contouring.

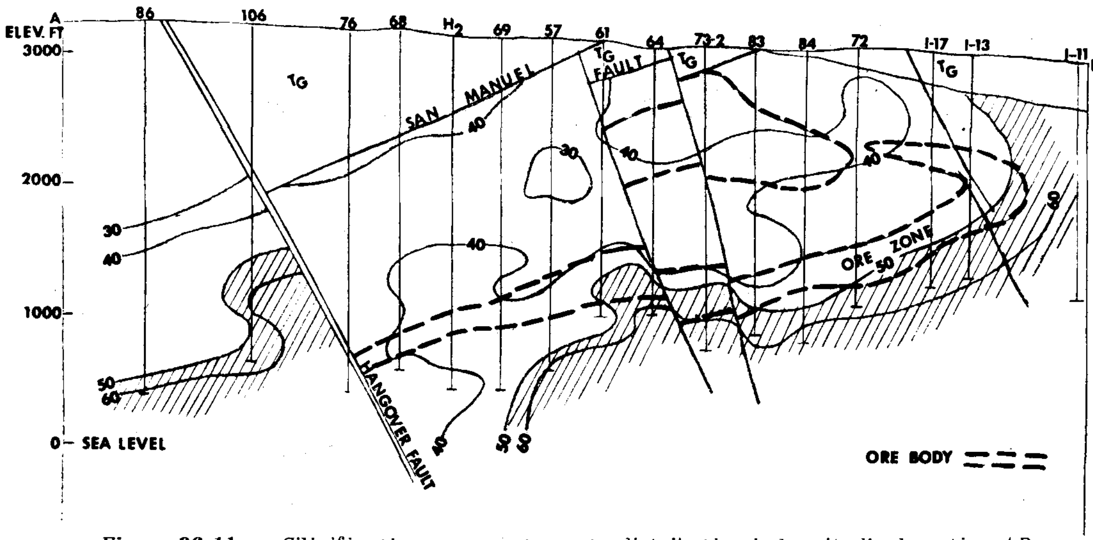

Figure 36.11. *Silicification: per cent quartz distribution in longitudinal section AB.*

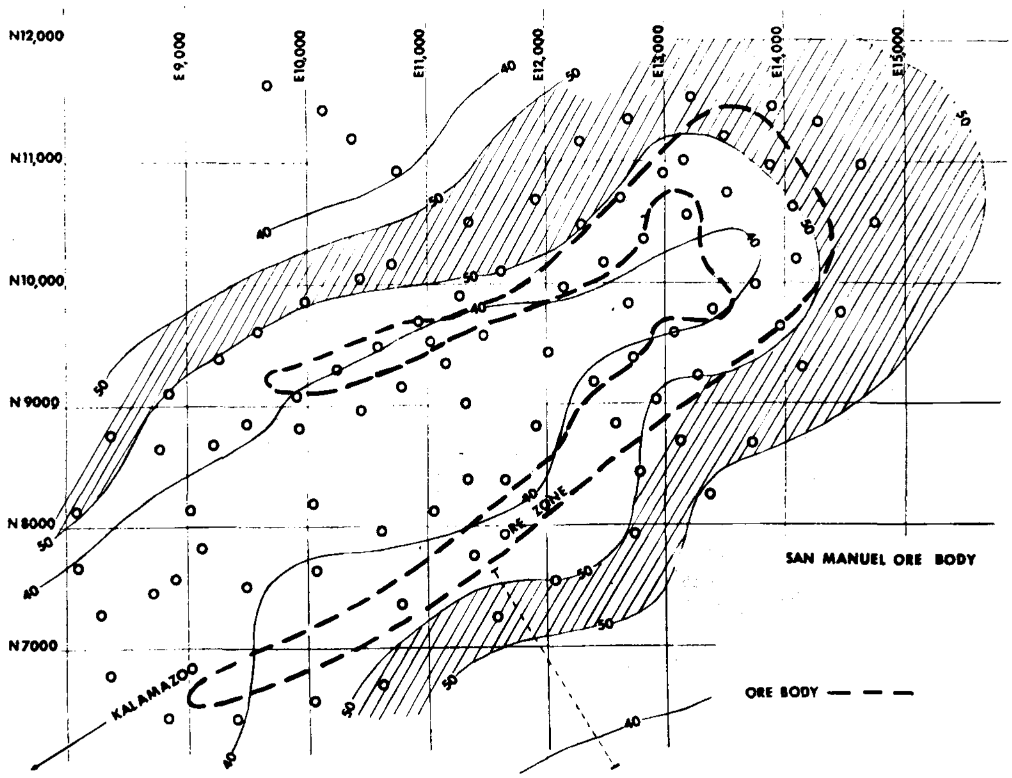

Figure 36.12. *Silicification: per cent quartz distribution horizontal section 2075 level.*

to over 20 per cent immediately outside the ore zone. A zone of high sericite follows the outer perimeter of the ore zone, thickening along the eastern margin. The 5 and 10 per cent sericite contours within the inner porphyry core are conformable to the orebody and to the sericite high around the exterior margins of the ore shell, and reflect the overall symmetry of the deposit. Contours are closed at both east and west ends of the deposit and appear to swing around the top of the deposit, intersecting the surface.

In longitudinal section (Fig. 36.8), the zone of intense sericitic alteration occurs as a blanket layer, conformable to the lower margins of the primary ore zone and the contact zone between the porphyry and underlying Oracle quartz monzonite. Contours of sericitization (5, 10, 15, and 20 per cent) are conformable to the general outline of copper mineralization and appear to swing around the top of the upper oxidized orebody on the east, and to intersect the surface in the vicinity of the San Manuel fault.

FEATURES OF ALTERATION

Relevant alteration minerals, including sericite, quartz, feldspars, pyrite, etc., were analyzed by X-ray diffraction, as described above. Semi-quantitative values for each alteration mineral are plotted and contoured in sections, analogous to copper values, to outline the trends of wall rock alteration.

Sericitization

Estimated percentages of sericite are plotted and contoured in cross-section in Figure 36.7, showing a conformable halo of sericitization surrounding the orebody. Sericite values range from about 5 per cent or less in samples from the inner porphyry core and outermost zones away from ore,

In horizontal section (Fig. 36.9), sericitization occurs as a conformable halo, surrounding the orebody and outlining its general U-shaped configuration. The zone of highest sericite values (20 per cent or more) averages about 500 feet (150 m) in thickness, becoming thicker along the major flexure at the northeast end of the orebody. Sericite diminishes inside and outside of this curvilinear blanket around the ore shell, decreasing to 10-15 per cent within the ore shell, and to less than 10 per cent within the central porphyry core. Sericite also decreases along the exterior margins, although more gradually on the north and east sides within porphyry. Contours remain open to the southwest towards the Kalamazoo segment.

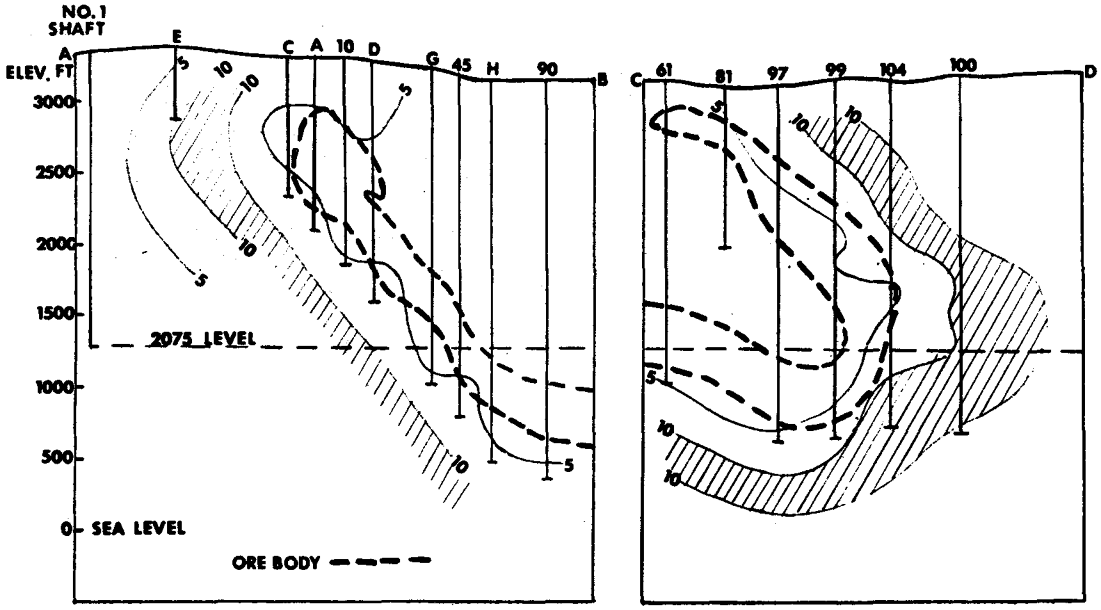

Figure 36.13. Pyritization: per cent pyrite distribution cross-sections AB and CD.

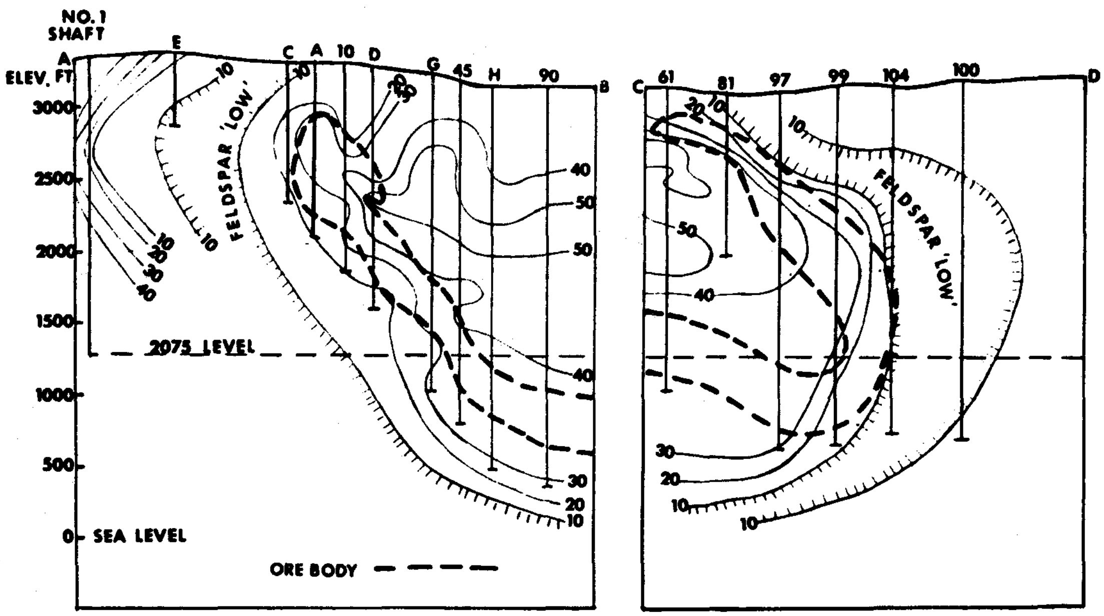

Figure 36.14. Percentages of total feldspar in cross-sections AB and CD.

Silicification

Most features of the silicification in cross-section (Fig. 36.10) are conformable to the orebody and similar in shape and dimensions to the sericite halo. Anomalous quartz values, defined by the 50 per cent contour, occur as a crescent-shaped zone along the perimeter of the orebody, extending away from the ore for distances up to 1000 feet (300 m) or more. Thickening of this zone occurs along the eastern margin.

Contours of decreasing silicification (40 and 30 per cent quartz) show conformable relations to the orebody along the inner and exterior margins of the deposit. Contours are closed inside the orebody, but open upward toward the surface where they lap over at both ends in a recumbent manner.

The features of the silicification in longitudinal section are also conformable (Fig. 36.11). High quartz values occur as a peripheral zone of silicification underlying the primary ore zone. The thickness of this exterior fringe cannot be determined because none of the holes penetrated through this zone. Within the ore shell contours of decreasing silicification are concentrically distributed, showing conformable geometry to the orebody and extending around the eastern nose of the deposit.

In horizontal section (Fig. 36.12), high quartz values form a continuously concordant zone paralleling the ore shell and overlapping the sericite blanket outside of the ore zone. The silicification halo has similar dimensions and shape as the sericitization halo, and shows similar decreases in intensity both inside and outside of the ore shell. Contours are open at the southwest end toward the Kalamazoo segment.

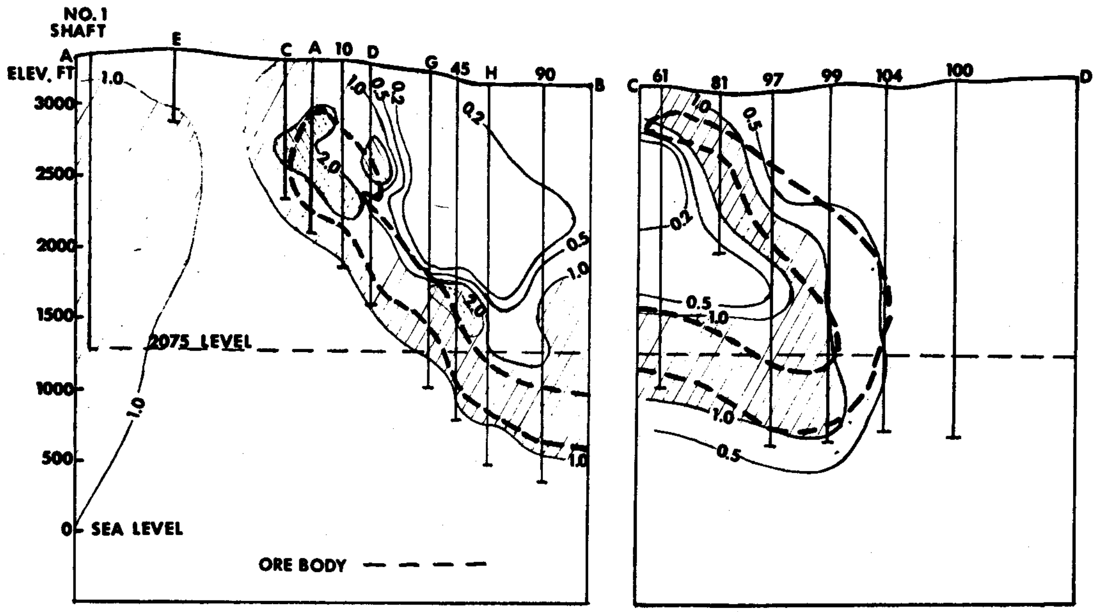

Figure 36.15. *K-feldspathization: ratios of K-feldspar/plagioclase in cross-sections AB and CD.*

Pyritization

In cross-section a zone of pyritization, defined by the 10 per cent contour, follows the perimeter of the outer ore boundary, surrounding the orebody as a crescent-shaped halo (Fig. 36.13). Contours are generally closed around the ore shell, except toward the surface.

In longitudinal section, pyritization is limited mostly to the underside of the primary ore zone, where pyrite values commonly range up to 8 to 10 per cent. No attempt was made to extrapolate the zone of high pyrite around the eastern closure of the orebody, because of the oxidized condition of samples from the upper ore zone.

In horizontal section, a similar zone of moderate pyritization (5-10 per cent pyrite) surrounds the ore shell, defining its general shape, and is similar in form to the zones of sericitization and silicification. Contours are generally open towards the Kalamazoo orebody to the southwest.

Feldspar Distributions

Two parameters were chosen to define the changes in feldspar distribution through the San Manuel orebody, (1) percentages of total feldspars (plagioclase and K-feldspars), and (2) ratios of K-feldspar/plagioclase.

Contours of percentages of total feldspars in cross-section (Fig. 36.14) reveal a strong feldspar low, lying just outside of the ore zone, overlapping zones of sericitization, silicification, and pyritization. Total feldspars comprise less than 10 per cent of the rock in this zone, and apparently have been replaced in most part by sericite, quartz, and pyrite. Contouring of percentage feldspar lows may thus be used to considerable advantage, since they magnify the cumulative effects of various types of alteration.

Amounts of feldspar increase inward through the orebody, and into the inner porphyry core, as defined by the contours 20, 30, 40, and 50 per cent feldspar. Each contour is conformable to the ore zone and may be used to delineate roughly the general shape of the orebody.

Total percentage of feldspars also increases sharply on the external side of the feldspar low (away from the deposit). Contours generally enclose the entire orebody, except at surface, where they remain largely open.

In longitudinal section, feldspar "lows", defined by the 10 per cent contour, follow continuously the lower boundary of the ore zone, locally offset by normal faults. Contour closures around the ore flexure at the east end are inferred for the 30 and 20 per cent contours. Contours are open above most of the orebody to the west, where the inner core is exposed. This is the portion of the orebody from which the Kalamazoo segment is assumed to have been removed.

Segments of the San Manuel orebody and associated alteration zones are in apparent agreement with concept of Lowell (1968) of a faulted cylindrical ore shell for the two segments.

The distribution of total feldspar in horizontal section reflects the concentric horseshoe-shaped outline of the orebody. A feldspar low surrounds most of the ore shell, and generally overlaps zones of high sericite, quartz, and pyrite. Contours of increasing feldspars are well defined inside the barren core, as well as exterior to the deposit. Contours are open to the southwest towards Kalamazoo, as in the case of other forms of alteration.

Ratios of K-feldspar/plagioclase were contoured in cross-section in Figure 36.15 to outline the zones of K-feldspathization. Zones of anomalous K-feldspar follow the inner part of the ore shell throughout the deposit. This feature is also confirmed by the contoured distributions in longitudinal and horizontal sections. This zone of high K-feldspathization (as defined by the 0.1 contour) lies just inside the zone of sericitization within the ore shell, and extends for several hundred feet into the barren core. However, the inner edge grades sharply into relatively unaltered (slightly propylitized) porphyry with low K-feldspar and high plagioclase.

PRELIMINARY COMPARISON OF SAN MANUEL SEGMENTS WITH LOWELL'S MODEL

Sufficient alteration data are available from cross-sections of the San Manuel orebody for limited comparison with the cylindrical model proposed by J.D. Lowell (1968) for the Kalamazoo and San Manuel segments. According to Lowell, the two orebodies represent one cylindrical-shaped orebody with concentric alteration zoning that was tilted and bisected by the San Manuel fault.

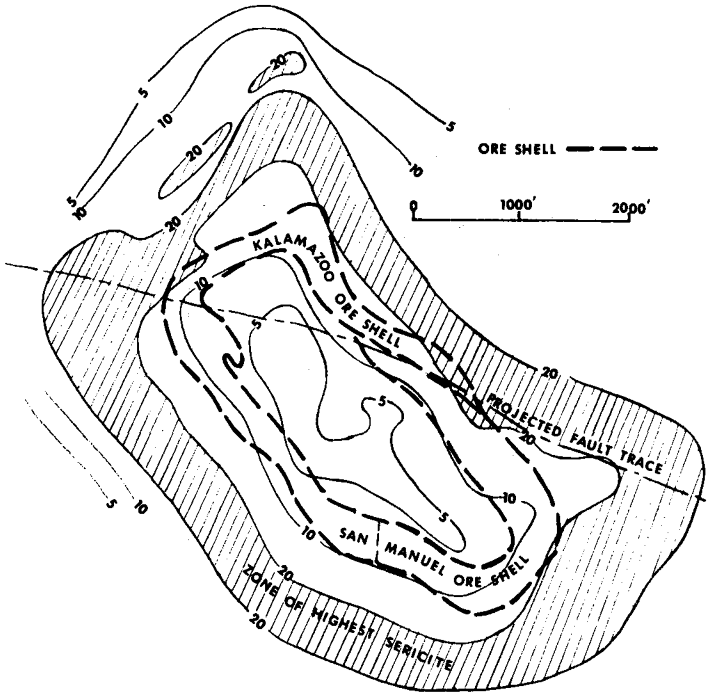

Figure 36.16. *Sericite halo around composite San Manuel-Kalamazoo ore shell.*

Samples available from churn drilling during the mid-1940s in the San Manuel segment indicate a U-shaped orebody with concentric zones of wall rock alteration, similar to the Kalamazoo segment (unpublished NEL Report), except that the zoning is inverted, following the underside of the San Manuel orebody compared with the topside at Kalamazoo.

Alteration contours are open above most of the San Manuel segment to the west, where the inner core is exposed along the San Manuel fault. This portion of the deposit provides a reasonably good geometric fit with the Kalamazoo segment, where contours of alteration and mineralization are open (unpublished NEL Report) and are believed to connect between the two ore segments (Fig. 36.16).

This evidence strongly supports the conceptual cylindrical model proposed by Lowell (1968). The repetitive patterns for each type of alteration (sericitization, silicification, pyritization, etc.) all show similar zonal distributions that reach maximum intensities along the outside perimeter of the ore zone and display textbook concentric symmetry around the ore. On the basis of this supportive evidence, a distinction can be made with some certainty between the outside and inside boundaries of the ore shell from any of its segments.

GENERAL CONCLUSIONS

X-ray diffraction analysis of alteration minerals has been found useful and practical in delineating trends in wall rock alteration in the San Manuel deposit. The relationship of alteration to mineralization is readily apparent after comparison of monomineralic contouring with that of copper. Alteration contouring should find increasingly wider application in the evaluation of wall rock alteration, supplementing the interpretation and use of such classification terms as propylitic, phyllic, potassic, argillic, etc., which depend mostly on the qualitative and deductive judgment and experience of the observer.

On the basis of alteration contouring to date, major mineralized trends at San Manuel are clearly defined by intense zones of alteration. Chances for discovery of additional significant tonnages of ore do not appear favourable without the association of these zones of intense alteration.

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