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## RESUMEN

El distrito minero de Santa Eulalia se encuentra en la parte central de Chihuahua, a 400 kilómetros al sur de El Paso, Texas. Su principal zona minera se presenta en un domo ligeramente plegado, con estructuras sencillas asociadas, y contiene cuerpos mineralizados distribuidos en un intervalo vertical de más de 900 metros (3,000 pies).

Se describe la estratigrafía de la columna geológica de 1,945 metros (6,350 pies), y se proporcionan evidencias de un abrupto encogimiento en el volumen de las calizas inmediatamente asociadas con grandes cuerpos mineralizados. Este encogimiento, denominado COLAPSO, ocurrió durante el curso de la mineralización.

Los contactos de las calizas con mantos ígneos, y 366 metros (1,300 pies), de lechos de calizas fosilíferas, en particular el lecho fosilífero principal, han sido importantes controles de localización de cuerpos minerales. Los controles gravitacionales echado arriba pueden haber sido importantes. Las fracturas sólo han ejercido un control local y a corta distancia.

Las zonas de empuje han desplazado a los mantos de diabasa y a su vez han sido intrusionados por los miembros superiores de un grupo de mantos de pórfido riolítico. Los agentes mineralizadores estaban relacionados con el pórfido riolítico, y el mineral fue introducido a la caliza donde ciertos mantos yacen entre los segmentos de diabasa desplazados, y han sido cortados por fisuras orientadas de norte a sur.

Se hacen especulaciones acerca de qué campos de esfuerzos no liberados puedan haber tenido influencia en la localización de los cuerpos mineralizados; que la configuración zonal puede ser un reflejo de los efectos filtrantes de grandes volúmenes de caliza; y que las soluciones ricas en metales, movilizadas por o incorporadas dentro del pórfido invasor, puedan ser la fuente de los mineralizadores.

## INTRODUCCION

El distrito de Santa Eulalia tiene una producción que se aproxima o excede a los 35.000,000 de toneladas de minerales de plata, plomo y zinc, de cuerpos de reemplazamiento en calizas. Operando desde los primeros años del siglo XVIII, la producción se ha confinado a dos áreas intensamente mineralizadas, separadas por 2 km de caliza estéril, el Campo Occidental y el Campo Oriental; probablemente el 50% ha sido extraído desde 1908, del cual más del 90% provino del Campo Occidental.

El Campo Occidental, explotado hasta una profundidad vertical de 1,945 metros y ahora casi exhausto, es el tema de este artículo.

Aunque desde 1911 se ha estudiado cuidadosamente, no existe ninguna publicación en la que se le coloque en su marco regional, y excepto por algunos cuantos artículos que tratan de temas específicos o de amplios resúmenes, solamente las contribuciones de Prescott de 1916 y 1926 describen en detalle la geología. En los últimos años se ha establecido la relación entre los cuerpos mineralizados y los 900 metros de caliza plegada en un suave domo sin complicaciones de grandes pliegues o fallas. Se ha rechazado la importancia de las fracturas en el control de los cuerpos mineralizados, a la que generalmente se le había asignado un papel preponderante. Se ha observado un adelgazamiento de los estratos reemplazados, adyacentes a los cuerpos mineralizados. Se ha establecido la relación entre los cuerpos mineralizados y una serie de intrusivos que no afloran, y el papel de haber introducido los sulfuros mineralizados ha sido asignado a un intrusivo específico. Durante este período de 40 años el autor fue un geólogo residente en Santa Eulalia de 1933 a 1954, y aunque estuvo en deuda con otros, fue el responsable de obtener los detalles geológicos en los dos tercios boreales del distrito desde 1934 a 1954.

Si se han de desentrañar alguna vez los procesos de reemplazamiento, la geología del Campo Occidental de Santa Eulalia, el ejemplo clásico mundial de cuerpos de reemplazamiento en calizas, debe entenderse primero, porque la localización de estos cuerpos no puede explicarse relacionándola con rasgos estructurales o estratigráficos fácilmente discernibles. Su marco estratigráfico es una serie de calizas monótonamente semejantes. Su marco estructural es igualmente sin complicaciones. Ni se debe esta falta de correlación a los efectos de enmascaramiento de las complejidades mineralógicas. Los cuerpos son simples, concentraciones masivas de sulfuros de plomo-zinc-hierro o sus óxidos equivalentes. No están contaminados por silicatos metamórficos de contacto, están claramente confinados por paredes de caliza no alterada, y rara vez han sufrido la plaga de problemas serios de agua.

Desgraciadamente al aproximarse este Campo a su agotamiento, los informes geológicos se han desperdigado o se han perdido. El propósito de este artículo es el de conservar las observaciones recogidas y exponer la imagen geológica tal como se ha desentrañado en los últimos 40 años.

Con referencia al Campo Oriental, un productor de minerales de plata-plomo-zinc de cuerpos masivos dentro de paredes claramente definidas y de sulfuros diseminados en los silicatos, y de tonelajes importantes de estaño y vanadio, y en el que se ha encontrado grandes volúmenes de agua, el lector puede consultar a Knapp (1906), Hewitt (1943) y Syner y Hewitt (1952).

## ABSTRACT

The Santa Eulalia mining district lies in central Chihuahua 400 kms south of El Paso, Texas. Its main mineral zone occurs in a gently warped dome with simple associated structures and contains ore-bodies distributed through a vertical range of over 900 ms (3,000 ft).

The stratigraphy of 1,945 ms (6,350 ft) of geologic column is described and an abrupt shringkage is documented in the volume of limestones immediately associated with large ore-bodies. Termed COLLAPSE, this shrinkage occurred during the course of mineralization.

Contacts of limestone with igneous sills, and 366 ms (1,300 ft) of fossiliferous limestone beds, particularly the main fossil bed, have been important localizers of ore-bodies. Up-dip gravitational controls may have been important. Fractures have exerted only local controls and over short distances.

Thrust zones have displaced diabase sills and in turn have been intruded by the upper members of a group of rhyolite porphyry sills. The mineralizers were related to the rhyolite porphyry, and ore has been introduced to the limestone where certain sills lie between the displaced segments of diabase and have been cut by north-south fissures.

Speculations are raised that fields of unreleased strain may have influenced ore body locations; the district's zoning pattern may be a reflection of the filtering effects of large volumes of limestone; and that metal-rich brines mobilized by or incorporated within the invading porphyry might be the source of the mineralizers.

# INTRODUCTION

The Santa Eulalia district has a production record approaching or exceeding 35,000,000 tons of silver, lead, zinc ore from replacement bodies in limestone. In operation since the first years of the 1700's, production has been confined to two intensely mineralized areas separated by 2 kms of barren limestone, the West Camp and the East Camp. Probably 50 per cent has been mined since 1908, with over 90 per cent from the West Camp. The West Camp, exploited through a vertical depth of 1,945 ms and now approaching exhaustion, is the subject of this paper.

Since 1911 it has received careful study but there is no literature that sets it in its regional framework, and except for a few papers dealing with specific items or broad summaries only Prescott's 1916 and 1926 contributions describe the geologic detail. In the last 40 years the relationship between ore bodies and 900 ms of Mesozoic limestone, warped into a gentle dome uncomplicated by major folds or faults, has been documented. The importance of fractures in the control of ore bodies, usually assigned an over-riding role, has been denigrated. Adjacent to ore bodies, a thinning of replaced strata has been observed. The relation between ore bodies and a series of intrusives that do not outcrop has been established, and the role of having introduced the sulphide mineralizers has been assigned to a specific intrusive. During this 40-year period the author was a resident geologist at Santa Eulalia from 1933-1954, and, although indebted to others, was responsible for procuring the geologic details in the northern two-thirds of the district from 1934 through 1954.

If replacement processes ever are to be unravelled, the geologic background of Santa Eulalia's West Camp, the world's classic example of replacement bodies in limestone, must be understood because the locations of these ore bodies are not to be explained by relating them to readily discernible stratigraphic or structural features. Their stratigraphic setting is a series of monotonously similar limestones. Their structural settings are equally uncomplicated. Nor is this lack of correlation due to the masking effects of mineralogic complexities. The bodies are simple, massive concentrations of lead-zinc-iron sulphides or their oxide equivalents. They are uncontaminated by contact metamorphic silicates, are sharply confined by unaltered limestone walls, and seldom have been plagued with serious water problems.

Unfortunately as the Camp has approached exhaustion, geologic reports have become scattered or lost. It is the purpose of this paper to preserve recorded observations and to set forth the geologic picture as it has unravelled in the last 40 years.

For reference to the East Camp, a producer of silver-lead-zinc ores from massive bodies within sharply defined walls as well as from sulphides disseminated through silicates, and of important tonnages of tin and vanadium and which has encountered great volumes of water, the reader is referred to Knapp (1906), Hewitt (1943), and Syner and Hewitt (1952).

## LOCATION

The Santa Eulalia district lies in a group of high mountains in central Chihuahua in northern Mexico. It is 400 km (250 miles) south of El Paso, Texas, and 22 kms (14 miles) southeast of Chihuahua City (Figure 1).

The mountains are one segment of a narrow northwesterly trending range that extends 75 kms (47 miles) from the San Pedro River on the south to the Chuviscar on the north. This range, rising abruptly from wide, low plains on both west and east, is divided by a series of low passes into prominent semi-isolated mountains. Those that contain the Santa Eulalia district are isolated by the Ojito Pass on the south and the Dolores Pass on the north, lie in the north- central part, and trend N 30°W. Rising abruptly 700 ms (2,300 ft) above surrounding plains to a severely dissected table-land surface approaching 2,100 ms (6,800-6,900 ft) above sea level, they are 26 kms (16 miles) long and 10 kms (6 miles) wide (Figure 2). To the south, this table-land is cut by shallow southwesterly trending valleys that give way, northward, to open arroyos and steep-walled canyons carving the surface into rolling uplands, broad individual mountains, and isolated peaks.

The highest and most spectacular of these is Chihuahua Viejo, a volcanic neck that rises to 2.232 ms (7.320 ft); the most important is the broad rolling surface of Cerro de Santa Eulalia, which, rising to 2,100 ms (6,888 ft), is some 7 kms (4.4 miles) long and dominates the entire northern part of the area. Although the northern part is specifically named Cerro de Santa Eulalia, Figure 2 refers to the entire sierra between the Ojito and Dolores Passes as the Santa Eulalia Mountains. The Santa Eulalia district, including both camps, lies within the Cerro de Santa Eulalia.

On the south flank of the Cerro at an elevation of 1,850 ms (roughly 6,100 ft) is the mining village of Santo Domingo. The West Camp, centering around Santo Domingo, extends 1 km (0.6 miles) to the southeast of the village and 3 kms (1.9 miles) to the northwest. Separating Cerro de Santa Eulalia from the rest of the mountains and heading along its southern flank is the deep, widely open, Arroyo de Santa Eulalia. Along its bed, 2 kms (1.3 miles) southwest of Santo Domingo, at an elevation of 1,710 ms (5,609 ft) is the 260-year-old Real de Santa Eulalia. After the Revolution, these villages were officially renamed Francisco Portillo and Aquiles Serdan.

A paved road throught the Arroyo de Santa Eulalia connects the Real with the Pan American Highway, but in the mountains vehicles travel on dirt roads. Two narrow-gauge railways enter the mountains though the Arroyo. One terminates at Santa Eulalia but is connected with the mines by a series of aerial tramlines. The other leads directly to the mines at Santo Domingo.

## REGIONAL GEOLOGY

Thick-bedded middle Cretaceous limestones, probably Aurora, form the great bulk of the Cerro de Santa Eulalia. These have been warped into a gentle dome truncated on the north by the Dolores Pass, an erosional valley now standing as a wind gap above adjacent plains; covered to the south by volcanics; and severed on the west by a faul-line scarp. The dome is of such slight magnitude that for 6 kms (2.8 miles) south of the Pass beds on the precipitous west flank of the Cerro appear essentially horizontal.

A thin sequence of capping rocks, probably Tertiary, overlies the limestones and is separated from them by an erosional surface of rugged relief. They are composed of acidic tuffs and flows intercalated with continental sediments derived from volcanics and limestones. Absent at the north they appear some 4 kms (2.5 miles) south of the Dolores Pass as thin, isolated erosional remnants which increase southward in thickness and extent until, in the vicinity of Santo Domingo, it is the limestone outcrops that occur in small, widely isolated exposures (Figure 3). From Santo Domingo south to the Ojito Pass the mountains are composed of capping rocks that dip gently southward. In the vicinity of Santa Eulalia these are exposed over a vertical distance of possibly 400 ms (1,400 ft), beneath which an unknown thickness of capping material should overlie deeply buried limestone.

Block faulting, superimposed on the dome at the north, has severed the westerly dipping strata on the west side of the Cerro de Santa Eulalia and elevated them a minimum of 1,000 ms (3,300 ft) above the down-faulted bordering plains to the west. On the east side, east of the East Camp, the limestones dip sharply eastward beneath the adjacent valley. Although the western edge has been truncated by faulting, the precipitous western flank is probably a fault-line scarp.

Regional topography resembles Basin and Range country of the western United States.

## WEST CAMP ORE BODIES

West Camp ore bodies, massive replacements of pre-existing limestone, are confined within unaltered limentone walls. The transition from mineralization to country rock is sharp and immediate. The majority are pipe-like with their long axis horizontal or vertical. A minority are tabular and vein-like. Horizontal pipes have occurred vertically above each other, separated by hundreds of meters of barren limestone in some areas, through a vertical range of 1,000 ms (3,280 ft).

These ore bodies occur beneath an area, roughly elliptical in outline, extending slightly west of north for nearly 4 kms (2.5 miles) and up to 2 kms (1.3 miles) wide (Figure 4). The eastern and northern edges are marked by important near-surface ore bodies at elevations of up to 2,000 ms (6,560 ft) above sea level. These, first mined in the 1700's relate to the district's earliest discoveries. Beneath them, ore bodies in depth are missing. Inside this fringe zone is a belt of 3 km length (1.9 miles and up to 1 km width (0.6 miles) where ore bodies occur from near surface elevations of 1,900 ms (6,230 ft) to depths of 1,550 ms (5,080ft) above sea level. Although important in the 1700's they received their greatest development from the late 1800's up to the mid-1920's. Since then the south end of this inner belt within a 1 km length (0.6 miles) and 700 ms width (0.4 miles), phenomenally productive, has been exploited to a depth of 1,000 ms (3,280 ft) above sea level (Figure 5). Whereas the Spaniards exploited near-surface ore bodies by following ore. Twentieth Century exploitation has been through deep vertical shafts.

Throughout the West Camp, individual ore bodies appear to wander aimlessly yet there are two preferred directions — slightly west of north and northeasterly.

## SURFACE GEOLOGY

Limestones account for less than three per cent of the outcrops above the main mineral zone. Their dips, uniformly gentle, rarely exceeding 10 degrees, exhibit a regional southward tilt, possibly with a slight preference to the southwest. Upon them is superimposed a series of gentle undulations (Figure 3). There is no observed correlation between the trend or location of the mineral belt and the regional tilt of the surface limestones, or their superimposed flexures; but the northeast trends of individual ore bodies in the southern third of the district may reflect an up-dip rise in response to simple gravitational control. Perhaps the only conclusion drawn from a surface study is that the mineral belt lies on the south flank of the regional dome.

The capping series is composed of ash beds, rhyolite flows, and intercalated detrital material. The lower members, predominantly rhyolitic and irregularly present, dip southward as much as 30 degrees, the upper members, predominatly andesitic, dip more gently. Spurr (1911) considered the capping series of continental origin, their steep dips a response to initial dip off the rugged pre-capping surface.

A series of narrow, essentially vertical, northeasterly trending dikes cut the limestones and the capping volcanics. Two of these, the Potosí at the south and the Mina Vieja at the north, both andesitic, are well known in the district. A third, the Velardeña Dike, somewhat north of the center, is rhyolitic. All three strike about N 50°E, yet none has controlled a northeasterly trending ore body (Figure 3). Surface exposures do not show age relations. Mine exposures do: the Potosi and Mina Vieja Dikes, vertical chimney-like mineralization associated with them, are pre-ore; the Velardeña Dike, clearly transecting ore bodies, is presumably post-ore. The Velardeña Dike may have implications on ore genesis.

On the surface all three dikes are altered to a variable extent. Spurr (1911) reported the andesite dikes contain feldspars, chiefly oligoclase-andesine, and their groundmass much calcite and chlorite as alteration products; the Velardeña Dike abundant quartz phenocrysts with embayed outlines, and in its severely altered groundmass, quartz and sericite, locally abundant calcite and "small probable zircons", — a rock that might "represent an original alaskite rather than a typical rhyolite." The Mina Vieja Dike, underground, is intensely argillized in the vicinity of ore bodies.

Of possible local importance in the directional control of near-surface ore bodies is the San Lazaro Fissure: a zone of widely spaced veinlets up to 1 cm thick of N 40°-50° E strike and 65°-80° northwesterly dips that are mineralized with iron oxides, scattered galena grains and small patches of lead carbonate. Prominently displayed within the capping series and traceable northeasterly for 750 ms (2,400ft), it is about 40 ms (130 ft) wide in the vicinity of the Buena Tierra Shaft the northwest edge of the deeply developed block. Some 500 ms (1,600 ft) northeast of the Buena Tierra Shaft, it traverses a small limestone exposure and narrows to a single *prominent fissure.*

## GEOLOGIC COLUMN

As exposed or tested through a depth of approximately 1, 950 ms (6, 390 ft) the geologic column, from the surface down, is as follows (Figure 6):

| | Ms | Ft |
|---|---|---|
| Capping series: | 0 - 290 | 0 - 950 |
| acidic tuffs and flows interbedded with conglomerates and marls; thickness unknown. | | |
| Erosion surface, rugged relief. | | |
| Limestone series: | | |
| fossiliferous | 366 | 1,200 |
| nonfossiliferous | 397 | 1,302 |
| *intermixed nonfossiliferous* limestone, medium basic and acidic porphyritic intrusives | 406 | 1,332 |
| fossiliferous | 100 | 330 |
| Evaporite series: | | |
| anhydrite, black limestone, calcareous shale, minor intrusives | 184 | 603 |
| *Intrusive quartz monzonite:* | 202 | 663 |
| | 1,945 | 6,380 |

These measurements were obtained, from the surface down, as follsw:

| | Ms | Ft |
|---|---|---|
| Surface exposures: | *290* | *950* |
| Measured sections: | | |
| Velardeña and Santo Domingo Shafts | 641 | 2,100 |
| Buena Tierra Shaft | 250 | 820 |
| Diamond drill cores: | 764 | 2,510 |
| | 1,945 | 6,380 |

### CAPPING SERIES

In the East Camp a limestone conglomerate within the capping series has produced ore. In the West Camp these pre-mineral rocks have not produced ore bodies, but lower members of the series are gashed by veinlets of iron oxide with lead carbonates and lead sulphides, and ore bodies of minor importance occur along the contact with underlying limestones. They conceal over 90 per cent of the productive West Camp mineral zone and obscure large areas of limestone throughout the Cerro de Santa Eulalia. They include interbedded tuffs and conglomerates. As listed from youngest to oldest, Spurr (1911) recognized the following units:

| | |
|---|---|
| 4th conglomerate: | only a few meters thick; eroded from the northern part of the district; composed of limestone pebbles. |
| 4th tuff: | 20 ms average thickness; andesitic; greenish; fine-grained. |
| 3rd conglomerate: | 10 50 ms thick; tuffaceous limestone conglomerate; eroded after deposition. |
| 3rd Tuff | 10 ms or less ;andesitic; minor limestone pebbles, deposited on an uneven surface. |
| 2nd conglomerate: | 50 ms; rounded Cretaceous limestone boulders; large amount of fine volcanic tuff and boulders, and fragments of rhyolite; minor andesitic material. |
| 2nd tuff: | 0-4 ms; andesitic with rhyolite fragments; brown; eroded during and after deposition of 2nd conglomerate. |
| rhyolite flow: | 0-100 ms; fine-grained; buff colored; exceed- |

| | |
|---|---|
| | ingly irregular surface. eroded prior to deposition of 2nd tuff. |
| rhyolite tuff: | 210-225 ms; rhyolite in angular fragments; similar from top to bottom; rests either on limestone conglomerate or on limestone. Elongated shards may represent ash flows rather than falls, and the sequence may contain welded tuffs. Spurr remarked that locally the formation has the appearance of rhyolite flows, which he attributed to silicification. |
| 1st conglomerate: | 0-20 ms; rounded Cretaceous limestone pebbles; fills arroyos on the underlying pre-capping erosion surface; rests on limestone. |

Absent in the northern part of the district, the capping series approaches a thickness of 290 ms (950 ft) in the southeast part. Spurr's mapping, confined to the mineral belt, does not record a great thickness of still younger shales and volcanics exposed in the Cerro de la Campana, an isolated mountain rising from the southeast wall of the Arroyo de Santa Eulalia. Farther south the thickness may approach or exceed 1,000 ms. Spurr summarized the series as follows:

"Subsequently a very active period of volcanic activtiy took place, and the limestone was buried deep under showers of ash and fragments of rhyolitic and andesitic lavas from volcanic eruptions, mixed with and alternating with detrital material partly derived from the volcanic rocks, and partly from the erosion of higher portions of the same limestone series, in the form of lime mud and lime boulders of all sizes. The total thickness of this accumulation which evidently did not take place under water, but as an ordinary "continental" deposit, is very great. The top of the series has not been found,but the total thickness exposed in the southeastern part of the area mapped amounts to about 290 meters or about 950 feet."

The series, subjected to severe erosion during its deposition, exhibits extreme variability, and West Camp subdivisions are of local significance.

Marls, not mentioned in Spurr's description but recognized as "lime mud", are particularly prominent in road cuts and arroyos southwest of his mapping. Fossil gastropods are abundant in marls which outcrop 200 ms (660 ft) east of the Baltimore Shaft in the Arroyo del Baltimore, a headward tributary of the Arroyo de Santa Eulalia. This exposure, 2 ms (16 ft) thick by 8 ms (25 ft) long, is thought to lie near the top of Spurr's rhyolite tuff. Fossils collected by the author in 1948 and submitted by Charles F. Behre to the Instituto de Geología in Mexico City were not diagnostic, although F. K. G. Mulleried suggested they were Upper Cretaceous types (Charles F. Behre, personal communication, 7/31/50). Similar specimens were shown to Wm. Lee Stokes, University of Utah (personal communication, 1961), who suggested they were Tertiary and might be *Viviparus* sp. of Eocene or Paleocene age. The site was revisited on June 30, 1964, by Ing. A. R. V. Arellano and the author, and another suite collected. Ing. Arellano identified the gastropods as long-ranging continental types, among them a species of *Urocoptidae*, and submitted the collection to the Instituto de Geología in Mexico City. Ing. Guillermo P. Salas, Director of the Instituto (personal communication, 8/24/64), reported the following identifications:

*Holospira* sp.
*Viviparus paludinaeformis* (Hall)
*Planorbis* sp.

accompanied by the following remarks, translated:

> "The specimens of *Holospira* sp. are similar to *H. leidyi* (Meek) of the Eocene of Wyoming; and to *H. grangeri* Cockerell, of the Oligocene in the vicinity of Méndez, Tamaulipas. *Viviparus paludinaeformis* (Hall) is found in the Paleocene and Eocene of Wyoming and Colorado. All the fossils of this suite are fresh water terrestrial gastropods."

## LIMESTONE SERIES

A series of limestones 1,033 ms (3,388 ft) thick underlies the capping series and is separated from it by an erosion surface of pronounced relief (Figure 6). It conformably overlies an evaporite sequence and passes into it, apparently gradationally.

The upper 366 ms (1,200 ft) and lower 100 ms (330 ft) contain abundant poorly preserved fossils interspersed with beds barren of fossils. The intervening 567 ms (1,860 ft) of sedimentary strata are essentially nonfossiliferous. From 763 to 1,169 ms (2,503–3,834 ft) below the known top of the series, the column has been expanded to a total length of 1,269 ms (4,162 ft) by the intrusion of 236 ms (774 ft) of volcanics:

42.5 ms (139 ft) of andesite-diorite-diabase
193.5 ms (645 ft) of acid felsite.

Surface limestones strongly resemble the Aurora, a Georgetown equivalent widespread throughout northern Mexico, but there has been virtually no faunal identification. Spurr (1911) referred to the entire series, at that time exposed over a depth of 730 ms (2,400 ft), as "the Mesozoic (probably Cretaceous) limestone such as occurs all over this portion of Mexico." He observed that certain beds carried fossils, some scattered, others abundant, but always poorly preserved; that chert nodules, "usually arranged in rude bands parallel to the bedding", were more abundant in certain beds than in others; that the limestones were so similar in appearance that only one semi-crystalline highly fossiliferous stratum, lying at about the 1,500 m elevation, could be identified unerringly throughout the camp. He referred to this stratum as the main fossil bed.

By 1928, the upper 845 ms (2,770 ft) of limestone had been subdivided on an informal basis into the following horizons (Benham, 1928b):

| | Ms | Ft |
|---|---|---|
| Upper fossiliferous beds | 151 | 495 |
| Intermediate beds | 163 | 535 |
| Lower fossiliferous bed | 51 | 167 |
| Black limestone | 480 | 1,575 |
| | 845 | 2,772 |

The lower fossiliferous bed is the same stratum as Spurr's main fossil bed. In 1931 the underlying black limestone, on the basis of a suite of well-preserved fossils, * had been correlated tentatively with the "blue limestone" of probable Glen Rose age of Los Lamentos, * * making it a tentative equivalent of the basal Comanchean Glen Rose Formation of the Trinity Group of Texas — in United States terminology, Lower Cretaceous.

* Collected in 1928 by W. M. Benham from the black limestone on the Santo Domingo 6th level, currently the Santo Domingo 11th level, at an elevation of roughly 1,478 ms (4,848 ft) above sea level and some 75 ms (250 ft) beneath the lower fossiliferous bed, the suite was delivered to a paleontologist for identification (Benham, 1928b). Apparently the identifications were made in 1931, but the original correspondence has been lost. The reference has been described by Hewitt (1943) and cited by Horcasitas and Snow (1956). At Los Lamentos the "blue limestone" is 500 to 1,500 ms thick (1,640 to 4,920 ft) and is underlain by "red beds" which in 1928 were considered Permian (Benham, 1928b see above).

** Los Lamentos, a mining camp some 215 kms (135 miles) north of Santa Eulalia, was an important lead producer in 1928.

Hewitt (1943), on the basis of regional similarities, concluded the limestones are probably Aurora equivalents, therefore Aptian-Albian in age, and consequently fall in the middle of the Cretaceous.

In 1933, on the basis of a rigorous examination of the upper 718 ms (2,358 ft) of the limestone series, Thomas P. Clendenin, at that time Chief Geologist of the Mexican Mining Department of the American Smelting and Refining Company, obtained the first completely detailed field picture of the stratigraphy and structure of the limestone beds, and discovered a relationship between a peculiar structural condition in the limestones, which he named "collapse", and adjacent ore bodies. This relationship, clearly a result of the replacement of pre-existing limestone by massive sulphides, should be of fundamental interest to all student of limestone-replacement bodies. Described in the section COLLAPSE, its identification depend on detailed knowledge of the stratigraphic column. The following stratigraphic details are drawn from the report of the 1933 investigation (Clendenin, 1933).

To correlate strata exposed in mine development with strata in the geologic column, geologic sections were made of two shafts — the Velardeña and the Santo Domingo (Plates 1 and 2). An effort was made to locate every bedding plane exposed in each shaft. These were plotted on a 1/100 scale, with strengths indicated by symbols. All fractures, dolomitic beds, recrystallized limestone beds, and the majority of chert horizons were carefully located and plotted; and for each bed, color, fossil content, and amount of manganese staining were recorded. Bedding planes were then assigned two-part names: an initial corresponding to the shaft in which it occurred (V — for Velardeña, and S. D. — for Santo Domingo), followed by its exact location in meters above sea level in that particular shaft. Thus, bedding plane V-1771.6 occurs in the Velardeña Shaft at 1,771.6 ms above sea level. With this body of data it was possible to identify bedding planes throughout the mine, assign their proper designation, compare their changes in elevation with their known location in a shaft, and study the nature of their enclosed beds. It developed that the most distinctive member of the geologic column is the lower fossiliferous bed, and no apparent stratigraphic distinction exists between the upper fossiliferous and intermediate beds.

### Lower Fossiliferous Limestone, or Main Fossil Bed:

The lower fossiliferous bed, 52.5 ms (172 ft) thick in the Velardeña Shaft thickens by about 3 ms (10 ft) at a point 63.5 ms (2,080 ft) to the south, but thins by approximately 10 ms (33 ft) within 300 ms (1,000 ft) to the southeast. There are no bedding planes and no cherts. It carries a good content of fossils, more abundant in certain horizons and more prevalent near the top. In the Velardeña Shaft the lower 40 ms (130 ft), finely recrystalline and moderately to intensely manganese stained, are, where not obscured by manganese, either a light grey color or completely bleached. The upper 10 ms (30 ft), relatively free of recrystallization and manganese stain, are light grey and contain two beds of dolomitic limestone, each less than 50 cms (2 ft) thick. In the Santo Domingo Shaft the recrystallization is generally absent, and the dolomitic horizons were not observed.

*Beds Above the Lower Fossiliferous Limestone:*

In the 313 ms (1,027 ft) of limestone from the top of the lower fossiliferous stratum to the top of the known geologic column, bedding planes occur in fair numbers, but not in abundance, and laterally maintain good stratigraphic continuity. Intervening limestone beds show a moderate degree of thickening and thinning, their color usually a medium grey, seldom dark. Interspersed throughout the column are horizons of bleaching and recrystallization. Throughout the entire interval are beds that carry chert interspersed with those that do not, and groups of beds in which fossil content ranges from sparse to moderately abundant interspersed with beds that lack fossils; but there is no single prominent unit comparable to the lower fossiliferous limestone. The distinction between the upper fossiliferous and intermediate beds, Clendenin (1933) stated: "... has not been found to be supported by any very clear grounds. The portion of the column which was known as the Upper Fossiliferous is not fossil-carrying in its entirety, but merely has scattered fossiliferous beds, while down through the section which was called the Intermediate Beds, similar fossiliferous beds continue to occur. The Upper Fossiliferous has, in fact, never been precisely defined, and on the basis of the present study it would seem a difficult problem how to define it. and to say just where the dividing—line between it and the Intermediate Beds should be placed. Further, there seem to be no pronounced differences of character in any other matters than the one of fossils between the beds of the two section. "As observed by Spurr, all fossils are poorly preserved from the top of the konwn column to the base of the lower fossiliferous limestone.

Limestones Beneath the Lower Fossiliferous Bed:

That part of the limestone series beneath the lower fossiliferous unit, referred to as the black limestone in 1928, is herein divided into an upper thick sequence of dark nonfossiliferous beds and a lower thinner series of black fossiliferous beds. Prominent fossil-bearing beds are absent in the 804 ms (2,635 ft) of geologic column beneath the lower fossiliferous limestone — 567 ms (1,860 ft) of limestone and 237 ms (775 ft) of intrusives —, but the occasional fossil has been well preserved. Beneath this 804-m interval are 100 ms (330 ft) rich in poorly preserved fossils. All beds, uniformly dark, become darker with depth. Zones of bleaching or recrystallization generally are lacking.

*Dark nonfossiliferous beds:* These beds, 567 ms (1,860 ft) of dark, fine-grained, nonfossiliferous limestones, underlie conformably and apparently gradationally the lower fossiliferous stratum and overlie 100 ms (330 ft) of interspersed fossiliferous and nonfossiliferous material. The lower contact has been complicated by igneous intrusions but available data suggest a continuous uninterrupted sequence of calcareous deposition. The main characteristic of the dark beds is a monotonous similarity; but, based on variations in thickness of the individual beds, they can be divided crudely into the following groups:

| | Ms | Ft | Ms | Ft |
|---|---|---|---|---|
| Thin-bedded, poor continuity | | | 70 | 230 |
| Massive-bedded | | | 385 | 1,265 |
| beds about 1 m (3 ft) thick | 40 | 130 | | |
| beds about 2-9 ms (6-30 ft) thick | 175 | 575 | | |
| beds about 1-6 ms (3-20 ft) thick | 123.5* | 405 | | |
| beds about 0.2 ms (½-16 ft) thick | 46.5 | 155 | | |
| | 385 | 1,265 | | |
| Thin-bedded, persistent beds about 0.2-1m. (½-3 ft) thick | | | 54 | 175 |
| Massive-bedded beds about 1-3 ms (3-10 ft) thick. At this depth igneous intrusives become predominant, and in 279 ms (915 ft) of column there are only 52 ms (170 ft) of limestone. From here on columnar details | | | | |

* Within this interval at a depth of 111.5 ms (336 ft) the sequence is interrupted by an andesitic sill, the uppermost of the intrusives.

| | | |
|---|---|---|
| have been taken from diamond-drill core, thus: | | |
| Dark limestone, included within and occurring at various horizons in the volcanic sequence. The upper 17 ms (56 ft) are marbleized and bleached. | 52 | 170 |
| | 567 | 1,860 |

The above tabulation is generalized, and within each subdivision are variations from the indicated bedding thicknesses. But, from the tabulation it appears the sedimentary sequence commenced with a series of thin-bedded limestones, gradually passed upward into a thicker section of massively-bedded material, then returned gradually to a section of thin-bedded limestone. The beginning and ending sequences are of the same general thickness.

For the initial 70 ms (230 ft) bedding planes are abundant but generally weak, disappear within short distances, and are replaced by new bedding planes which disappear. The beds between planes thin and thicken rapidly. The 1928 suite of fossils came from this interval. No fossils have been observed since.

In the ensuing 215 ms (705 ft) beding planes, known chiefly from exposures in the two shafts ,there being little information as to lateral behavior, are less numerous and show good strengths. In the first 40 ms (130 ft) the stratigraphic height between planes averages about 1 m 3 ft), but in the following 175 ms (575 ft) the limestones become exceedingly massive with numerous stratigraphic intervals between planes of 2 to 9 ms (6-30 ft). Some planes are noticeably wavy with 15 to 20-cm (6 to 8-inch) crests on a 50-cm (20-inch) base, but most are linear.

This 215 m (705-ft) interval marks the deepest extension of the 1933 study, which terminated 10 ms (33 ft), above the bottom of the 175-m segment. The columnar section to the bottom of formal development, a distance of 250 ms (250 ft), was obtained from the Buena Tierra Shaft (Plate 3). The final 765 ms of section (2,510 ft) were obtained from diamond-drill cores.

The massive limestones continue 170 ms (555 ft) [123.5 ms (403 ft) of excessively thick-beds grade into 46.5 ms (152 ft) of thin beds intercalated with massive beds], and have been developed extensively in this interval. Their bedding planes, traced laterally with good continuity for 0.5 kms (0.3 miles), show insignificant variations in stratigraphic intervals between planes.

The uppermost members of the igneous intrusives appear in the lower part of the excessively thick-bedded sequence as a series of thin andesitic-dioritic sills with a maximum combined thickness of 6.5 ms (21 ft). There is a 2.5 m (8-ft) sill-like acid felsite in the thinner basal portion.

The massive-bedded limestones pass downward gradationally into a 54-m (175 ft) thickness of relatively thin-bedded material that ranges from 0.2 to 1.0 ms (8 in to 3 ft) in thickness. Laterally the bedding planes exhibit good continuity. Within this interval is a 1-m (3-ft) thickness of acid felsite.

Beneath the thin-bedded material is 6 ms (20 ft) of massive limestone with bedding planes 1-3 ms (3-10 ft) apart. These rest on 62 ms (204 ft) of interspersed diabase sill, marble, and limestone. In the initial 279 ms (915 ft) beneath the 6-m (20-ft) interval there are:

| | Ms | Ft |
|---|---|---|
| Diabase | 36 | 118 |
| Marble | 18 | 57 |
| Limestone | 34 | 113 |
| Acid felsite | 191 | 627 |
| | 279 | 915 |

The marble occurs within and immediately beneath the main diabase thickness; the limestone occurs beneath the lower marble but above the lowest member of the sill ,and between the lowest diabase sill and the top of the 191-m (627-ft) thickness of acid felsite.

*Black fossiliferous beds*: The black, fossiliferous limestones and calcareous shales are identified in core from five deep holes on the edges of a block of ground extending from the Buena Tierra Shaft northward 1,400 ms (4,700 ft) to the Purisima Shaft, and northeasterly 500 ms (1,700 ft) to the Peñoles Fissure. In the southern holes they lie immediately beneath the 191-m (627-ft) acid-felsite intrusive; in the northern holes, in the vicinity of the Purisima Shaft, acid felsites are absent and this black, fossiliferous sequence grades upward into dark nonfossiliferous limestones. There is no shaft control, beding planes have not been identified, and there is no way to make precise correlations from hole to hole. The dark nonfossiliferous beds in the northern holes contain a vertical transition interval of 3 to 15 ms (10-50 ft) within which dense dark beds, 2-10 cms thick (1-5 in) gradually become more numerous, then grade into the black underlying beds.

In all five holes these black beds represent an intercalated series of limestones and calcareous shales conformably overlying an evaporite sequence. In four of the five holes the basal portion of the series is a black shale horizon, not identified in the fifth hole. In each case the basal portion of the sequence has been taken at the top of the highest underlying anhydrite bed. As determined in the five holes, thicknesses are a follows:

| Hole | Station | General Location | Interbedded Material | | Basal Shale | | Total Thickness | |
|---|---|---|---|---|---|---|---|---|
| | | | Ms | Ft | Ms | Ft | Ms | Ft |
| 1115 | V-1661-A | Purisima Shaft | 133 | 435 | 13 | 43 | 146 | 478 |
| 1473 | P-1661-B | Purisima Shaft | 118 | 387 | 15 | 50 | 133 | 437 |
| 1267 | V-1662-A | Purisima Shaft | 116 | 380 | 13 | 42 | 129 | 422 |
| 1658 | V-2105-A | Peñoles Fissure | 130 | 427 | Absent? | | 130 | 427 |
| 1813 | SD-2103-B | Buena Tierra Shaft (Chorro Chimney) | 26 | 84 | 75 | 245 | 100 | 329 |

It appears the hole 1813 location is shy 30-45 ms (100-150 ft) of total thickness, but 34 ms (112 ft) of black slatey limestone immediately above the diabase sill have been included in the description of the overlying dark, nonfossiliferous limestone series. If they were included in this series, the hole 1813 thickness would be of the proper magnitude.

The lower 85-100 ms (280-330 ft) contain poorly preserved fossils, in places abundant, interspersed with nonfossiliferous beds. In each of the holes, the thickness of the fossiliferous horizon is as follows:

| Hole | Ms | Ft |
|---|---|---|
| 1115 | 86 | 281 |
| 1473 | 88 | 289 |
| 1267 | 90 | 295 |
| 1658 | 87 | 284 |
| 1813 | 101 | 331 |

Specimens from the top of the horizon, taken from holes 1115 and 1813, were sent in 1964 to the Instituto de Geología in Mexico City for identification. As reported by Ing. Guillermo P. Salas, Director of the Instituto (personal communication, 8/24/64), identifications were non diagnostic. They contained species of *Caprinuloidea*, *Gryphaea*, and *Ostrea*, other unidentifiable pelecypods and fragments, as well as species of *Radiolaria* and *Miliolidae* together with other unidentifiable microfossils.

## Evaporite Series

A series of anhydrite beds, 0.6 to 17 ms thick (2-57 ft), interbedded with black calcareous shales and limestones, conformably underlie the black, fossiliferous limestones, and overlie a quartz monzonite intruded into them. Within five deep holes the series greatest thickness is 184 ms (605 ft) in hole 1813 beneath the Chorro Chimney in the vicinity of the Buena Tierra Shaft. In the vicinity of the Purisima Shaft the intrusive has cut out all but the uppermost anhydrite.

Included in the 184-m thickness are 16 ms (53 ft) of acid felsite and 1 m (3 ft) of diorite (?). The acid felsite occurs only in hole 1813, the diorite (?) in holes 1813 and 1658.

Interbedded with the anhydrite are horizons rich in poorly preserved fossils, interspersed with nonfossiliferous horizons. Specimens from hole 1813 —one from the top of the series, the other from a depth of 123 ms (405 ft) beneath top— were sent to the Instituto de Geología for identification. They contained unidentifiable microfossils and small fragments (Ing. Guillermo P. Salas, personal communication, 8/24/64).

## Intrusive Igneous Rokcs

A series of intrusives appear in the column at 762 ms (2,500 ft) beneath the capping-limestone contact. Continuing to the deepest prospected depth, they occur as sills; as sill-like dikes that transect the limestone beds at low angles; rarely as narrow dikes; and as a large, possible stock-like mass of unknown shape and size that transects the deepest known sediments. They are grouped as follows:

1. A series of mediumly basic, finely to moderately crystalline rocks, variously described as andesites, dolerites, diorites, or diabases that occur in multiple sills, of which there are two important pre-mineral members, the Upper Sill and the Lower Sill;
2. A series of acid felsites, extremely important, pre mineral or possibly pene-contemporaneous in age, occurring in a complex series of sills and sill-like dikes;
3. A medium-grained holocrystalline rock, referred to in the field as a monzonite, quartz monzonite, or granodiorite, that is known only in the bottom of the deepest drill holes. Probably a quartz monzonite, its relationship to ore is not known.
4. Acid-felsite fragments in a minutely brecciated limestone matrix are referred to as "rhyolitized limestone".
5. A few commercially unimportant narrow dikes are post-ore.

**Upper Sill:**

The highest igneous intrusive lies in the lower portion of the nonfossiliferous, massive-bedded, dark limestones; rises from the south as a single unit, 15 ms (50 ft) thick; splits into three sheets, each 1-5 ms (3-17 ft) thick, occupying the same 15 ms interval; and degenerates into a single sill 1.5 ms (4-5 ft) thick to the north and up to 4.2 ms (13.8 ft) to the east. Referred to as andesite ,diorite ,or diabase, it is greenish grey in color, is porphyritic, and varies in texture from aphanitic to moderately granular. In hand specimens its thicker members contain lath-like plagioclase in a granular groundmass. It carries olivine, is sprinkled with pyrite, and is pre-mineral (Figures 6 and 7). It differs from the Lower Sill only in being finer grained. Petrographically, specimens have been identified in unpublished correspondence as doleritic diabase, diabasic dolerite, and sodic diorite by both R. J. Colony and F. F. Grout; as a quartz-bearing dolerite approaching a quartz monzonite by C. P. Berkey.

Lower Sill:

The Lower Sill (Figures 6 and 7) intrudes the basal portion of the nonfossiliferous dark limestone 890 ms (2,920 ft) beneath the limestone capping contact. Its upper surface is roughly 150 ms (480 ft) beneath the base of the Upper Sill. It rises from the south as a more or less massive unit, roughly 50 ms (160 ft) thick, but in some localities its lower portion becomes complexly multiple and splits into as many as eight thin sheets interlayered with marbleized limestone. To the northeast and north it degenerates into a series of individual sills, each 1-10 ms (3-30 ft) thick, lying within a zone 40-50 ms (130-160 ft) from top to bottom. It is uniformly greenish; varies from fine-grained to moderately coarse; is referred to as andesite, or diabase; and differs from the Upper Sill only in being somewhat coarser grained. It contains disseminated pyrite and in many places marmatite and minor galena. It is pre-mineral. Specimens have been identified by R. J. Colony and F. F. Grout as dolerite, diabase, diabasic dolerite, doleritic diabase, and sodic diorite.

From 15-60 ms (50-200 ft) beneath the base of the upper sill is a tongue of similar material 3-6 ms (10-20 ft) thick. Not uniformly present, the exposures are of limited lateral extent.

Acid Felsites ("rhyolites"):

In the southeast a sill-like mass of white aphanitic rock, rising from the east and southeast, exceeds 300 ms (650 ft) in thickness and lies within the basal members of the limestone series 90 ms (300 ft) beneath the Lower Sill (Figure 6 and 7). As this body approaches the eastern edge of the district an 80 ms (260 ft) segment separates from its upper surface and continues northwesterly as a flatly inclined dike until it reaches the lower surface of the Lower Sill immediately beneath the east edge of the district's most productive ground. At this position the 80 ms segment rises precipitately along a thrust-like structure that displaces the full thickness of the Lower Sill. Upon reaching the sill's upper surface it reverts to its flatly transecting character and splits into a series of flatly transecting sheets. The highest of these reaches mid-way between the Upper and Lower Sills (Figure 7).

Westward the deeper main body maintains an apparent sill-like attitude, but beneath the center of the district's most productive block the upper surface again expels a flatly rising dike that reaches the Lower Sill, follows beneath it for several hundred meters, then transects it on a thrust-like structure beneath the west edge of that productive block. Less than 20 ms (60 ft) thick it raises the upper surface of the diorite 10 ms (30 ft), or less (Figures 7 and 8).

Both spurs become sill-like to the north and disappear. More important, there is a demonstrable field relationship between their transection of the Lower Sill and overlying ore.

Beneath these spurs, the main body, sill-like in a west-east plane, nearly 200 ms (630 ft) thick, rises northward as a flatly transecting dike; and splits into a series of sheets 5-35 ms (16-116 ft) thick within a zone of 150 ms (500 ft) thickness. These, too, transect the Lower Sill, but bear no relationship to overlying ore (Figures 8, 9, and 10). At the north end of the district ,in the vicinity of the Purisima Shaft, they disappear within a 400 ms (1,350 ft) interval. Data described in the section on DIKES suggest they may have turned abruptly upward into the Velardeña Dike (Figure 9). Hereinafter the two spurs are referred to as the No. 1 and No. 2 "rhyolites," or acid felsites; the deep main body as the No. 3.

Megascopically, all members of the group are uniformly fine-grained and feature less. Referred to as rhyolites, but more properly designated acid felsites, the only rhyolitic structures have occurred at the terminal points of sill-like sheets (Rodolfo Kirschner, personal communication). Specimens identified by Max P. Erickson are quartz porphyries with 3 mm phenocrysts of quartz, orthoclase, albite, and plagioclase. Some have been identified as rhyolite porphyry by F. F. Grout.

Megascopically, all members carry disseminated iron sulphide, possibly pyrrhotite or pyrite. Frequently the upper members carry grains of marmatite, occasionally galena. All members are gashed by veinlets of pyrite, marmatite, and galena. Although considered pre-ore, they may be penecontemporaneous with it.

"Rhyolitized Limestone":

Masses of minutely brecciated limestone, with fragments of "rhyolite" occur in front of small acid-felsite tongues. Many "rhyolite" fragments, not typical of those ground in a gouge, appear to have been introduced

(Figure 11). The interface between severely crushed matrix and underlying limestone is often paper-sharp. These bodies grade from brecciated material with minor limestone fragments through a mixture, not always present, wherein the crushed matrix appears to become silicified, to an acid felsite that exhibits sharp undisturbed walls. Their thickness is comparable to that of the adjacent "rhyolite" tongue. Although numerous, they do not occur in front of all "rhyolite" tongues. They are interpreted as an explosion breccia that preceded the advancing tongues of acid felsite. Recorded occurrences are not associated with ore.

Minor Sills:

This category contains "diorite" and "rhyolite" members. Within the two deep holes located beneath the Chorro Chimney (near the Buena Tierra Shaft) and on the Peñoles Fissure, a "diorite" sill, 1-2 ms (3-7 ft) thick, occurs just below the top of the evaporite series. Disseminated sulphides were not recorded. Within the hole beneath the Chorro Chimney a single 17 ms (53 ft) thick "rhyolite" lies 85 ms (280 ft) beneath the top of the evaporite series. It contains disseminated pyrite grains.

Deep Quartz Monzonite:

This, the deepest rock encountered in the West Camp, occurs in four of the five deep holes drilled on the edges of a block of ground extending from the Buena Tierra Shaft northward 1,400 ms (4,700 ft) to the Purisima Shaft, and northeasterly 500 ms (1,700 ft) to the Peñoles Fissure. It lies within the evaporite series, which it intruded from the southeast. Between the Buena Tierra and Purisima Shafts it rises 175 ms (575 ft) into the section, being 184 ms (605 ft) beneath the top of the series at the Buena Tierra Shaft and within 9 ms (30 ft) of the top in the vicinity of the Purisima Shaft.

It is a greenish, medium grained, holocrystalline rock, listed as a diorite monzonite, quartz monzonite, granodiorite, and granite. Microscopic identification places it in the quartz monzonite family, with variations from syenite to aplite.

Penetrated for 202 ms (663 ft) in the vicinity of the Purisima Shaft, and for 101 ms (337 ft) and 67 ms (222 ft) in the Peñoles Fissure and the Buena Tierra Shaft locations respectively, the body's only prominent differences are in its selvage facies. Field identifications describe the upper 11 ms (33 ft) beneath the Purisima Shaft as andesitic; the selvage zone in the southern holes, only 2.1-2.4 ms (7-8 ft) thick, as a dense, white rhyolite that grades downward into the underlying mass. Petrographycally the former is aplitic; but the latter varies within 1 m (3 ft) from an aplite, through a syenite porphyry, into a quartz monzonite (B. Stringham, petrographer).

Disseminated pyrite is ubiquitous in all penetrations. Minor marmatite, galena, and occasionally chalcopyrite, have been observed.

Age relations, with respect to ore mineralizations, and to other intrusives, are not known.

Dikes:

Described under SURFACE GEOLOGY are three well-known narrow dikes of northeast strike. The Potosí and Mina Vieja Dikes, the southern and northern members ,are andesitic. The central member, the Velardeña, is rhyolitic (Figure 3).

The Mina Vieja Dike, explored through vertical depth of 356 ms (1.170 ft), varies from a few cms to 7.5 ms (less than an inch to 25 ft) in thickness, but is absent in many places. All underground exposures have been altered to a brown clay, possibly the result of circulating waters derived from the oxidation of adjacent ore bodies. It is pre-ore, but seems to have exerted no control on the location of ore-shoots, except that the Purisima Chimney, an important ore body of the district, banked against it.

The Velardeña Dike is a discontinuous en-echelon feature in which individual dikes, twisty, irregular and usually less than 1 m (3 ft) wide, die out and spring up within a zone about 20 ms wide. It has been identified in mine workings to a depth of 447 ms (1,470 ft). It cuts a series of oxidized mantos and appears to be post-mineral. Although not identified on the Velardeña 16 th level, 697 ms (2,290 ft) beneath the collar of the Velardeña Shaft, it may be represented by a 4 ms (13 ft) wide rhyolite dike 300 ms (990 ft) north of its projected position.

A deep drill hole 110 ms (360 ft) south of the 16th level exposure cuts three sheets of the underlying acid felsite; 300 ms (990 ft) north three deep drill holes show no sign of an acid felsite (Figure 9). Therefore it is possible the 16th level dike represents the extreme northern extensión of the underlying acid felsites.

The Potosi Dike, essentially vertical, maintains its 6 ms (20 ft) width throughout a depth of 1,000 ms (3,300 ft). Like the Mina Vieja Dike, it is pre mineral, and, except that ore bodies have banked against it, exerted no control on the location or direction of ore shoots. At depth ;in contact with the "U" ore body, it has been altered to a pasty, grey, clay-like material.

North of the Potosi Dike are three narrow, post-mineral northeast-trending, essentially vertical dikes that have been identified by F. F. Grout as olivine basalt.

## STRUCTURAL FEATURES

### FOLDING

Structurally, the limestones can be compared to a tabular feature flexed into a series of gentle folds, and inclined flatly to the southwest. There is no change in this picture from the outcrops down for 1,000 ms (3,300 ft) (Figures 3 and 12).

The contour lines of Figure 12 represent conditions in the bottom 370 ms (1,200 ft) of mine development at depths of 560-930 ms s(1,830 3.050 ft) beneath the top of the limestone series. The solid lines in the southern part of the district are contours certain dolomites, as drawn by Messrs. Thornburg and Horcasitas of the old Potossi Mining Company. Elsewhere on the map, dashed lines, not representing a particular bed, are the composite trends of innumerable dips and strikes of bedding planes exposed throughout the 370 ms (1,200 ft) interval.

Over the deep, relatively narrow, but intensely mineralized southern portion of the district, the limestones trend northwesterly and dip to the southwest at inclinations of 5 - 12 degrees. As they rise from the southwest, their strikes change in less than 500 ms (1,650 ft) from N 28°W at the extreme south end of the map, to N 57°W in the vicinity of the Buena Tierra Shaft. The axis of the southwesterly "plunging" almost insignificant syncline thus produced trends up-dip at about N 50°E.

North of the Buena Tierra Shaft the beds swing abruptly from their N 57°W strike to a northeasterly trend; their dips change from SW to NW to northerly, but without alteration in their overall magnitudes of 2-8 degrees. The axis of the anticline "plunges" westerly about 300 ms (1,000 ft) north of the Buena Tierra Shaft. This anticline overlies a zone where acid felsites have breached the Lower Sill (Figures 12, 13, 14). A few bedding planes on the northeast flank of the flexure strike southeasterly and dip flaty to the northeast, suggesting a possible dome-like closure farther east.

Some 1.250 ms (4.100 ft) north of the Buena Tierra Shaft, the northeasterly striking, northwesterly dipping bedding planes reverse their dips and rise to the north. The axis of the corresponding syncline trends up-dip N 65°E. West of the projected location of the Purisima Shaft, bedding planes are again striking northwesterly and rising flatly from the southwest.

### FAULTS AND FRACTURES

In Santa Eulalia's West Camp, faults are of the same insignificant magnitude as the folding. A 3 ms (10 ft) throw is exceptional; the greatest recorded is only 15 ms (50 ft). Prescott (1916) analyzed the fissure systems, divided them into groups according to their strikes, and assigned economic characteristics to them. Thus, to the N-S, N 10°E, N 10°W, and N 30°W groups he attributed great importance as carriers of silver-lead-zinc ores; to others he assigned the role of oxidation carriers.

From 1932 to 1954 in a block of ground between the Buena Tierra and Purisima Shafts, an effort was made to locate and map every fracture traceable across a drift. Those engaged in this undertaking sympathize with Prescott's remarks, applicable to all fractures in the district, that the northerly trending groups are remarkable in their "tightness and inconspicuousness in the country rock," and "it is not an easy matter determine the continuity of any of these fissures,... but as a rule the great extent is arrived at by assuming that developed segments will connect continuosly." They are not prepared to accept all the economic characteristics assigned to the fractures, nor to agree with the over-riding importance usually assigned Santa Eulalia's West Camp fractures in the control of ore body locations.

Of some significance is Prescott's remark (1916, p. 67), "... very few North-South fissures are found in the northern half of the developed zone, the N 10°W fissures being the rule up to the extreme northern limits, where the N 30°W class appear almost to the exclussion of other fissures of the North-South group." Referring to Figure 15, it is apparent that ore bodies south of the Buena Tierra Shaft occur in linear trends of N 12°W, N 9°W, N 5°W strike that can be visualized as radiating from a common zone some 3 kms (1.9 mile) south of the Camp's most southern mineralization, and possibly 4.5 kms (2.8 miles) southerly from the Buena Tierra Shaft. These trends, referred to as fissures, have been named. From west to east the prominent members are the Chorro, J-north, and Q-Dennis. They are normal faults. The weakest are the most western. The strongest is the eastern, the Q-Dennis. Throws increase in magnitude from west to east, and average values are:

| | |
|---|---|
| Peru Fissure | 1.0 ms (3 ft) |
| Chorro Fissure | 0.5 - 1.0 ms (1.5-3.0 ft) |
| J-north Fissure | 4.5 ms (15 ft) |
| Q-Dennis Fissure | 8.5 ms (28 ft) |

Thorws, uniformly down to the west, increase to the south (Rodolfo Kirschner, personal communication) but steadily weaken to the north.

Opposite the Buena Tierra Shaft the Chorro Fissure has lost its vertical continuity and there is no displacement along it. It dies in depth and is replaced laterally by a similar feature, which, in turn, dies and is replaced (Figure 16). The J-north (Figure 17) is equally insignificant: south of the Shaft it possessed a vertical displacement of 4.5 ms (15 ft); opposite the Shaft it has a maximum throw of 40 cms (1.3 ft) and this only on the 18 th level. On the 16th level, 100 ms (328 ft) higher, there is neither northerly trending fissure nor 40 cm displacement; in a series of slusher drifts within the highest of the acid-felsite "sills", some 80 ms (264 ft) beneath the 18th level, there is a series of northeast fissures but no sign of a northerly feature; yet on the 20th and 21 st levels, 100 and 150 ms (328 and 498 ft) beneath the 18th, a weak N 5°W and N 15°W fissure cuts both the limestone and Lower Sill respectively, but without vertical displacement.

Conditions north of the Buena Tierra Shaft are markedly different. Orebody adherence to the named trends is less pronounced; the composite stope pattern, where stopes are clustered, is more braided. There are numerous small faults, most of them northeasterly striking and frequently mineralized, but the prominent northerly trending fissures to the south of the Shaft are represented only by the Q-Dennis extensions: the Tiro Alto and an en-echelon extension, the Peñoles Fissure. The latter has a displacement of 2.8 ms (9.2 ft) as measured by bedding plane displacement on the 16th level. Northerly trending fissures occur, but usually exhibit little or no displacement and are limited vertically and horizontally.

There are a few scattered calcite-healed "fractures", but displacements have not been observed. Here and there a bedding plane appears to have acted as a glide zone. Possibly some the northerly trending fissures north of the Buena Tierra Shaft are the bounding planes of southward horizontal-gliding limestone blocks. If so, the lack of vertical continuity of the fissures would be explained; as would their lack of vertical displacement, or in places the presence of apparent vertical displacements of 5 and 10 cms (2-4 in); and their origin could be related to the action of the more southern fissures along which the throw is increasing steadily to the south. There is no evidence horizontal gliding has involved displacements of appreciable magnitude.

Prescott (1916) felt northerly trending fractures were the important pre-mineral ore structures. From the standpoint of ore control, the post-1932 study not only denigrates the importance of all fractures, but fails to substantiate a significant pre-ore and post-ore origin for the various directional groups. It may be true, as indicated by the absence of northerly fissures in the acid felsite within the J-north Chimney, that northerly trending fissures were formed earlier that those of northeasterly strike; it is true that the post-mineral northearsterly trending Donald Fault has the largest throw in Camp. But it is felt that all systems were well represented prior to ore introduction *. The mineralized northeast fractures, particularly, persist horizontally and vertically, and cut all rock types: limestones, diorites, acid felsites, and the lower members of the capping series.

Judging from the longitudinal sections, and the west-east cross-section through the Chorro and J-north Chimneys, acid felsites breach the Lower Sill along thrust-like structures. Field data substantiating such structures have not been observed in overlying limestones, although an occasional thrust fault of 30 degree dip and 30-cm (1-ft) displacement has been noted in limestones on the Buena Tierra 20th level between the J-north and Peñoles Fissures.

## Acid-Felsite Structures

Mention has been made of northeast fractures within one of the acid-felsite "sills". These features, always sulphide healed, are ubiquitous in the "rhyolites". Whether they represent small faults, or tension features, has not been proven.

Cliff-like upwarps on the upper surface of the "rhyolite sills" are another phenomenon. They rise vertically 2-7 ms (6.5-23 ft) and have the same NE strike as the mineralized fractures within the felsite bodies, but their courses are sinuous rather than linear (Figure 18). Curiously, they do not seem to be reflected by corresponding upwarps in overlying bedding planes, yet the acid felsites are known to dilate the geologic column.

* In the majority of exposures, the Donald Fault is post-mineral. In a few places it appears pene-contemporaneous to post-mineral, notably on the Peñoles Fissure.

# ORE BODIES

## Shapes and Distribution

Santa Eulalia ore bodies are typical limestone replacement features mantos, chimneys, replacement veins and associated bedding replacements. Mantos and chimneys, pipe-like bodies in which the long axis is tens or even hundreds of times the length of the largest cross sectional axis, are abundant. They are essentially similar — mantos being horizontal, chimneys vertical. In both cases the courses followed by their long axis vary from simple linear paths, through irregular but sometimes rectilinear patterns, to the vaguest and most unpredictable wanderings. In each case, their idealized cross sections vary from roughly circular to crudely compressed ellipses and exhibit all types or irregularities and variations. Spurr (1911) described them as comparable to "...the first slab cut from a knotty log...", but with many variations from the typical form. Santa Eulalia mantos, although essentially horizontal and tending to lie within some particular stratum, or horizon within it, also tend to work irregularly upwards and frequently step, chimney-like, from bed to bed. Many mantos have been fed from chimneys, and some chimneys appear to have been fed from mantos.

Replacement veins are less numerous, but the Peñoles Fissure is an example. On the Peñoles Fissure stope patterns resemble ore shoots along a vein (Figure 10). These shoots have been fed from mantos that either crossed it and then kept on their own course, or turned and followed it. As viewed in longitudinal section the upper and higher shoot extends over 400 ms (1.300 ft) vertically and flares outward from a base that is 200 ms (660 ft) long to an upper length that exceeds 600 ms (1,900 ft). It is fed from a manto that enters from the east. Separated from it by 200 mss (600-800 ft) of barren limestone, and fed from a manto that enters from the southwest, is a lower, smaller, more southern area in which stope patterns resemble a chain along which the stopes dangle, one above another.

Some 150 200 ms (500-650 ft) above this lower zone is another area where mantos both enter and take off from the Fissure.

In these developed areas, mineralization is roughly tabular in shape and ranges from a few centimeters to several meters in width. Only the strongest areas have been mined. Mineralization in the weaker stretches is too low grade or too narrow to be profitable.

In the lower, smaller area, stopes have been developed on bedding replacements that spread laterally into the walls and produced ore shoots of minable width. In the three highest stopes, bedding replacement ocurred immediately beneath dolomitic horizons. Records indicate a similar dolomite may exist immediately above the back of the fourth and largest of the group. Connecting the stopes is a mineralized fissure a few centimeters wide.

Southern Concentration:

In the southern and deepest part of the Camp, from the Buena Tierra Shaft southerly for 900 ms (3,000 ft), ore bodies are concentrated in a block of ground 600 ms (2,000 ft) wide and 440 ms (1,450 ft) thick. The top of this block is the lower fossiliferous stratum within which is a wide-spread development of mantos that follow northerly and northeasterly, and, in the extreme south, pronounced west-north-westerly courses. Virtually no mantos occur above it and few within the initial 200 ms (660 ft) beneath the lower fossiliferous stratum. But from this depth to the top of the Lower Sill, through a vertical distance of 240 ms (800 ft), and to a minor extent to the bottom of the Lower Sill, there has been an intense development of chimneys and northerly trending mantos that cluster along named fault-fissures: Chorro, J-north, Q-Dennis, and Potosí the latter being a less important member midway between the Chorro and the J-north. Mantos also break away from the fissures, follow easterly courses at various horizons and interconnect from fissure to fissure (Figure 15).

Stopes from this deep block lead horizontally or vertically, often torturously, to almost every working in the district. Some rise southward and extend the Camp an additional 500 ms (1,650 ft) to the south. Yet, north of the Buena Tierra Shaft there is only one occurence of deep ore, the Tiro Alto extension of the Q-Dennis Fissure.

Stopes on the Chorro Fissure terminate in the Chorro Chimney, which rises vertically 660 ms (2,200 ft) from the Lower Sill to the limestone-capping contact (Figures 7 and 8). Those on the J-north Fissure terminate in the J-north Chimney which exceeds 200 ms (660 ft) in length, approaches 100 ms (330 ft) in width ,and occupies a 55-70 m (180-230 ft) interval between the top of the No. 1 acid felsite and the Upper Sill. It has minor extensions rising 40 ms (130 ft) above the Upper Sill and reaching down to the Lower Sill through a total vertical height of 170 ms (550 ft). Mineralization on the Potosí Fissure terminates in a replacement vein, possibly 200 ms (660 ft) long and up to 4 ms (13 ft) wide; extending from 10-190 ms (30 630 ft) above the Upper Sill. Although Peñoles Fissure mineralization continues north of the Buena Tierra Shaft for possibly 250 ms (800 ft), it terminates in a series of chimney-like bedding replacements extending from 20-185 ms (65-610 ft) above the No. 1 acid felsite, to a height of 90 ms (300 ft) above the Upper Sill.

The exception is the Tiro Alto extension of the Q-Dennis Fissure where a manto trends northerly for 500 ms (1,650 ft), chimneys for 110 ms (330 ft), then abruptly mantos southwesterly and feeds into the Peñoles Fissure. With this exception, mineralization at the north end of the deep block rises 500 ms (1,650 ft) above the top of the Lower Sill before it again spews northward as a series of great mantos.

Northern Concentration:

Northerly 1.9 kms (6,200 ft) from the Buena Tierra Shaft, throughout a block of ground 1.4 kms (4,600 ft) wide by 450 ms (1,475 ft) deep, extending from the lower fossiliferous stratum upward through the fossiliferous beds to the limestone capping contact-is an abundant development of widely-spaced ore bodies, mostly mantos. This block ends in depth where the deeper block begins, extends westerly and easterly beyond the latter's boundaries, yet has its greatest concentration of ore bodies along a central axial zone resembling a lineal projection of the J-north Fissure. In plan view, mantos seem to have been pulled toward this zone, from both the Chorro and the Q-Dennis Fissures, and braided loosely around it.

The northern block has been fed from various sources. One, at the top of the southern block, rises easterly from the Q-Dennis zone as an inclined chimney through vertical and horizontal distances of 300 and 450 ms (1,000-1,500 ft), respectively; approaches the capping; turns northward for 3 kms (9,500 ft), following beneath the capping in limestone not along the contact as a near-surface manto. This is the Bustillos Manto on the fringing eastern edge of mineralization. Another issues as a manto from the Chorro Fissure, 300 ms (1,000 ft) southerly from the Buena Tierra Shaft, heads westerly in the lower fossiliferous stratum for 450 ms (1,500 ft), then turns northerly on an irregular twisting course for 1.2 kms

(4,000 ft). This, the West ore body, has been mined as a series of disconnected stopes on the fringing western edge of the district's mineralization. But the important sources are the Chorro and the Mapula Chimneys.

The Chorro Chimney, immediately east of the Buena Tierra Shaft, occurs at the extreme north end of the Chorro Fissure rises vertically 660 ms (2,200 ft) from the Lower Sill to the limestone-capping contact (Figure 8). It spews off a series of mantos in the 200 ms (660 ft) immediately beneath the capping. These wander irregularly northward for 1.9 kms (1.2 miles) (Figures 4 and 15). The deepest lies in the lower fossiliferous stratum, the others 100-300 ms (330-1,000 ft) higher (Figure 5). All connected with the Purisima Chimney, 1.5 kms (4,900 ft) north of their source in the Chorro and none follows the path of any other. Each leaves the Chorro on a northeasterly course, but rapidly assumes its independent path. Some swing slightly westerly, others easterly as much as 400 ms (1,300 ft), but 500 ms south of the Purisima Chimney their paths again coalesce, this time in a zone of general N 30°W trend. After reaching the Purisima Chimney, two leave it. One, in the lower fossiliferous stratum, travels southwesterly an additional 250 ms (800 ft); the other, 215 ms (700 ft) higher, continues northwest 450 ms (1,600 ft), then turns abruptly southwest for 1.2 kms (4,000 ft).

The Mápula Chimney, 340 ms (1,100 ft) east of the Buena Tierra Shaft, lies at the north end of the J-north Fissure. Only 225 ms (740 ft) deep, it rises from the lower fossiliferous stratum through the overlying fossiliferous series to the limestone-capping contact (Figures 7 and 9). At its base it either feeds ,or is fed by, a northeasterly trending manto that connects with the Peñoles Fissure; but near its top it sends off a series of mantos that trend northwesterly and tie into the group that originates in the Chorro Chimney. Although it overlies the J-north Chimney, the two are separated by 400 ms (1,300 ft) of limestone in which the upper 350 ms (1,150 ft) apparently are barren.

Another source, like the Bustillos Manto, rises above the deep southern block from a point in the Q-Dennis Fissure, then splits into two diverging prongs which approach the limestone-capping contact and swing northwesterly as near-surface mantos following arcuate courses. The more easterly, tying in with stopes from the Chorro and Mápula Chimneys, eventually reaches the Purisima Chimney.

It has been pointed out that stopes from the deep, intensely mineralized southern block of ground can be traced, tortuously, into almost every mine working in the district. The chief exceptions are small, near-surface, isolated stopes at the extreme north end of the belt — probably erosional remnants from the known mantos; small, near-surface stopes in the northwestern part of the Camp in the vicinity of the Carmen and Reina de Plata Shafts; and large, isolated near-surface stopes at the extreme south in the vicinity of San Antonio Chico and Coronel Zubiate. It is thought all of these relate to mineralization that has wandered beneath the capping. But one exception, the "U" ore body near the Potosí No. 2 Shaft, is isolated and deep. It is 250 ms (900 ft) east of the Q-Dennis Fissure, a similar distance south of the inclined easterly trending chimney that feeds the Bustillos Manto, and 820 ms (2,700 ft) beneath the surface. Banked against the Potosí Dike, it lies within a small northeasterly trending graben, roughly 70 ms (230 ft) wide, that has dropped the Lower Sill some 35 ms (120 ft). It has replaced limestone and altered-sill. It has no recognized connection with any ore body in Camp.

Chorro — Mápula — Purisima System:

It is a demonstrable field fact that within the fossiliferous limestone series, a 366 ms (1,200 ft) interval from the lower fossiliferous stratum to the limestone capping contact, a series of mantos from three diverse chimney sources, separated laterally one from the other by 250-300 ms (825-1,000 ft) of intervening limestone, has travelled by diverse, irregular, often widely separated paths for 1.5 kms (4,900 ft) to the north and tied into a common chimney. The chimneys suggest the poles of a battery; the mantos the leads between poles.

The three southern sources are the Chorro and Mápula Chimneys, and the ore body that originated in the Q-Dennis Fissure. The northern terminus, the Purisima Chimney (Figure 19), apparently terminates in the lower fossiliferous stratum, seems to be fed by the lowest of the mantos that originated from the Chorro, and rises roughly 250 ms (800 ft).

Between the southern and northern chimneys, manto mineralization undergoes a change in metallurgy. At the south are "normal" Santa Eulalia irony lead ores with a modest silver content (250-400 grams); at the north are irony ores rich in silver (1 kg) with a minor lead content. All are thoroughly oxidized. It is presumed the pre oxidation "normal" sulphides might have approached 250 300 grams Ag. 12% Pb, 12% Zn, 12% Fe; whereas those to the north might have assayed 500-1,000 grams Ag, 4% Pb, 4% Zn, 25% Fe.

## DISTRIBUTION OF TRENDS

The overall district trend of the ore bodies is distinctly north-northwest

(Figure 15). This is particularly true of ore bodies clustered around the Chorro, J-north, and Q-Dennis Fissures in the deep southern part of the West Camp, and of those above the lower fossiliferous stratum. There are exceptions. Prominent are the deepest sulphide mantos of the intensely mineralized southern block ,and those in the lower fossiliferous bed, where the average trend is predominantly to the northeast. Above the lower fossiliferous bed are a few short norteasterly courses — as in those mantos that break northeasterly from the Chorro Chimney and in the small, isolated near-surface bodies that fringe the district to the northwest. A west-southwest course exists at the extreme north end.

## Deepest Ores

The deepest ores originate in at least three places. Two are on opposite extremities of a northeasterly trending zone. One, the Peru Chimney, approximately 300 ms (1,000 ft) south of the Buena Tierra shaft and 100 ms (330 ft) west of the Chorro Fissure, rises from an intersection of the No. 2 acid felsite with the upper surface of the Lower Sill, trends northeasterly, and feeds northerly and southerly into the Chorro Fissure stopes (Figures 12, 13, 15). Its opposite member rises on the Q-Dennis Fissure from an intersection of the No. 1 and No. 2 acid felsites, here represented by a single intrusive, with the upper surface of the Lower Sill; and feeds southward, westerly, and northerly into the ore bodies on the Q-Dennis, J-north, and Tiro Alto Fissures (Figures 12, 13 and 20). The third, smallest of the three, lies vertically beneath the Chorro Chimney at the north end of the Chorro Fissure 100 ms (330 ft) east of the Buena Tierra Shaft (Figures 7, 8, 12 and 13). Rising from an intersection of the No. 2 acid felsite with the upper surface of the Lower Sill, it feeds an insignificant chimney. This chimney rises for about 100 ms (330 ft), then picks up mineralization from sources feeding into it along the Fissures, and continues for a total height of 660 ms (2,200 ft) as one of the district's important ore bodies.

## Replacement Fillings

Santa Eulalia ore bodies are massive sulphide replacements (of their oxidized equivalents) of pre-existing limestone beds. In all cases the interface between massive sulphide and megascopically unaltered limestone is as sharp as the difference between two sides of a sheet of paper, yet bedding planes pass uninterruptedly from unaltered limestone into and through sulphide bodies with no loss in definition or characteristics. Within the sulphides, bedding-plane argillaceous material is unreplaced and perfectly preserved. Figure 21, a reproduction of data measured in the mine and recorded on geologic plans, shows bedding planes as they pass from limestone into massive sulphides of the J-north Chimney. This detail is from the 19th level of the Buena Tierra Shaft at a depth of 665 ms (2,180 ft) beneath the surface and 80 ms (260 ft) above the top of the Lower Sill.

Within this same body were various examples of chert nodules encased by massive sulphides. These were inherited from pre-existing limestone beds, yet there is no megascopic evidence of alteration within the chert or along the interface between chert and sulphide.

With these data it might be surmised that the replacement process could have occurred under several conditions. Among them:

1. The temperature was below that necessary to transform a chert-limestone interface into wollastonite.
2. Energy normally available for the production of wollastonite was consumed by the replacement process.
3. The replacement process occurred so rapidly that the chert-limestone interface remained intact.

## OPEN CAVES

There are two types of open caves in the district. One, an ore cave, results from the oxidation of a sulphide body. It lies above oxide mantos and occasionally within or along the sides of chimneys. Ranging from a few centimeters in height to rooms in which a person stands with comfort, ore caves lie between a limestone roof and a cave floor that is often a jumble of fallen limestone blocks overlying and obscuring the oxidized remnants of the ore body. In part they represent a leaching of material from the ore, in part a solution of adjacent limestone. Their walls are lined with calcium-carbonate precipitates, helictites of all types, but none recorded has containe dog-tooth spar. They occur from the highest outcrops to the deepest oxide-sulphide transition zone at depths of 740 ms (2,400 ft).

The other is a dry cave. The name has no reference to water, but only to the absence of mineralization. Dry caves, found at all depths down to 1.170 ms (3,840 ft) above sea level, occur for at least 220 ms (725 ft) beneath the top of the sulphides. Within this sulphide zone all have been filled with water, creating mining hazards; all are pre-mineral; and in the two recorded examples where sulphide bodies have made contact with them, sulphide deposition ceases. Such caves have been lined with dog-tooth spar. In one case there was a suggestion that a strong sulphide fissure had been healing its trucated end with calcite, scab like, and in turn had been replacing this calcite scab with sulphide minerals. In this cave the white dog-tooth spar was lightly banded with shades of red and amber which fluoresced a brilliant orange under ultra-violet light. According to Frank Ebbutt (personal communication), an analysis of these bands made at the Smithsonian Institution indicated a variation in lead content. From this, inferences have been made that the crystals grew within a cave filled with water, that the various color bands represent varying lead concentrations within the water, and that these varying fluctuations were caused by varying mineralization impulses entering from the fissure.

Abode the water table, in all ocurrences known to the author, dry caves and ore bodies have remained isolated from each other and there is no way to relate age of cavern development to age of mineralization. Caves lined with severely twisted and contorted helictites are those most prone to be associated with ore, whereas ore has not been reported from caves lined with dog-tooth spar. If the latter were present at one time, it might have been destroyed by sulphuric acid waters produced during oxidation.

## ORE CONTROLS

### Favorable Horizons

For decades, possibly centuries, it has been observed that certain beds within the Santa Eulalia limestones have appeared to be more susceptible to manto replacement than have others. Those carrying mantos have been called "favorable" horizons, those lacking mantos, "unfavorable", with no knowledge of the inherent factors making one favorable or the other unfavorable, or whether a difference exists between them. In 1922 Mr. Say, an employee of the Potosí Mining Company, sampled the Inglaterra, Carolina, Buena Tierra, and the Potosí No. 1, No. 3 and No. 4 Shafts, segregated his sampling according to physical characteristic that could be traced from shaft to shaft, and assayed for $SiO_2$, Fe, Mn, CaO, Mg and Al. The results, reproduced in Figure 22 and summarized as follows, clearly indicated that chemical differences between the beds are so sligth as to appear irrelevant.

| | % | | | | | |
|---|---|---|---|---|---|---|
| Type of Limestone | $SiO_2$ | Fe | Mn | CaO | Mg | Al |
| Dark, bluish gray, argillaceous (Black limestone of 1922). | 3.2 | 0.6 | 0.1 | 48.1 | 0.35 | 0.92 |
| Gray | 2.5 | 0.1 | 0.2 | 54.0 | 0.35 | 0.56 |
| Light gray, slightlv crystalline | 5.0 | 0.1 | 0.1 | 51.2 | 0.30 | 0.45 |
| Crystalline and marbleized | 0.5 | 0.7 | 3.8 | 51.0 | 0.30 | 0.42 |

Mr. Say's sampling was concerned only with groups of beds that formed recognizable field units, not with the precise horizons that had been replaced. But as a result of the 1932 study, it became possible to define precisely the horizons in which known mantos occurred and to compare these horizons with their corresponding physical characteristics as recognized within the Velardeña and Santo Domingo Shafts:

amount of recrystallization or manganese stain;

content of fossils, chert, bedding-planes;
presence or absence of dolomites; color.

As remarked by Clendenin (1933), "This comparison yielded no results whatever... therefore, as to why these zones are favorable, this problem will have to await some more-detailed study of the limestone characters, and perhaps can be solved, if at all, only by microscopic or chemical investigations." The problem is still there.

### FRACTURES

One of the longest held, most widely accepted, theories regarding the location of Santa Eulalia ore bodies is that of fracture control. Spurr (1911) stated: (1) that a manto "... is caused by the intersection of a vertical ore-bearing fissure, with a favorable limestone..."; (2) "...where two or more strong vertical fissures intersect... a strong vertical ore chimney is formed..."; and (3) these are fed by "...ore-bearing solutions, which... availed themselves of the fissures in the limestone as circulation channels." From his conclusion, Santa Eulalia mantos and chimneys appear to be little more than bedding replacements. To some extent this view is still held, but as early as the mid-1920's a growing body of operators and geologists looked upon it with skepticism. Their opinions culminated in the 1926 paper by Basil Prescott, "The Underlying Principles of the Limestone Replacement Deposits of the Mexican Province," which rejected the idea that mantos were fed by fractures and proposed that mantos originated from chimneys. An awareness that fractures were not all-important in controlling the courses of mantos led Benham (1928a) to observe that "The bearing of the manto is sometimes determined by the pre-mineral fissures," but "In some of the smaller mantos one cannot always find controlling fissures."

As part of the 1932 study, which was confined to a definite block of ground north of the area now recognized as the deep intensely mineralized southern block, an effort was made to locate and plot every fracture that crossed a drift or cross-cut and to compare its location with the accurately plotted outlines of adjacent stopes. Except for the Peñoles Fissure — recognized as a pre-mineral fault along which a replacement vein and vein-like bedding replacements have developed no support could be adduced for fractures either in their role as the presumed feeders of mineralization or as a significant control in the overall course followed by Santa Eulalia mantos.

The study's summary report (Clendenin, 1933) states:

"...*no evidence of a relation between fractures and the courses taken* by mantos has been found as a result of the study... There are many places where the development extends more or less widely through ground close under a manto. In some of these places practically no fractures have been found. In others of the places fractures appear in fair abundance, but not in any greater abundance than they show in sections of the development far removed from any mantos. Further, in places where fractures do appear, there are usually almost no fractures among them which show strikes at all close to that of the manto; while the few fractures that do show such strikes are apt to be of only the weakest character. The mantos through most of their lengths follow courses close to north south, while fractures of similar strike are actually rather rare through the entire area. All of this suggests, first, that any manto has not followed along the line of a single fracture-zone-that is, a continuous zone in which fractures are abundant, though of diverse strike, not parallel to the trend of the zone. In ground above mantos, fractures seem generally to be somewhat more abundant than in ground below, but they show no greater tendency to parallel the mantos in strike, and they are not more abundant than they are in sections distant from any mantos; so that they do not offer any better support for the idea that fractures have acted to determine the locations of mantos."

As to mineralized fractures, the summary report continues:

"Such fractures are found rather commonly in various parts of the workings ...show strikes... of great diversity of direction, though the direction is usually somewhere in the northeast quadrant; but they only very rarely strike at all close to north-south, which is the usual direction of trend of the mantos... As a final characteristic, it often happens that one of these fractures is exposed at one level, but cannot be found at some deeper level which extends through the same area."

And the report concluded:

"... the fractures, though they existed at the time of mineralization, had nothing to do with controlling the courses taken by the mantos... instead they were simply fractures of random strike, which were traversed by the mantos as they developed, and were invaded to some extent by the mineralizing solutions. Furthermore ,it is thought that the mineralization, in following fractures, tended usually to travel upward from a manto, and travelled downward only rarely, or only to short distances. Finally, it is thought that the mineralization, in working upward along a fracture, may have tended also to be spread along the length of the fracture, but probably did so for only limited distances from the location of the manto which was its source, and then only in dying fashion."

In other words the 1932 study strongly indicated that fractures rarely guided mineralization more than a few meters, and where mineralized represent the extreme ,tenuous outer fringe of an ore body. In the ensuing 30 years there have been no additional data to change this picture. The forces that determined the location of the mantos are almost as unknown as when the district was discovered.

These conclusions seem contrary to facts obtained from the deep, mineralized southern block of ground wherein the named fault fissures appear to have controlled the location of ore bodies. Rather, although the author admits ignorance of geologic detail within this block, the conclusions indicate mineralization was fed into ore bodies that followed these fissures for limited lengths; and it is suggested that fissure control of ore location is greatest in the southern block.

There remains a body of opinion holding that chimneys are formed at the intersection of vertical, or nearly vertical .fissures. The 1932 study produced no evidence to support this view, nor have data accumulated in the ensuing 30 years substantiated it. The Chorro and J-north Chimneys are cases in point.

The Chorro Chimney, from its oxide-sulphide transition zone at about 1,380 ms (4.550 ft) above sea level to its roots 300 ms (1,000 ft) deeper, is developed by seven levels. On each of these is a mineralized northerly-trending fracture, but in no case is it continuous from level to level, nor are there intersecting fractures within the vicinity of the Chimney. The theory may have originated within the upper levels of the Chorro Chimney which hits the capping directly beneath the San Lazaro Fissure — a zone 40 ms (130 ft) wide of sparsely distributed post capping mineralized fractures up to 1 cm wide that strike N 40°-50°E and dip 65°-80° northwesterly. Instead of having guided the course of the Chimney, the Fissure occurs at the very top. Further, if it exerted an influence, it was to bleed out mineralization. Thus, as the Chimney approaches the limestone capping contact, a series of mantos are thrown off along the northeasterly San Lazaro course for possibly 150 ms (550 ft), then strike out on more northerly trends.

The J-north Chimney, also lacking in confirmatory evidence, is overlain, underlain, and cut by six formal levels as well as a series of slusher drifts. Within the Lower Sill, 60-110 ms (200-360 ft) beneath the base of the main mass of the Chimney, it would be difficult to find an area lacking mineralized northeast fractures. Also a mineralized N 12°W fracture, traceable horizontally for 40 ms (130 ft), directly underlies the Chimney. Where mineralized fractures cut thin limestone beds within the sill, there is no increased development of sulphides along the intersections of NW and NE fractures. Within limestone 30 ms (100 ft) beneath the main base of the Chimney, there is a mineralized N 10°W fissure, generally tight but swelling locally to 5 ms (18 ft) widths. Northeast fractures are absent, Within the acid felsite on which the Chimney sits, mineralized fractures of N 30°-45°E strike and diverse dips ranging from 50° NW to 80° SE are abundant, but there are no northerly fractures. Within the horizon of the Chimney proper, at 1,160 ms (3,830 ft) above sea level and 10-20 ms (30-65 ft) west of the Chimney, are there weak, pre mineral N 10°-.25°E fractures of 30°-43° easterly dip, that carry no displacement. There are no intersecting fractures. Immediately above the Chimney is a tight mineralized fracture of N 12°W strike, but no northeast fractures. Fifty meters (165 ft) above it a N 12°W fissure is intersected by a series of N 30°-45°E fractures that dip 47°-65° northwesterly, all of them mineralized; but there is no development of a chimney only a discontinuous replacement vein. And 100 ms (330 ft) above its top are four weak, premineral fractures of N 12°-40°E strike and dips of 65°SE to 57°NW.

Walker and Walker (1956), in their description of mantos in general, stated: "The determining factor in the localization of a manto... is the position of the source of the mineralizing agencies, and the most convenient direction in which they can escape to the surface, and if this direction chances to coincide with the course of a fissure, they may follow along the intersection of it with the manto horizon, but if not they may make their way through unfissured limestone in the direction they desire to take, crossing and ignoring any fissure they may encounter enroute." Their description of mantos in general aptly fits Santa Eulalia.

## DOLOMITES

In 1931 Hayward and Triplett, writing on the relationship of lead zinc ores to dolomitic limestones in northern Mexico, observed that all Santa Eulalia dolomites are secondary. The author is not familiar with the areas of their interest, nor has he observed dolomitic halos around Santa Eulalia ore bodies, but he has observed dolomitic beds throughout the entire column from the limestone capping contact down to 22 ms (70 ft) beneath the Upper Sill, a range of 785 ms (2,575 ft). They vary from 20 cms to 2.2 ms in thickness (10 in to 6 ft-7 in) and, whereas a few die out, most maintain their position in the geologic column over long distances. Identifications have been based on visual inspections. To the author's knowledge, their magnesium content has not been determined. Possibly they are better described as dolomitic limestones rather than dolomites.

In the upper horizons studied in 1932, there are 20 dolomitic beds and 9 recognized "favorable' 'horizons. Of the latter, one alone is associated with a dolomite. In deeper development, in the southern part of the district, one favorable horizon, the "19 bed" some 100 ms (330 ft) above the Upper Sill, is such a dolomite, yet north of the deep southern block its importance is inconsequential.

In the deep southern part of the Peñoles Fissure (Figure 10, a series of dolomites appear to have controlled the upper surfaces of a series replacement beddings that have produced a chimney like series of sulphide stopes. Among these dolomites is the "19 bed" at the back of the uppermost group. In this one area dolomites appear to have exerted a structural control on the location of bedding replacements; elsewhere on the Peñoles Fissure they have been unimportant.

## FLEXURES

### Regional:

Older writings presumed that Santa Eulalia's northerly trending mantos were controlled in some way by the domal structure of the range. Figure 12, based on modern data, does not support such an interpretation. It is possible to imagine that easterly trending mantos in the southern part of the area result from a simple, up dip, gravitational response of the ore-bearing materials, but in the northern part of the camp such mantos are more closely aligned with the strike of the beds.

### Specific:

West-east cross sections indicate a slight but definite flattening of the regional limestone dips in the vicinity of the Chorro and J-north Chimneys (Figure 16 and 21). Also there is a suggestion of a slight rise in dip just before the flattening occurs. It was first thought these flexures, with crestal rises of a few tens of centimeters (1-2 ft) over hundred of meters (300 ft, plus) of base length, might have localized the chimneys. Because of insufficient mine openings away from these chimneys, it was impossible to project these slight nuances of dip, and it is now the author's opinion that these particular regional flattenings are the result of two opposing processes. On one hand they reflect the intrusion of acid felsites in depth; in this respect they and their associated chimney may be controlled by the same feature. On the other hand, their flattening is a sagging effect produced by decrease in volume during the replacement of limestones by the Santa Eulalia sulphides, and is a result, not a cause, of the ore body's location.

## INTRUSIVE CONTACTS

### Andesite-Diorite-Diabase:

For the location of ore bodies contacts between limestone and the surfaces of the Upper and the Lower Sills rank high in the list of "favorable" horizons. Within this group, those at an intersection with one of the named northerly trending fault fissures or a transecting acid felsite have been particularly important. But whereas the surfaces of these diorite-diabase sills have been highly important, it is difficult to assign a similar status to the andesite dikes. In the north the Purisima Chimney lies against the Mina Vieja Dike, in the south the deep "U" ore body, against the Potosí Dike. With these exceptions ore bodies are not associated with them.

### *Acid Felsites:*

Limestone contacts with first and second members of the acid felsites, but not the third member nor the first-second-and-third combined, are "favorable" horizons of the highest magnitude. Their control seems to have been three-fold. First, as with the diorite diabase sills, their contacts may have localized the "flow" of invading mineralizers. Second, the northeasterly trending cliff-like "steps" along their upper surfaces have been especially favored for replacement of adjacent limestone; appear to have deflected northerly trending mantos onto northeasterly courses; and may have deflected mineralizers upward into the J-north Chimney. Third, the field relationship between overlying ore bodies and the immediately underlying thrust-like transection of the Lower Sill by the first and second members of the series may pass beyond simple structural interpretations and involve genetic implications (Figure 7, 8, and 20). Even the insignificant ore body on the "90" trend shows the relationship (Figure 23).

Quartz Monzonite:

The deep quartz monzonite intrusive, tested by five holes in there localities, is an unknown quantity. Penetrations showed trace quantities of disseminated sulphides: Pb, Zn, Fe, but without associated replacement mineralization.

## LIMESTONE-CAPPING CONTACT

Small, unimportant ore bodies have formed in limestone adjacent to the capping contact; others, upon approaching it, appear to have been repelled. The Chorro Chimney upon reaching the capping series did not follow the contact but mantoed into the limestone series. And where the Bustillos Manto first encoutered the capping, it immediately developed a path 30 ms (100 ft) lower, within limestones. There appears to have been a control other than mineralizers channelled along the limestone-capping interface. In the Las Animas Mine, Benham (1928a) described flat-lying mantos which could be followed from a course along the capping contact, into limestone ridges, and back to the limestone capping contact without change in form or cross-section.

## MINERALIZATION

Prior to the construction of a differential sulphide flotation mill in 1925, all production was oxide ore, predominantly lead-silver with varying proportions of iron and silica; folloing mill construction. oxide ores declined in importance. Since 1941 lead zinc-iron sulphide with important but minor silver content has maintained the district.

### MASSIVE REPLACEMENTS

Santa Eulalia ore bodies are massive sulphide replacements of massive limestone, and their oxidized equivalents. The "normal" sulphide is a mixture of pyrite, pyrrhotite, marmatite, and galena. Silver is present and important, but silver sulphide minerals are not recognized. Fluorite occurs in minor variable concentrations. Chalcopyrite and arsenopyrite are sparse. Average assays of "normal" sulphides mined from recently developed stopes, including limestone contamination, have approached:

| grams per metric ton | % | | | | | | |
|---|---|---|---|---|---|---|---|
| Ag | Pb | Zn | Fe | CaO | $SiO_2$ | S | Mn |
| 230 | 12 | 11 | 30 | 5.0 | 6.0 | 24 | 0.3 |

Channel assays have ranged between

| | | | | |
|---|---|---|---|---|
| 170-420 | 8-25 | 5-19 | 33-38 | 1-3 |

Rarely there is a trace of gold. In exceptional, highly silicified areas observed in dril lcore the insoluble content reaches 18-36%.

Santa Eulalia's West Camp sulphides are rich in pyrrhotite. Spurr (1911) describes a change in iron sulphides from predominantly pyrite at 1,630 ms (5,350 ft) above sea level, through a mixture of pyrite and pyrrhotite at 1,403-1,342 ms (4,600-4,400 ft), to nearly all pyrrhotite at greater depths. At greater depths not all iron sulphides are pyrrhotite, nor are all pyrrhotite equally magnetic. In the pre-sulphide solution cavern, described in the section on OPEN CAVES, the iron sulphides on the truncated fissure are pyrite and possibly marcasite.

With the exception of one ore body, all zinc sulphides are marmatite with an average zinc content of 48-49%. Under a microscope the included iron appears to be a pyrrhotite dust, densely distributes, cloud, in sphalerite. The exception, according to Rodolfo Kirschner, Manager for Minerales de Chihuahua, is the "U" ore body which carries light-colored sphalerite.

Paragenetically, arsenopyrite seems to be the earliest mineral; but the earliest ore minerals are iron sulphides followed by marmatite, then galena. According to Severn Brown, pyrite is identified in polished plates as microscopic veinlets cutting pyrrhotite; marmatite, galena, and chalcopyrite show "mutual" boundaries, but with chalcopyrite rarely observed cutting marmatite; and under high magnification an unidentified mineral appears along galena contacts with marmatite, but within the galena. This may be freibergite (notes in Cia. Asarco files).

Prescott (1916) mentions the possibility of finding a sulphide ore with a postulated assay of

%

| Pb | Zn | Fe | $SiO_2$ | S | Mixed Carbonates | As |
|---|---|---|---|---|---|---|
| 3 | 6 | 20 | 20 | 30 | 15 | 1 |

Although there must have been sulphide ores of low lead content, none seems to have been preserved. The closest approach to a low-lead ore is the deepest sulphide on the Peñoles Fissure, an isolated body between the underlying "rhyolite" and the overlying Lower Sill. Here coarse calcite, pyrrhotite, and marmatite are intermixed. Galena is lacking. This is the only body with calcite accompanying sulphides.

## Oxide Ores:

Prescott (1916), in an excellent account of oxide ore bodies, describes within a single portion of a manto variations in lead content from high-grade "sand-carbonate" (that might have averaged 40% Pb) to a yearly average of

| % | | | | | | | |
|---|---|---|---|---|---|---|---|
| Pb | Zn | Fe | Mn | $SiO_2$ | CaO | S | As |
| 13.9 | 1.8 | 28.5 | 1.5 | 19.6 | 6.1 | 1.5 | 1 |

He gave no silver assays, but it may have ranged from 250 to 500 grams per metric ton. Except for the high silica, the results compare favorably with the analysis of "normal" sulphides.

Not all oxides were of this type. Northward they changed to a low-lead, high silver, high-iron mineralization. These bodies have long been exhausted, but low-grade ramnants reported by Benham (1929) averaged

| grams per metric ton | % | | | | | |
|---|---|---|---|---|---|---|
| Ag | Pb | Zn | Fe | CaO | $SiO_2$ | Mn |
| 250 | 3.5 | 2.6 | 21.0 | 20.0 | 21.0 | |

This area was known for rich silver ore. Judging from small mantos discovered in the last thirty years, the richer might have assayed 1-10 kgs of silver per metric ton. These have been low in iron, rich in silica. Thus:

| grams per metric ton | % | | | | | |
|---|---|---|---|---|---|---|
| Ag | Pb | Zn | Fe | CaO | $SiO_2$ Insol. | Mn |
| 495 | 0.8 | 1.8 | 7.3 | | 34.3 | 31.2 |
| 5.320 | 3.1 | 3.0 | 11.9 | 13.6 | 24.8 | |

Higher grade material appeared dolomitic and weakly silicified, and carried slight showings of a black calcite-like carbonate, limestone, and galena. Adjacent limestone was deeply stained with manganese oxide. In contrast, silicified areas in the sulphides have not been rich in silver, nor have sulphides carried areas rich in manganese.

Silicate Bodies:

In addition to "normal" sulphides, masses of hard, black silicates are found, not of contact-metamorphic origin, which Prescott (1916) described in detal. He identified ilvaite, a hydrated Fe — Ca — Mn silicate, knebelite ($[Fe, Mn]_2 SiO_4$), and fayalite ($Fe_2SiO_4$); listed several chemical analyses; reported a magnetite association with fayalite and knebelite; described iddingsite (?), chlorite, and chalcedony as alteration products of ilvaite. He felt they belonged to an early silver-bearing iron-sulphide mineralization.

Occurring within mantos, replacement veins, and chimneys, these silicates are found in various parts of the district, principally in the upper horizons but also on deeper levels. From field examinations, other than those described in 1916, the author believes they are an integral but sulphur-deficient phase of normal mineralization. North of the deep intensely mineralized block, they are known in two oxidized mantos, — on the Velardeña 2nd level immediately west of the Velardeña Shaft and on the Velardeña 8th level in the Jean Cave stope to the east of the Velardeña Shaft, — and in a replacement vein of sulphides that developed on the Potosí Fissure on the Buena Tierra 16th level. Within the mantos they first appear along the bottom or walls, but gradually encroach until the principal part of each body is a dense, black silicate mass within which pyrite, marmatite, galena, crystallized quartz, calcite, and gypsum are irregularly distributed. The 2nd-leven body appeared to terminate mineralization. In the Jean Cave, "normal" oxides, greatly reduced in thickness, climbed over the top of the mass and continued without further silicate contamination. In the 16th level replacement vein, concentrations of hard, black, radiating silicate intergrowths, intermixed with minor pyrrhotite, sparse arsenopyrite, and fluorite, appeared within "normal" sulphides, sometimes to the full width of the body.

Samples assayed:

| grams per metric ton | % | |
|---|---|---|
| Ag | Pb | Zn |
| 50-150 | 0.8-1.6 | 1.4-1.6 |

X-ray determinations confirm the ilvaite identification (Robert Kayser, analyst).

Gypsum Ores:

In both the near-surface Bustillos Manto, on the east edge of the district, and the deeper West ore body in the lower fossiliferous stratum on the west edge, portions of each manto change from an irony to a gypsum gangue that carries silver ore with a low lead content, and in one manto a low gold content. Several gypsum areas, separated by stretches of irony gangue, occur in each manto. In one stope in the West ore body the gypsum is associated with pyrite, marmatite, minor galena, and fluorite.

Such areas, interpreted as the reaction from sulphate waters produced during oxidation, should occur in abundance throughout the district. They do not. They may be primary features introduced by mineralizers whose valences were undergoing changes, locally, from reduction to oxidation.

### DISSEMINATED MINERALIZATION

Infrequently, in the upper levels, grains of pyrite, marmatite, and rarely galena, occur disseminated in limestone, but never abundantly. Nothing is known about them except that some are close to known ore bodies.

Manganese staining abundant in some beds, absent in others, is widely disseminated throughout the fossiliferous sequence in the upper part of the column. Consisting of varying concentrations of soft black spots up to 1 cm in diameter (probably pyrolusite), dendrites, and a rosy stain that saturates the limestone, these impregnations frequently occur adjacent to or beneath oxide ore bodies. There is a strong implication they have been leached from the body; but certain horizons, notably the lowest fossiliferous stratum and some of the surface limestones in the north, appear to have been soaked with manganese salts, and the staining bears no relation to immediately adjacent ore.

Some manganese staining accompanies a silver impregnation of limestone. Spurr (1911) mentions a jacket of "pay lime," 6-12 ms (20-40-ft) thick, surrounding high-grade bodies in the north, and describes a jacket around the Purisima Chimney with a vertical range of 240 ms (800 ft). The upper portions assayed 600-800 grams of silver and carried little or no manganese stain. In depth the silver content decreased, whereas manganese staining increased and went deeper than the silver. Like the silver, it disappeared with greater depth. Spurr attributed "pay lime" and associated manganese staining to leaching from the adjacent ore body. It would seem possible both silver and manganese were introduced to the limestone during mineralization.

### SILICIFICATION

Silicification is insignificant. Although Spurr (1911) and Prescott (1916) mention extensive silicification of the capping the author suspects they observed ignimbrites. He is aware of minor areas of silicification within deep sulphide bodies, which seemed a part of normal mineralization. Prescott (1916) described an oxide body in which silicified areas occurred.

He interpreted them as a post-oxidation phase of mineralization. The writer has not seen such areas; but he is aware that some oxide mantos, or parts of mantos, are much richer in silica than others, and contain poorly formed, distorted quartz crystal up to 7 or 8 cms (3 in) in length. Such crystals have not reported from the "normal" sulphide bodies. Such crystals might be inherited from patches of sulphide-rich silicate mineralization, completely oxidized and not recognized, since similar crystals have been found in vugs within unoxidized silicate bodies at the south. There is complete agreement with Prescott's observation that "channels in the limestone along which oxidizing waters have passed are not silicified, nor are any large occurrences of silicified limestone known in the district."

### MINOR SILICATES

Within the West Camp there are no bodies of silicate minerals of known contact-metamorphic origin. Yet, in addition to the ilvaite-fayalite-knebelite complex within ore bodies, two silicate minerals have been observed.

One is "mountain leather", an asbestos. It occurs in widely separated areas of the camp in the general horizon of the lower fossiliferous limestone, distant from known bodies of mineralization or recognized intrusives. Loose, flat sheets up to 40 or 50 cms (16-20 in) in diameter by 1 cm thick occur (personal recollection), along the bottom of a solution cave some 350 ms (1,150 ft) beneath the Bustillos Manto in the vicinity of the Central Shaft. Paper- thin sheets — in places alone, elsewhere with a slight, clay-like, iron-stained substance, or with a black calcite — occur sparsely distributed in tight fractures in limestone in the extreme north and west on the Buena Tierra 5th, Ventura 7th, and Mina Vieja 10th levels.

The other is a dense, moderately soft, black, radiating mineral cored by each of three deep holes at a depth of some 600 ms (1,900 ft) beneath the Purisima Chimney. The intercepts, 5-20 cms (2-8 in) thick, occur in a black shale at the bottom of the limestone series, and 18-26 ms (59-82 ft) above the deep quartz monzonite intrusive. It has not been found elsewhere. It has been called wollastonite. X-ray patterns confirm the identification (Wm. B. Wray, Jr., analyst).

### CALCITE

In the upper levels are numerous calcite-healed fractures. Generally insignificant, they bear no apparent relation to ore processes. Similar features in deeper levels seem to represent calcite fillings derived and expelled from space occupied by adjacent sulphide bodies. Examples are the northern extremities of the Potosí and J-north Fissures — thin calcite veins 1-15 cms (0.5-7 in) wide with sparsely distributed grains of Fe, Zn, Pb sulphides; and calcite seams transecting bedding planes, as well as veinlets within beding planes, that carry disseminated sulphide grains around the edges of the J-north Chimney.

Calcite, with two exceptions, is not contained within sulphide bodies. One exception occurred at the extremity of a sulphide body immediately beneath a small, open, pre-sulphide solution cavern, where it occurs in coarse masses; the other, at the bottom of the Q Chimney (Augustin Horcasitas, personal communication) where sulphides degenerated into a mass of coarse calcite, pyrrhotite, marmatite, and minor galena.

The occurrences of dog-tooth spar and helictites have been cited in the section on OPEN CAVES.

### INTRUSIVES

Disseminated pyrite is ubiquitous to all intrusive groups; other sulphide types are not. Each group appears to have a characteristic sulphide mineralization. In the andesite-diorite-diabase sills marmatite and galena occur only in sulphide veinlets, usually with pyrite. With in the acid felsites all members are cut by galena, marmatite, pyrite, and pyrrhotite veinlets with or without calcite. In the deeper felsites disseminated grains are principally pyrrhotite. whereas in the upper members disseminated iron sulphides (pyrite ? or pyrrhotite ?) and marmatite are common to nearly all specimens, and galena occasionally occurs. In the deep quartz monzonite, weakly disseminated chalcopyrite, bornite, marmatite, and galena grains occur erratically, but long intervals are barren and sulphide veinlets have not been observed.

### ZONING

Some observers of the deep southern bodies feel the ratio of marmatite to galena increases with depth. There is no convincing evidence for such a change in the Chorro or J-north Chimneys. Sulphides in the former extend from the oxide-sulphide transition, in the neighborhood of 1,380 ms (4,550 ft) above sea level, to the roots of the chimney at about 1,060 ms (3,500 ft); in the latter, from the top of the chimney at 1,200 ms (4.000 ft) to the deepest sulphides at 1.060 ms (3,500 ft) above sea level.

Changes are recognized in the metallurgy of ore bodies and mineralogy of the district. Spurr (1911) described a change from near capping pyrite to pyrrhotite at depth. Many oxidized ore bodies carry a high silica content, which is recorded in the sulphides in isolated unimportant patches. There is abundant manganese staining in the upper levels, in contrast to its absence in depth. There is a pronounced change from a lead-zinc-iron mineralization with a modest silver content in the southern sulphides to an irony ore with a low lead content, but rich in silver, in the oxide bodies at the north. Asbestos, a magnesium silicate, is reported only from the extreme fringes of the district.

Formed writers have thought various types of ore were introduce in different stages, not all of economic importance. Prescott (1916) recognized silver- bearing iron sulphide with silicate gangue, silver-lead-zinc ores, and lead sulphide — all, he felt, separated by time intervals. The writer has not observed places such distinctions appear significant, and feels they are normal to a single continuing period; that mantos, forming at the same time, might each have developed its own mineralization pattern varying with distance from the mineralizing source, with the strength of the feeding mineralization, and with the amount of removal through precipitation within its own system.

## OXIDATION — LEACHING

The water table at Santa Eulalia is deep, and under the West Camp its upper surface is weak and indistinct. As a result, the oxide sulphide transition zone varies through a vertical range of some 365 ms (1,200 ft); is inclined upward from north to south; yet exhibits vertical variations of over 100 ms (330 ft) within distances of 180 ms (600 ft). Contrary to expectation, it is at great depth beneath the highest part of the mountain, but is relatively shallow beneath the somewhat lower southern part. It lies at 767 ms (2,530 ft) beneath the Tiro Alto Shaft in the central part of the camp, but only 170 ms (560 ft) beneath the collar of the Potosí No. 1 Shaft in the southern part, as shown in the following table.

| | Location: | | Elevation Above Sea Level | | | | |
|---|---|---|---|---|---|---|---|
| | Asarco coordinates | | Collar | | Oxide-sulphide Transition zone | | References |
| | N | W | Ms | Ft | Ms | Ft | |
| Tiro Alto | 3373 | 6330 | 2032 | 6665 | 1265 | 4150 | observation |
| Santo Domingo (Asarco) | 2718 | 6778 | 1858 | 6094 | 1478 | 4848 | Spurr (1911) |
| Buena Tierra | 2708 | 6972 | 1859 | 6098 | 1380 | 4526 | approximation |
| Santo Domingo No. 5 | 2572 | 6875 | 1838 | 6029 | 1401-1341 | 4595-4398 | Spurr (1911) |
| Potosí No. 1 | 2245 | 6786 | 1860 | 6101 | 1630 | 5346 | Spurr (1911) |

At Santa Eulalia the depth of oxidation does not reflect surface topography but relates to the presence or absence of capping material and to the amount and strength of open fractures. In general, a thick mantle of capping series has protected underlying sulphides; but where limestone outcrop there has been a deep, wide-spread penetration of oxidizing waters, except, as noted by Prescott (1916), where wide, prominent channels with great rapidity have channelled surface waters away from adjacent ore bodies.

Although Santa Eulalia had been in production over 200 years, when

Spurr made his examination, surface waters were still leaching unmined oxide bodies. He observed the actual process in bodies at an elevation of 1,656 ms (5,432 ft), well above the oxide-sulphide transition, and reported, "In one locality on the Chihuahua fissures on the 5th level Potosí (within the zone of zinc ores) the water trickling from the roof along the fissure was observed to be practically a saturated solution of zinc, so that it formed pendant small stalactites or 'icicles' of mother liquor, in which a skeleton intergrowth of calamine crystals were seen to be forming; at the touch of a finger the liquor was drawn off, but the crystals still remained coherent... an extremely interesting illustration of the solution, transfer, and deposition of oxidized zinc ores." (Spurr, 1911). Prescott (1916) likewise recorded important observations on the oxidation and leaching of Santa Eulalia ores.

## ALTERATION

Generally absent ,alteration in the Santa Eulalia district is, with minor exceptions, singulary weak where present. In the West Camp Hayward and Triplett (1931) claimed that Santa Eulalia domolites are secondary. If they are correct, dolomites — together with the upper level manganese staining and a minor amount of recrystallization that occurs both in the upper levels and within limestone beds interlayered within the Lower Sill — represent the only obvious alteration features in the limestone sequence.

Neither is there significant alteration within the andesite-diorite-dolerite-diabase sills. Even sulphide contacts are megascopically unaltered, and only from a thin dike within the J-north Chimney were the feldspars argillized. There is one exception: the interface of the Potosí Dike and the Lower Sill with the "U" ore body, where both igneous bodies are altered to a grey, clay like material, and the Lower Sill is mineralized (Rodolfo Kirschner, personal communication). In contrast to lack of alteration in the sills, the andesitic Mina Vieja and Potosí Dikes, where exposed on the upper levels, are intensely argillized, and, according to Spurr, carbonatized. It has been suggested their alteration is related to the oxidation of adjacent ores bodies, but in depth, where the unoxidized "U" ore body has banked against the Potosí Dike, the latter has been severely altered. Possibly argillic, this deep alteration has not been studied.

Acid felsites rarely contain megascopic alteration, but two occurrences are prominent. One is on the Peru Fissure beneath a sulphide chimney where the No. 2 "rhyolite" has a greenish cast and has been sericitized (Rodolfo Kirchner, personal communication). The other, adjacent to a sulphide manto, is on the 19th level in the 1924-Q drift (3060 N-6362 W, Asarco Co-ordinates) in the vicinity of the Tiro Alto trend. Here the felsite surface contains a cliff-like face 16 ms (53 ft) high. A manto has banked against this surface, and from 6-15 ms (20 50 ft) inside the felsite-sulphide contact, the felsite has been altered to an incompetent grey mass, thoroughly sericitized. Diffraction X-ray patterns confirm the identification (Lee Sutton, analyst, Dec. 1964).

Also on the 19th level in the 1905 drift, "rhyolite" contacts adjacent to sulphide bodies in the vicinity of the Peñoles Fissure had, when first exposed in the mid-1940's, a selvage of white, clay like paste. J. L. Kulp in the late 1940's considered selvage samples to be unaltered rock flour (J. L. Kulp, personal communication). By 1964 these exposures, covered with sulphide fragments spilled from adjacent ore passes, had altered to a mass of limonitic material a mixture of jarosite and partially altered fragments of pyrite and galena (Lee Sutton, petrographer, Dec. 1964).

Elsewhere diamond drill cores, particulary in the vicinity of the Potosí Fissure, recovered acid felsite that appeared, megascopically, to be sericitized. Petrographic examination of less altered specimens from Asarco diamond drill holes 578 and 569 (diamond drill station 1901-B) collected 15 ms (50 ft) beneath the 19th level indicated 3 per cent of the groundmass contained minute grains of sericite disseminated in otherwise unaltered feldspar.

In contrast to these deep occurences, Spurr (1911) reported the groundmass of the narrow Velardeña rhyolite dike intensely altered to quartz and sericite. This suggests a relationship to oxidation of upper-level ore bodies.

The deep quartz monzonite is unaltered.

Numerous places, all in the upper levels and within the zone of oxidation, contain bodies of tannish yellow "clay." Some are massive, but the majority are thin fillings, often less than a centimeter wide, within narrow fractures. A few are associated with "mountain leather," but without associated wall-rock alteration. It is speculated they may represent completely kaolinized andesitic intrusive material, or possibly the argillaceous matter expelled, along with the calcium carbonate of the limestone, from the space now occupied by sulphide bodies.

Only in the capping series is there noticeable weak alteration. Not studied, it consists of iron oxide discoloration vaguely defined over parts of the main mineral zone-which Rodolfo Kirschner (personal communication) suggests may be in part a detrital discoloration inherited from the erosion of an overlying severely dissected rhyolite flow; and a belt of alternating tan and light-red areas extending easterly to the East Camp. Only immediately adjacent to the mineralized fractures of the San Lazaro Fissure has the writer observed rhyolite tuffs altered to an intimate mixture of silicified and kaolinized patches, impregnated with sulphides now oxidized. A few meters from the Fissure, alteration consists of a splotchy chloritization; farther away there is no obvious reorganization that couldn't be assigned to deuteric effects within an ash flow.

Although Spurr (1911) and Prescott (1916) speak of extensive silicification of the capping, the writer has not seen it and suggests they may have observed features now attributed to ignimbrites; further that a possible relationship exists between Santa Eulalia's lack of regional silicification and its essentially fresh to weakly sericitized intrusives. Since rhyolites contain from 64-79% $SiO_2$, diorites from 48-62%, diabases 45 55% (Kemp, 1922), and sericite but 50%, large scale sericitization would have required the removal of large volumes of silica from the intrusives and either its subsequent redeposition as silicification or its complete removal from the district.

## COLLAPSE

The most significant observation derived from the numerous West Camp studies relates to a reduction in volume that occurred during the replacement process. First observed as a result of the detailed study carried out by T. P. Clendenin's 1932-1933 investigation, and recorded by him (Clendenin, 1933), it was at that time recognized only in association with oxide mantos. As the study continued, a similar feature was observed over the J-north sulphide chimney; but since the investigation was confined to areas north of the deep, intensely mineralized southern block, no information is available in that area. Originally referred to as a collapse, the phenomenon was reported at the October, 1953, Regional Meeting of the A. I. M. E. in El Paso, in an unpublished paper presented by Clendenin and Hewitt (1953).

The collapse, which is extremely subtle, and can be observed only on geologic cross sections, involves a reduction in the normal stratigraphic interval between bedding planes in those areas wherein an ore body occurs. Hence, its recognition is a function of the accuracy of the observation and identification of bedding planes, and of the accuracy of their plotting. Quoting from Clendenin's 1933 report:

"These cross-sections were plotted on a scale of 1/500. They were taken on vertical west-east planes, looking north, lying 50 ms apart, and located on the west-east co-ordinate lines marking even multiples of 50 ms from 2700 N. to 3500 N. On each of these sheets there were plotted first the workings cut by the plane of the section including the stopes as well as the levels and other formal workings. Then, from the data on the geologic plans, there were plotted the exposures of bedding-planes, and the principal ones of the exposed fractures, which were cut by the plane of the section, or which lay so close to this plane that they could be projected into it without serious question. In the plotting of the bedding-planes, however, it was decided, for simplicity, to plot only a selected few principal planes, and where an actual exposure was of some minor plane, the nearest one of the principal planes was plotted in its place, at the correct position as determined by the known interval betwwen the two planes. Finally, the geologic picture on each section was extended in some measure by interpolation. Fractures were connected up from level to level, where it was clear that it was the same fracture that was exposed at the different levels, and bedding planes were connected from exposure to exposure, where it was known in what manner the connection should be made, whether without interruption or with some definitely determined faulting. It was desired, however, not to extend this sort of work to the point where it became mere guesswork, and the interpolations were carefully restricted to cases, and lengths, where it was felt that the conditions were quite accurately understood."

The phenomenon is most easly explained by reference to Figure 24, a simplified reproduction of part of the geologic cross section at 3250 N. There are two stopes, A and B. Referring to stope A, the true stratigraphic interval between overlying bedding plane V-1861. 8 and underlying bedding plane V-1823. 8 is 38.0 ms as measured in the Velardeña Shaft. Between these planes the most western measurement, in an area uncomplicated by an intervening stope, is a normal 38.0 ms. Easterly, opposite the west edge and thickest part of the stope, the interval has reduced to 35 ms; in the center, to 36 ms; and at the east edge and thinnest part of the stope, to 37.5 ms. Then, east of the stope, in an area uncomplicated by an intervening ore body, the interval between bedding planes is again a a normal 38.0 Thus, the beds exhibit a normal thickness on either side of the stope, but thin abruptly in the interval containing the stope. The thinning is least where the stope is thinnest, greatest where the stope is thickest.

Referring to stope B, as measured in the Velardeña Shaft, the interval between overlying bedding plane V-1823.8 and underlying bedding plane V-1784.0 is 39.8 ms. Immediately east of the stope the measured interval is 39.0 ms, which might result from normal thinning. Directly over the stope the interval is 37.0 ms, an abrupt decrease in thickness within the ground that contains the stope.

In each case the reduction in volume occurred too suddenly to be a normal stratigraphic thinning, which suggests that the upper bedding plane collapsed into the area above the ore body. Quoting from the 1933 report:

"...a number of others, of varying degrees of clearness, have been brought to light... enough... to support strong belief in the idea which has been suggested, that the collapse has actually been caused by the ore body; but... for a large majority... collapse can be neither proved nor disproved, because of insufficient development, to afford stratigraphic data..."

Clendenin also warned that "even though the idea regarding collapse is true, ore bodies may not always, or may not at all points along their length, have brought about collapse."

As to whether this collapse phenomenon occurred during the introduction of the sulphides or results from the production of shrinkage caves above the ore bodies during the course of oxidation, the 1933 report continues:

"...the rock above the ore-body never shows any general or extensive shattering, and it is thought that such shattering would have been produced if the collapse has resulted from the oxidation of the ore, since the collapse would then probably have occurred as a sharp, sudden effect, after considerable undermining. Instead, the dropping down of the beds in a collapsed area is usually effected along just a few definite fractures, and these are sometimes so faintly marked as to be almost undiscernible, as though the rock had been under great pressure and had almost flowed rather than broken; and between these fractures the beds extend across the area in clean, unbroken fashion. and their beding planes can be traced without interruption. Further, the fractures along which a collapse is effected are sometimes mineralized, indicating that they were formed before the end of the period of mineralization. Finally, caves, believed to be the result of oxidation-shrinkage, exist as a very common feature over ore bodies, and if collapse resulted from the same sort of shrinkage; it would have had to come after the opening of just such caves, and would have squeezed many of them shut. All of this suggests, then, that the collapse effect must have been produced during the original deposition of ore-bodies."

Figure 25,, part of a geologic cross section along 2700 N, records a similar phenomenon associated with the deep J-north sulphide chimney. Here the effect takes place gradationally within 25-30 ms (80-100 ft) from the edge of the ore body. There are no associated bounding fractures. Complications of the Upper Sill, which occurs at the top of the chimney in the interval between bedding planes BT-1189.5 and BT-1135.9, are constant throughout the zone and can be ignored. In 270 ms (890 ft) from the Buena Tierra Shaft easterly to section line 6700 W the 53.6-m interval between these planes is constant. At 6700 W a 0.9-m northeast fault complicates the interval between bedding planes BT-1239.6 on the 17th level and BT-1135.9 on the 19th level. Adding 0.9 ms to the measured distance of 103.0 ms gives an adjusted acutal measurement of 103.9 ms versus a theoretical distance of 103.7 ms, indicating no significant change within the 270 ms from the Buena Tierra Shaft. But at 6685 W, 15 ms (50 ft) east and within 20 ms (66 ft) of the chimney, the distance between bedding planes BT-1237.8 and BT-1135.9 is 101.0 ms verssus a Buena Tierra Shaft interval of 101.9 ms, a shrinkage of 0.9 ms. At 6670 W, 30 ms (99 ft) east of 6700 W and 5 ms (17 ft) west of the chimney, the distance between bedding planes BT-1235.7 and BT-1135.9 is 98.0 ms, versus a Buena Tierra Shaft interval of 99.8 ms, a shrinkage of 1.8 ms. Directly over the chimney, 65 ms (205 ft) east of 6700 W, the measured distance between BT-1235.7 and BT-1132.3 is 101.1 ms versus a theoretical interval of 103.4 ms, or a shrinkage of 2.3 ms.

There are no data for judging whether other examples occur. However, Benham (1929), reporting on ore bodies in the northern part of the West Camp, drew a suggestive picture: "One peculiarity of the strata in the vicinity of the chimneys is that they tend to dip towards the ore body. In other words, there has been a sagging or settling of the strata at these points. This extends but a short distance from the chimney, say five or ten meters."

The shrinkages above the sulphide J-north Chimney, of the same magnitude as the shrinkages encountered in 1933 above the oxide mantos, should constitute clear proof, despite a volume of opinion to the contrary, that sulphide replacement of limestone need not be accompanied by an increase in volume. In Santa Eulalia it is accompanied by precisely the opposite effect, a volume decrease. The statement of Ames (1961) is most interesting: "...those reactions leading to negative volume changes can result in an overall volume shrinkage."

## MINERAL INTRODUCTION HYPOTHESES

Except for regional doming, possibly caused by the intrusion of a deep igneous mass, in turn possibly related to mineralizers, there is no evidence that the folding of the Santa Eulalia limestones has played a role in the loaction of the district. With one exception, that of the "U" ore body, sulphides have been fed into the deep southern block of ore bodies at several points within an area confined to the relatively narrow zone of north--south fault fissures. It seems improbable that mineralization has been fed into known ore bodies from areas still unrecognized.

With the exception of the "U" ore body, mineralization has fed upwards into the limestones at those points where the first or second members of the acid felsite, each relatively thin, have breached the Lower Sill along a thrust fault that has intersected a pre-existing north-south normal fault. The association between the first and second members of the acid felsite with overlying sulphide is so direct it seems a genetic relation existed between them.

In contrast, there has been no mineralization at those points where the Lower Sill has been breached by the third acid felsite — the lowest and thickest member — or by the combined upper sheets of the "rhyolite" body. In these latter cases, all tested locations lie along a northward projection of an ore-bearing fault fissure, beyond its zone of vertical displacement.

It is difficult to visualize a process whereby thin sheets of a specific igneous body carried and expelled sulphide mineralizers. It is popular to consider disseminated sulphides within an igneous body as introduced. In this case it is theorized that the residual brines of an ancient sea, related to the anhydrite-gypsum sequence at the bottom of the limestone series and rich in sulphur and metallic ions in a reducing environment, were intruded, after burial, by an igneous body that absorbed the metals and the sulphur and carried them along as a sulphide-silicate mix. * This body

* That brines can be rich in metallic ions is amply demonstrated by the geothermal brine well near Niland southern California (White, *et al*, 1963).

became the rhyolite porphyry. Through differentiation its upper horizons became enriched in metals and sulphur; and these horizons were those that were expelled from the main body as the first and second members of the acid felsites. When these members reached the Lower Sill, the metal-sulphide phase of the silicate-sulphide mix were "milked" from the porphyry. A minor amount of "milking" occurred at the contact of the lower members of the diabase complex, but the great proportion occurred when the porphyry breached the upper surface of the diabase. In part, the "milking" action may have been a filter-press type of process forced upon these relatevely thin "rhyolite" wings now caught in a vise, the jaws being the stiff, thick, diabase sill above them and the thick, main body of "rhyolite" that was continuing to advance and to apply pressure beneath them. If this picture has merit, it explains the spatial relation between sulphides and certain "rhyolites"; the absence of sulphides in relation to others; and the fact that some "rhyolites" appear to be pre-mineral, whereas others, seemingly related to the same body — in this case the Velardeña Dike — are as convincingly post-mineral.

After expulsion from the porphyry the metallic sulphides rose in a series of chimneys. From these they spread a relatively short distance southward but a long way to the north, in a series of great pipe like bodies of general northerly course interspersed with numerous segments of strong northeasterly trend. Forces controlling the northward progress of the mantos are enigmatic. The zone of widely spaced northerly trending fault-fissures in the southern part of the district appears to have guided their course in the immediate area of introduction, whereas mantos and chimneys were guided thereafter by some influence other than that of fractures.

Within the zone of introduction there is a suggestion that those mineralizers not controlled by northerly trending faults may have responded to a simple up-dip gravitational control, whereas in the northern area they may have followed the limestone bedding. But other factors must be explained. Hewitt (1954) suggested that north of the deep intensely mineralized, southern block of ground, the north-south trends might represent zones of tear separating differentially mõving blocks of limestone that were gliding horizontally. The fact that the cross section through the lower part of the Chorro Chimney (Figure 16) shows no through-going vertical fissure supports this idea. Instead, within blocks bounded vertically by bedding planes, there is a series of mineralized tension fractures which traverse each block, but in turn are limited vertically by the bounding planes.

Hewitt (1954) further postulated that the sulphides, possibly in a vaporous state or in a mixture of vapor and aqueous solutions, permeated great volumes of limestone — not only along fracture-induced permeability, but along sub-crystalline boundaries and within intermolecular structures; that precipitation was triggered, not by a simple dissolving of limestone as in laboratory beaker, but by a straining, not necessarily a shearing, of the molecular structures within the limestones. Under this theory only those zones structurally alive, even though they failed to reach megascopic straining, were capable of producing important replacement ores. The trigger that caused precipitation was an electrochemical reaction of geo-structural origin that had to be active at the time the solutes were present. North-south zones, actively moving or still under unreleased stress at the time of solute introduction, would have been favorable loci for ore precipitation.

Whether precipitation was triggered by geo-electric fields, it can be argued structurally alive zones were fields of unbalanced energy produced by straining molecular structures with mild compression, and these fields represented places of ready attack by invading mineralizers. If such a role can be accepted for these postulated areas, it is then possible that telluric currents might have been involved, and their paths might have been attractive loci for invading mineralizers. Such currents could be invoked to explain the apparent polarity between the Chorro and Mápula Chimneys on one hand, the Purisima Chimney on the other, and the interconnection of mantos between them.

As to the possibility that geo-electric fields were responsible for the triggering of sulphide precipitation, the picture would seem to require a rather short time-interval for completion of the action, which does not help the idea of differentiation within a manto. Yet differentiation along the length of a manto system has been invoked to explain the change from a low-silver, leady iron mineralization at the south end of camp to a high-silver, low-lead irony type at the northern end. Consequently, if there be merit such a picture, it would seem to require a differentiation controlled by the filtering effect of great masses of limestone whereby certain elements were able to travel greater distances before precipitation ocurred, rather than a differentiation brought on by precipitation and removal from the system. Currently the author favors the idea that such fields may have aided the ingress of the mineralizers, but did not trigger their precipitation.

As to the relative age and origin of the silicate masses, their greatest and most massive concentrations are in the upper levels, whereas their deepest occurrences, on the 16th level 1310 ms (4,300 ft) above sea level and 250 ms (825 ft) above the apparent zone of mineral introduction, is relatively weak. Furthermore, occurrences observed by the author appear to be an integral part of the ore body. Therefore, it is suggested their CaO and $SiO_2$ contents may represent material expelled from the ore zones by advancing mineralizers. Whereas most of these impurities have been flushed out of the system, these silicate masses represent concentration not removed when precipitation commenced. Furhtermore those concentrations which travelled farthest from the source were those richest in these fugitive impurities and are now the larger and more distant of the silicate masses.

There remains a questions as to why the lower fossiliferous limestone stratum has been abundantly productive of manto ore bodies. Neither additional data nor speculations have been produced since Spurr (1911) suggested that it may have a greater porosity than associated beds, and that by reason of a fetid odor the stratum is suspected of carrying hydrogen sulphide which should be a ready precipitant for metalliferous solutions.

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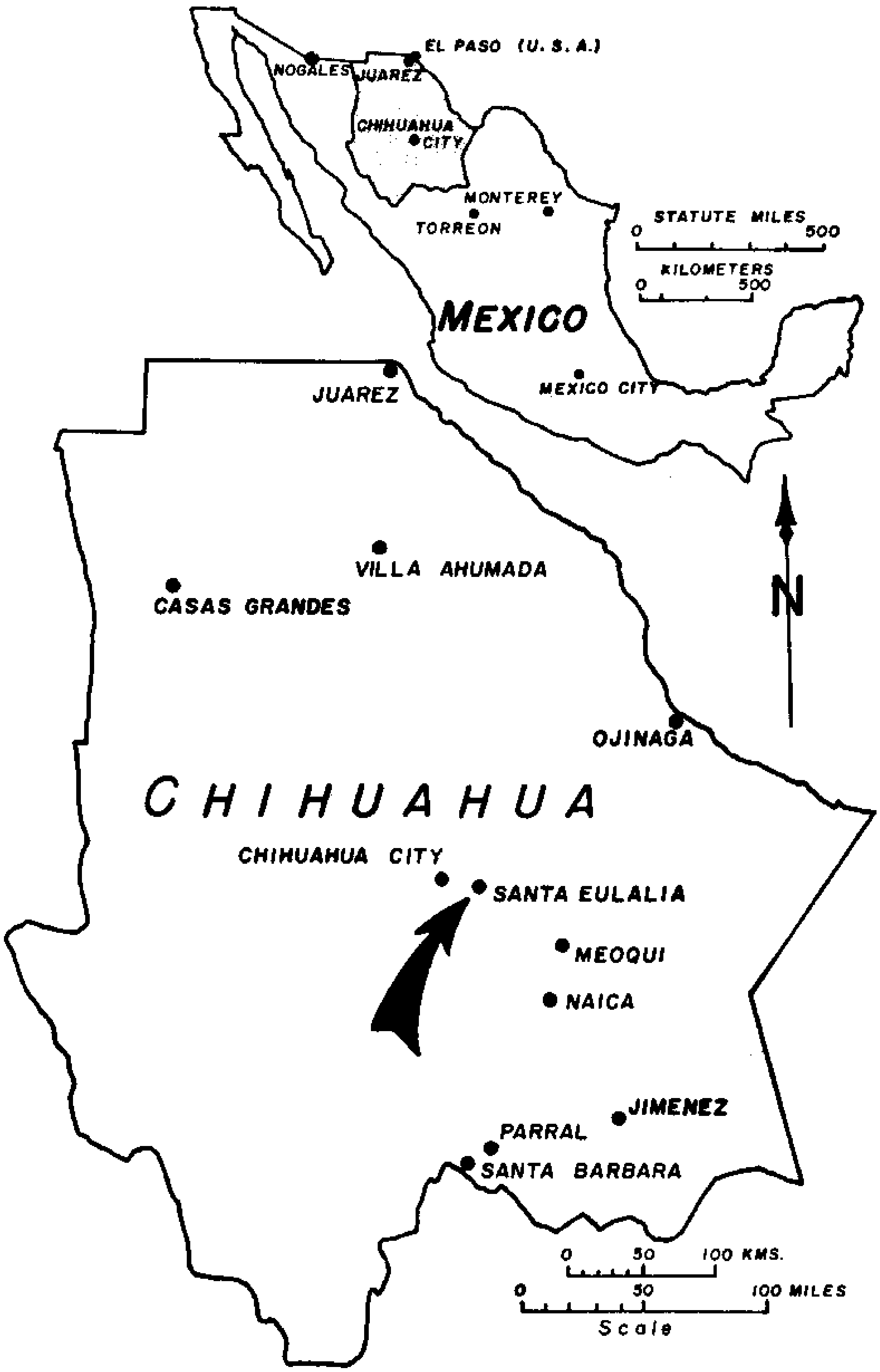



Figure 1. Outline mps: Republic of Mexico; State of Chihuahua.

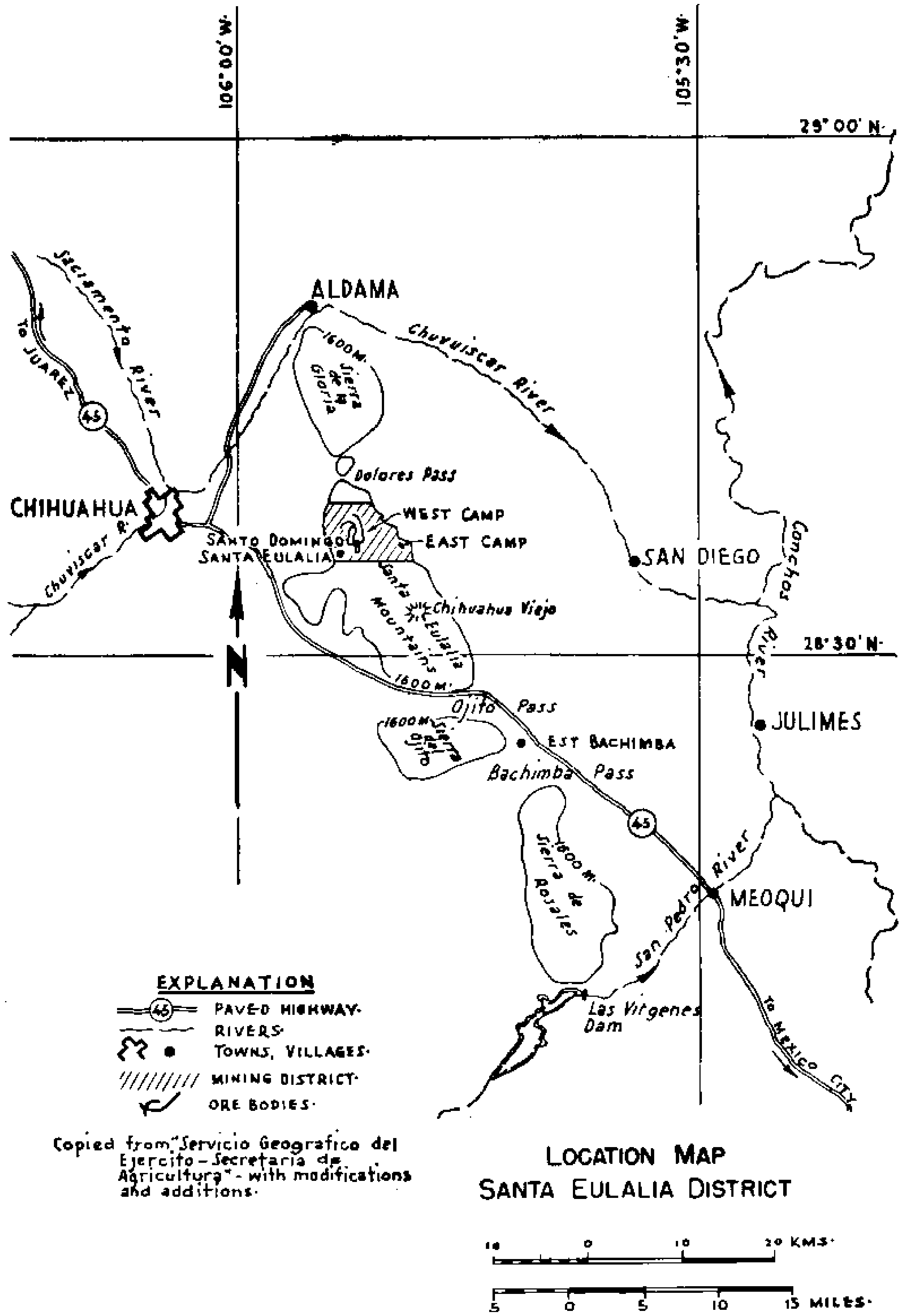



Figure 2. Location map: Santa Eulalia district.

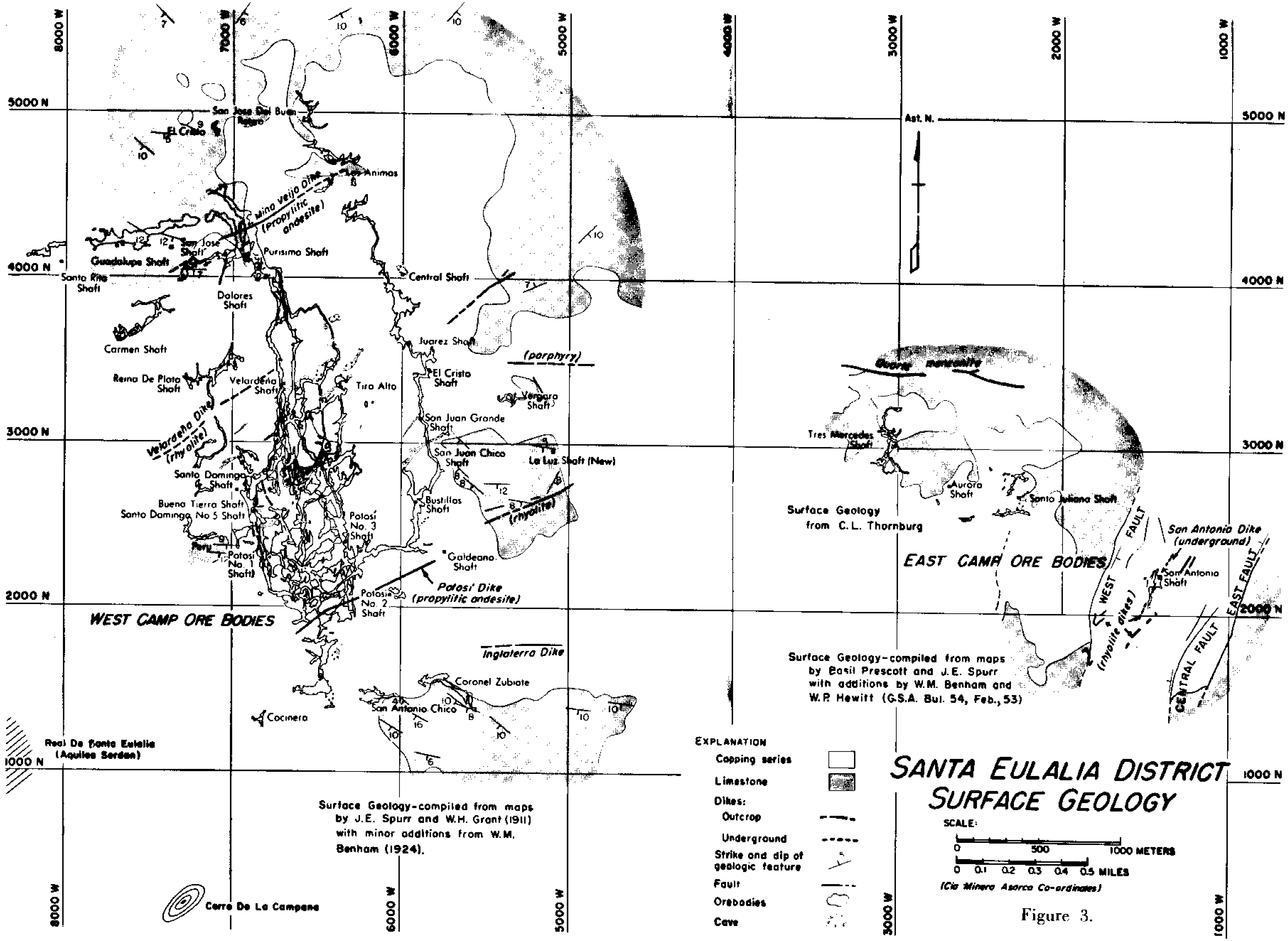
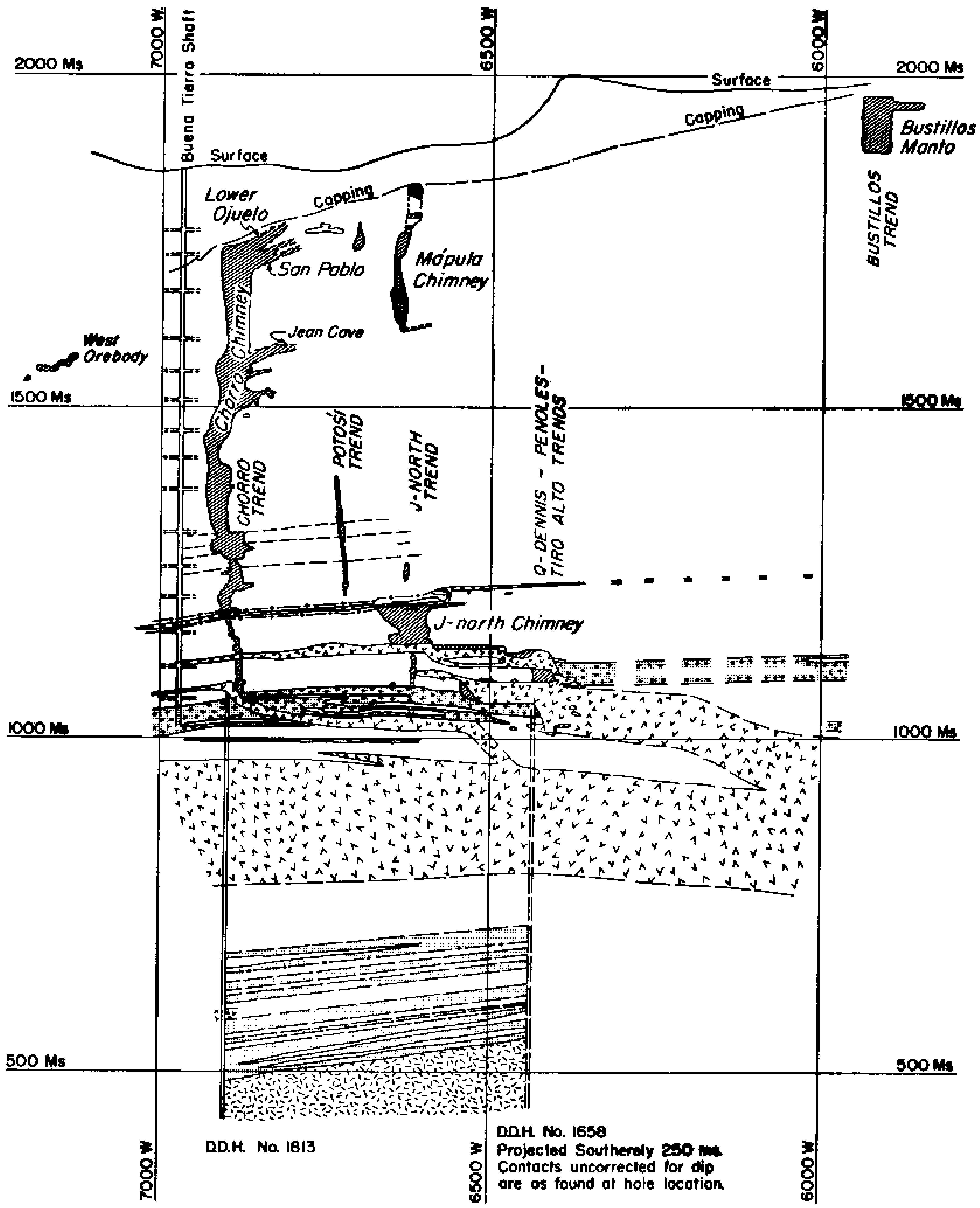

SANTA EULALIA DISTRICT
SURFACE GEOLOGY
SCALE:
0 500 1000 METERS
0 0.1 0.2 0.3 0.4 0.5 MILES
(Cia Minera Asarco Co-ordinates)
EXPLANATION
Capping series
Limestone
Dikes:
Outcrop
Underground
Strike and dip of geologic feature
Fault
Orebodies
Cave
Surface Geology–compiled from maps by J.E. Spurr and W.H. Grant (1911) with minor additions from W.M. Benham (1924).
Surface Geology–compiled from maps by Basil Prescott and J.E. Spurr with additions by W.M. Benham and W.P. Hewitt (G.S.A. Bul. 54, Feb., 53)
Surface Geology from C.L. Thornburg
WEST CAMP ORE BODIES
EAST CAMP ORE BODIES
Ast. N.
8000 W
7000 W
6000 W
5000 W
4000 W
3000 W
2000 W
1000 W
5000 N
4000 N
3000 N
2000 N
1000 N
San Jose Del Buen Retiro
El Cristo
Las Animas
Mina Veijo Dike (propylitic andesite)
San Jose Shaft
Purisima Shaft
Guadalupe Shaft
Santa Rita Shaft
Dolores Shaft
Central Shaft
Carmen Shaft
Juarez Shaft
(porphyry)
Reina De Plata Shaft
Velardeña Shaft
Tira Alto
El Cristo Shaft
Vergara Shaft
San Juan Grande Shaft
Velardeña Dike (rhyolite)
Santo Domingo Shaft
San Juan Chico Shaft
La Luz Shaft (New)
Bueno Tierra Shaft
Santo Domingo No 5 Shaft
Bustillas Shaft
Potosi No. 3 Shaft
(rhyolite)
Peru
Potosi No. 1 Shaft
Galdeano Shaft
Potosi Dike (propylitic andesite)
Potosi No. 2 Shaft
Inglaterra Dike
Coronel Zubiate
Cocinera
San Antonio Chico
Real De Santa Eulalia (Aquiles Serdan)
Cerro De La Campana
Tres Mercedes Shaft
Aurora Shaft
Santo Juliana Shaft
WEST FAULT
San Antonio Dike (underground)
San Antonio Shaft
(rhyolite dikes)
EAST FAULT
CENTRAL FAULT

Figure 3.




**WEST-EAST VERTICAL CROSS-SECTION, FACING NORTH, THROUGH THE CHORRO, MÁPULA, AND J-NORTH CHIMNEYS**

**(Deep detail east of Q-Dennis courtesy of Rodolofo Kirschner)**

Figure 7. West-east vertical cross section, facing north, through the Chorro, Mápula, and J-north Chimneys.

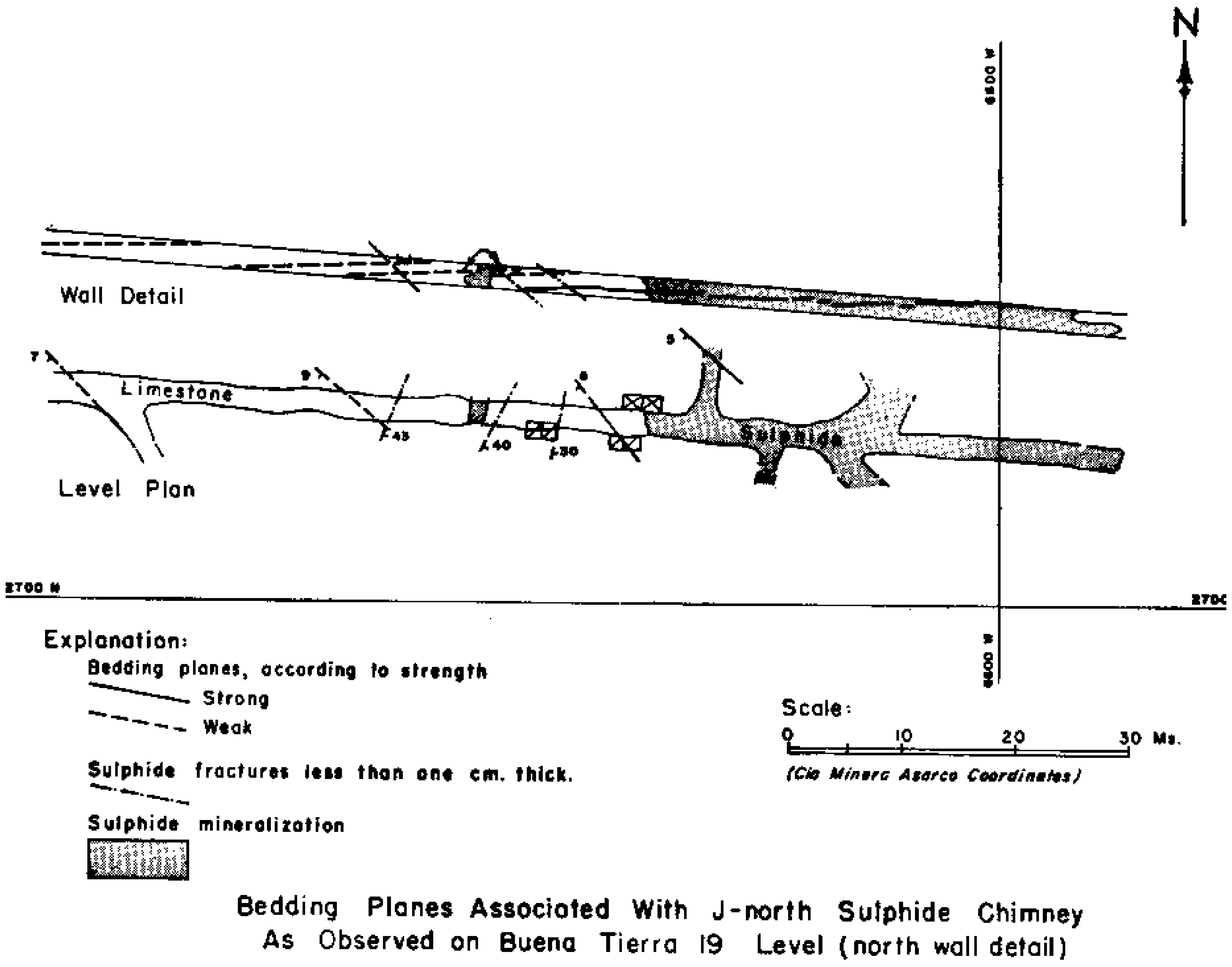
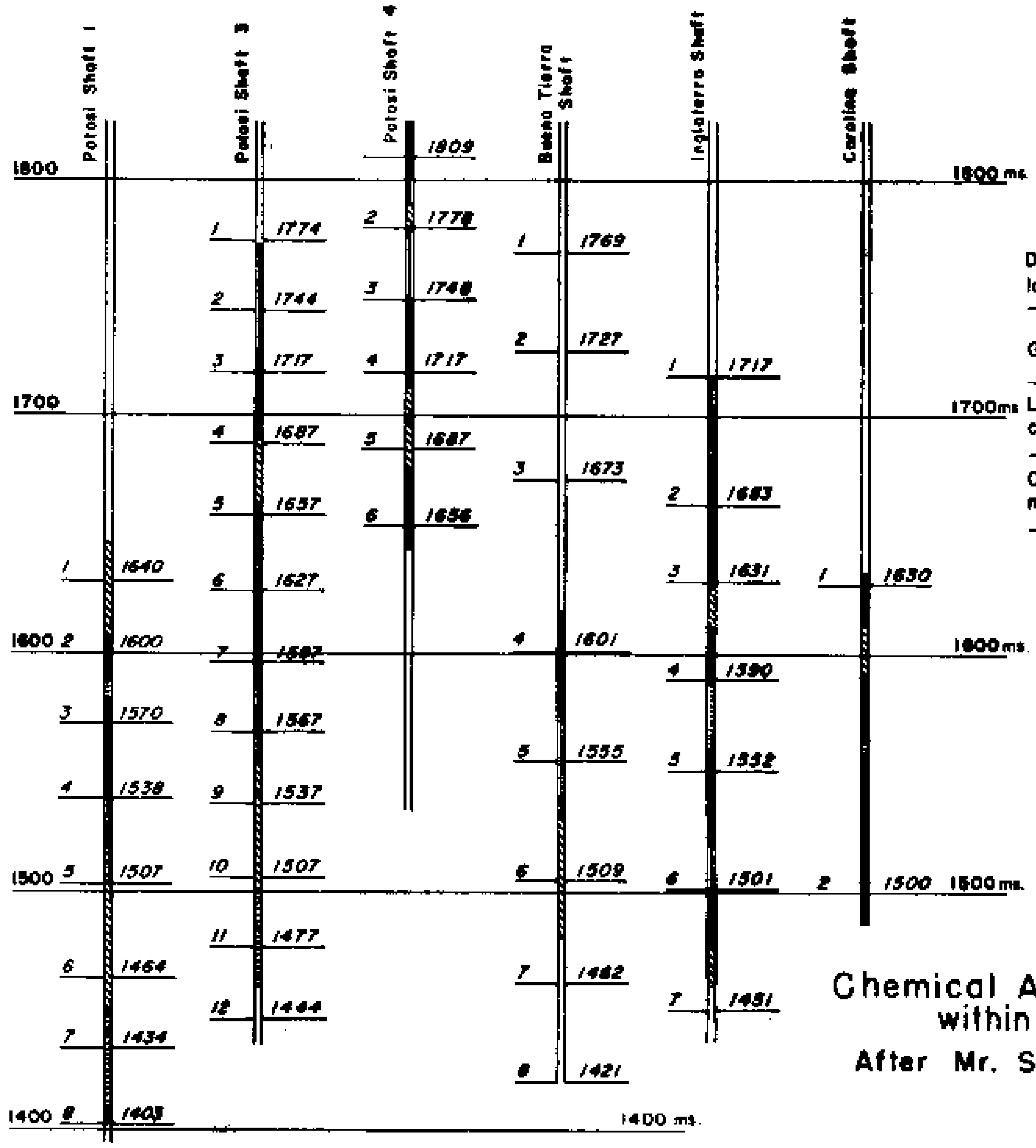



Figure 21. Bedding planes associated with J-north sulphide chimney as observed on Buena Tierra 19 level.




**LEGEND**

| | $SiO_2$ | Fe | Mn | CaO | Mg | Al |
|---|---|---|---|---|---|---|
| Dark bluish gray, argillaceous (Black ls.) | 3.2 | 0.6 | 0.1 | 48.1 | 0.35 | 0.92 |
| Gray Limestone | 2.5 | 0.1 | 0.2 | 54.0 | 0.35 | 0.56 |
| Light gray, slightly crystalline | 5.0 | 0.1 | 0.1 | 51.2 | 0.30 | 0.45 |
| Crystalline and marbleized | 0.5 | 0.7 | 3.8 | 51.0 | 0.30 | 0.42 |

**Chemical Analyses of Geologic Horizons within Selected Shafts**

**After Mr. Say – Potosi Mining Co. – 1922**

Figure 22. Chemical analyses of geologic horizons within selected shafts, after Mr. Say - Potosí Mining Company, 1922.

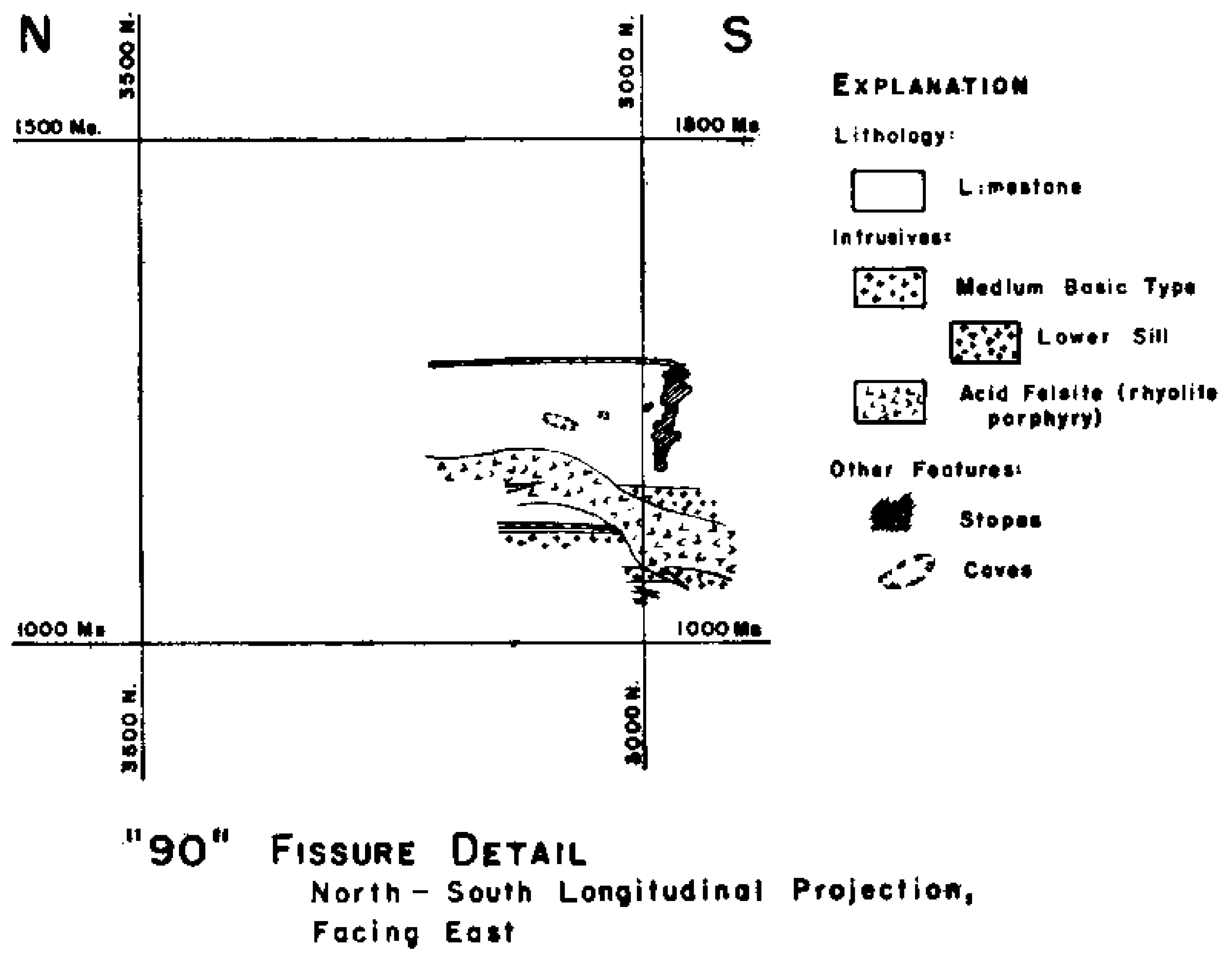



Figure 23. "90" Fissure detail: north-south longitudinal vertical projection facing east.

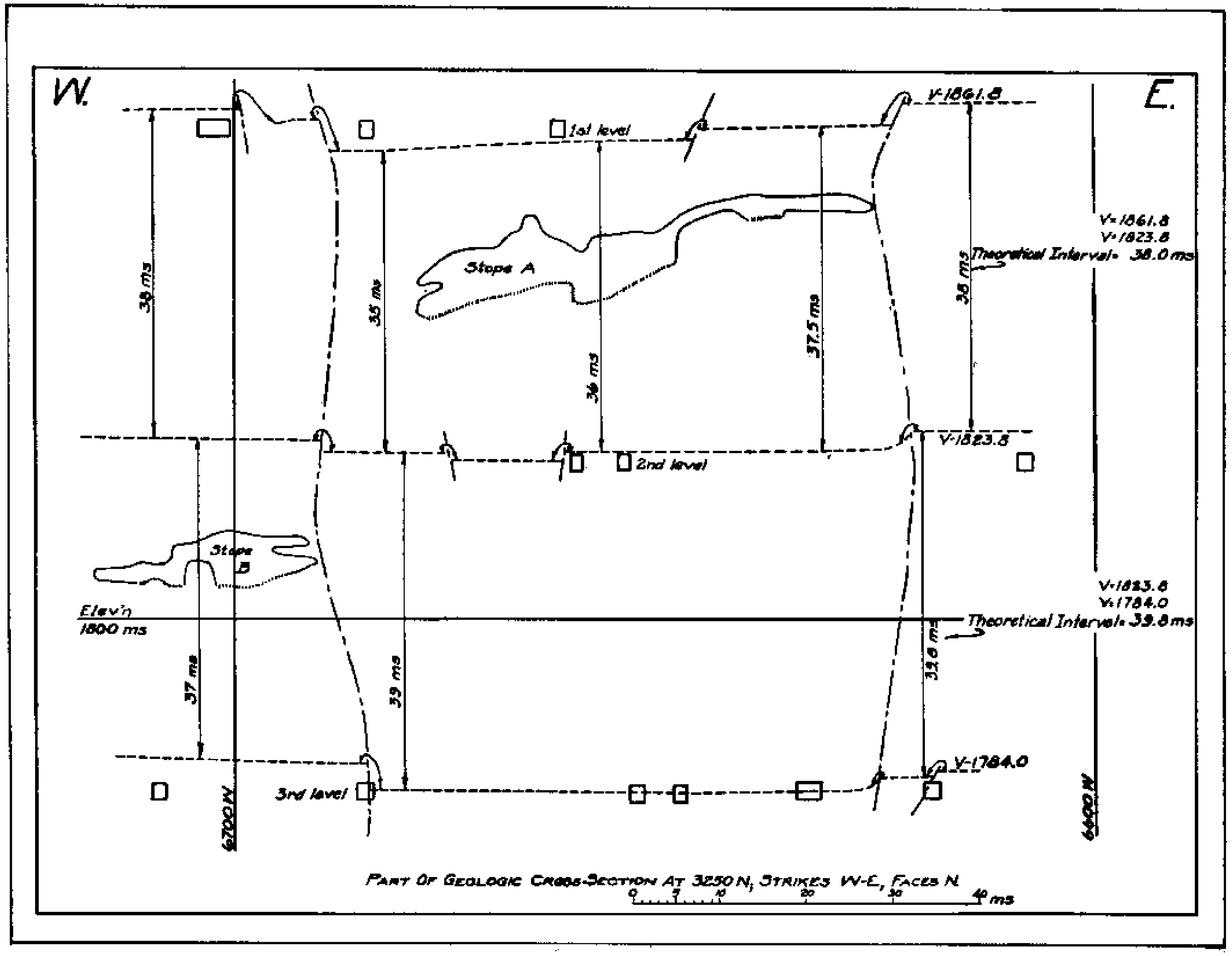



Figure 24. Part of geologic cross section at 3250 N, strikes W-E, faces N.

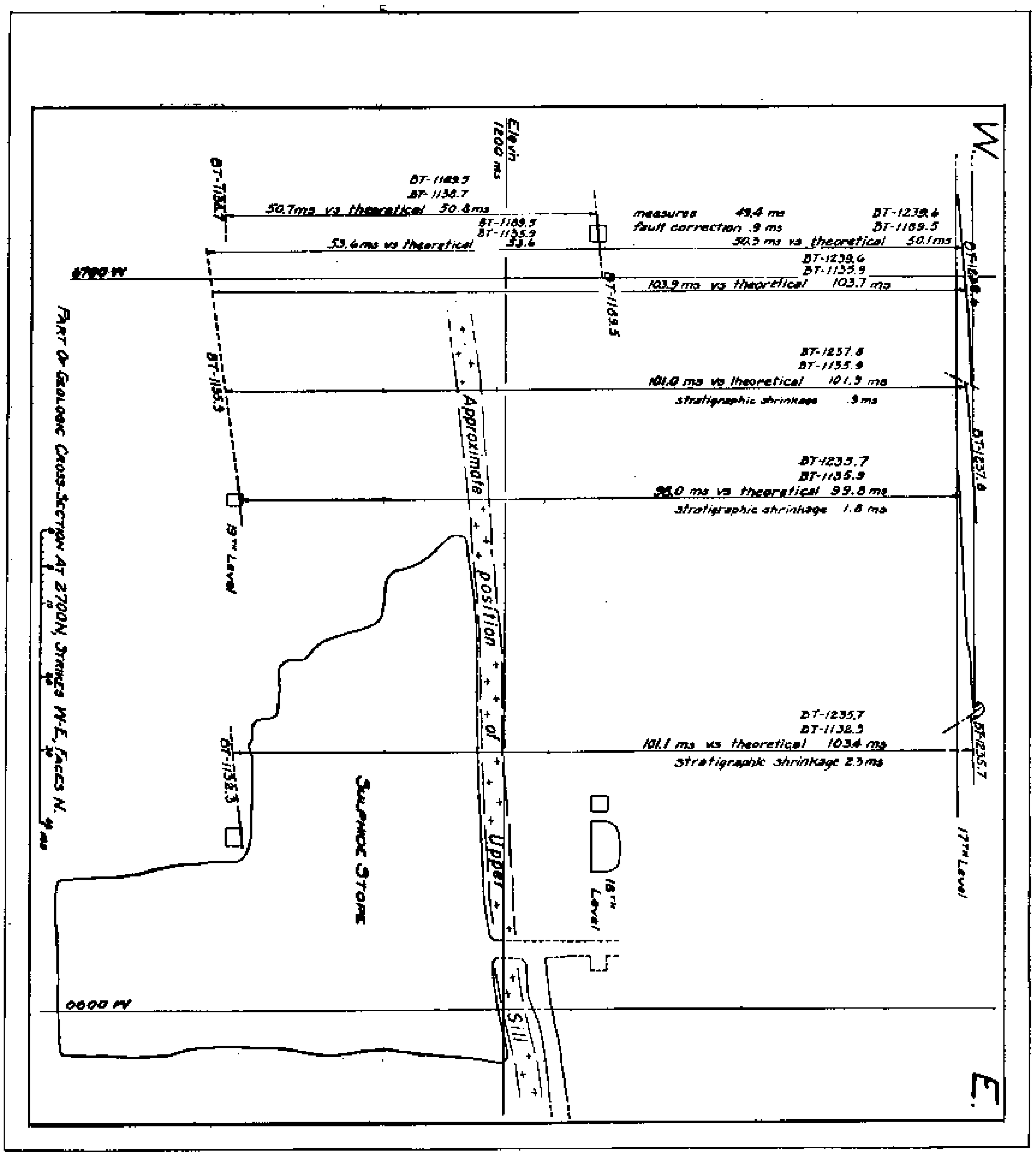



Figure 25. Part of geologic cross section at 2700 N, strikes W-E, faces N.

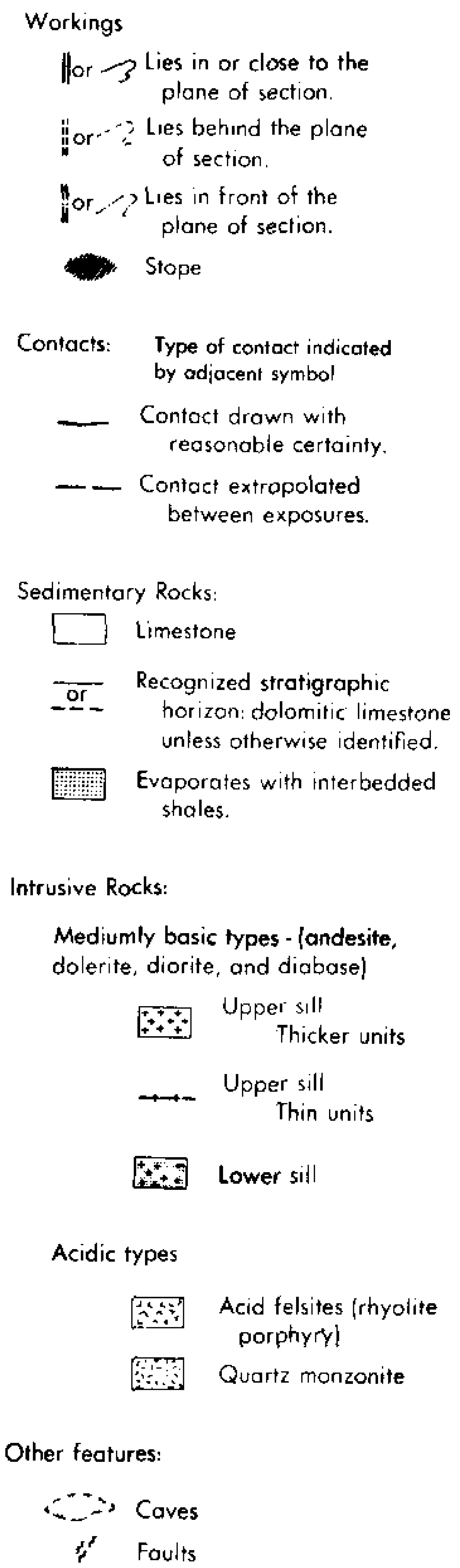



**Figure 26.** Explanation of geologic symbols: figures 7, 8, 9, 10, 14, 20, 23.

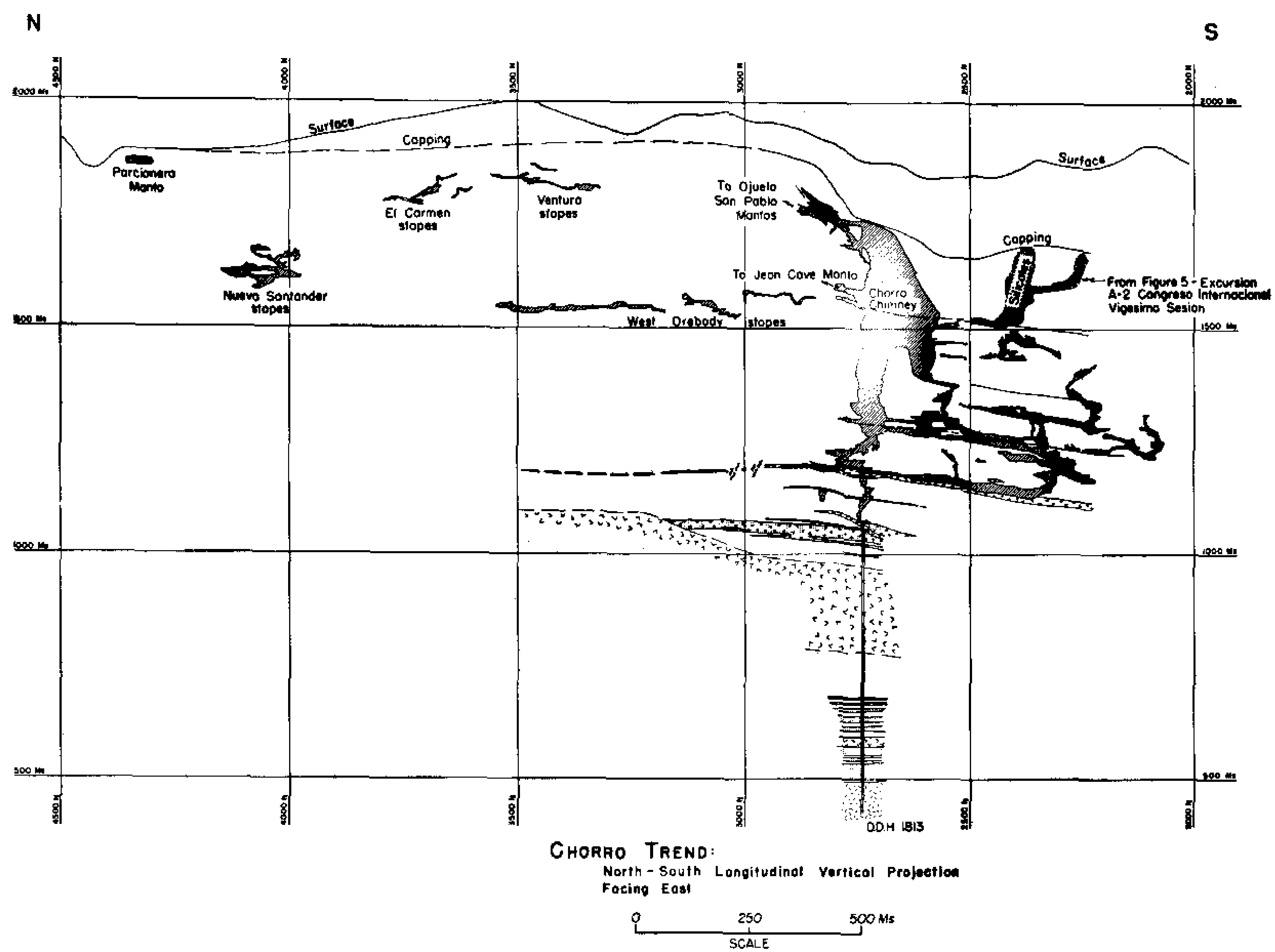
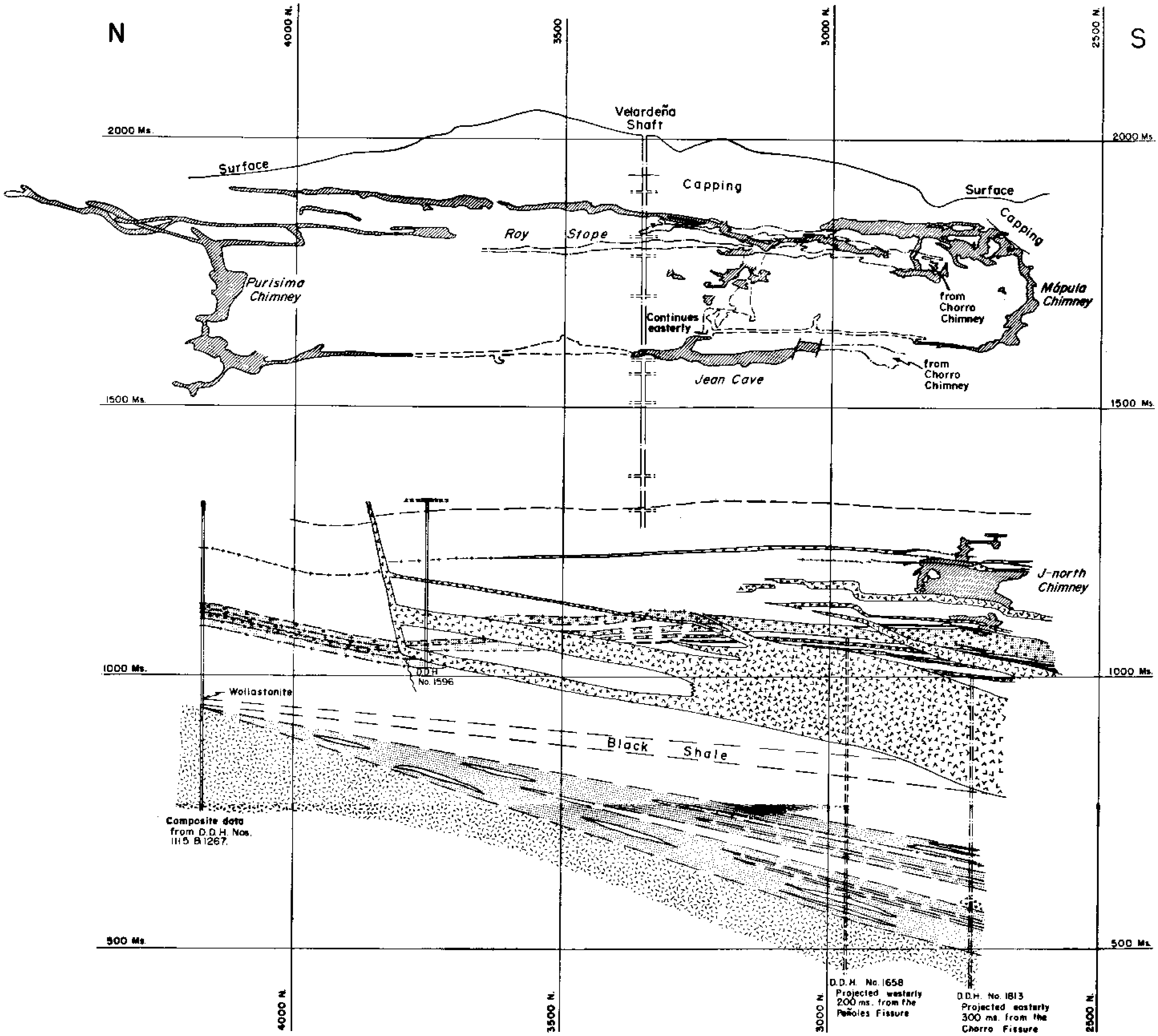



Figure 8. Chorro trend: north-south longitudinal vertical projection facing east.




**J-NORTH TREND:**
**North-South Longitudinal Vertical Projection**
**Facing East**
**(Stope detail south of 2500 N, not shown)**

Figure 9. J-north trend: north-south longitudinal vertical projection facing east.

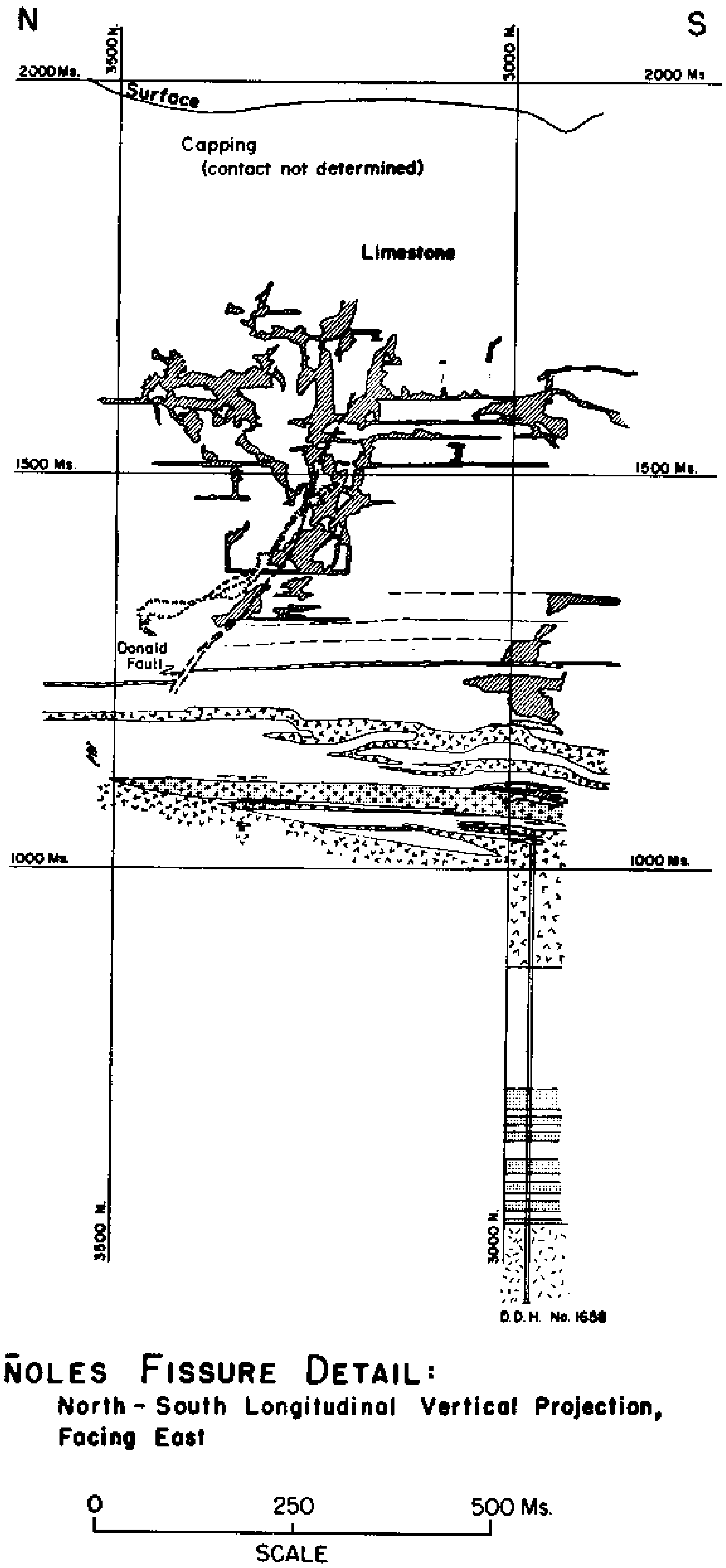



Figure 10. Peñoles Fissure detail: north-south longitudinal vertical projection facing east.


Figure 11. Photograph of "rhyolitized limestone".

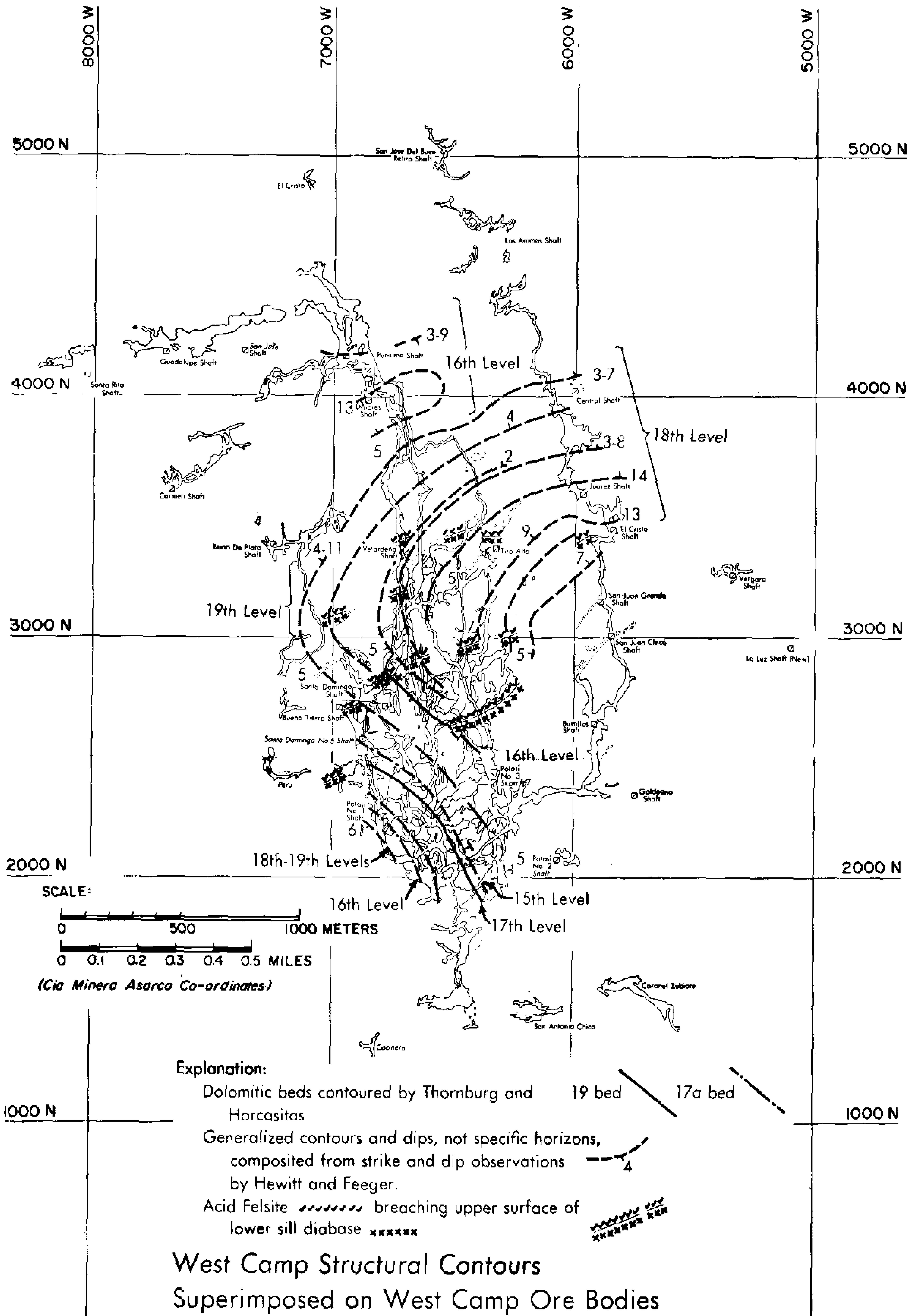
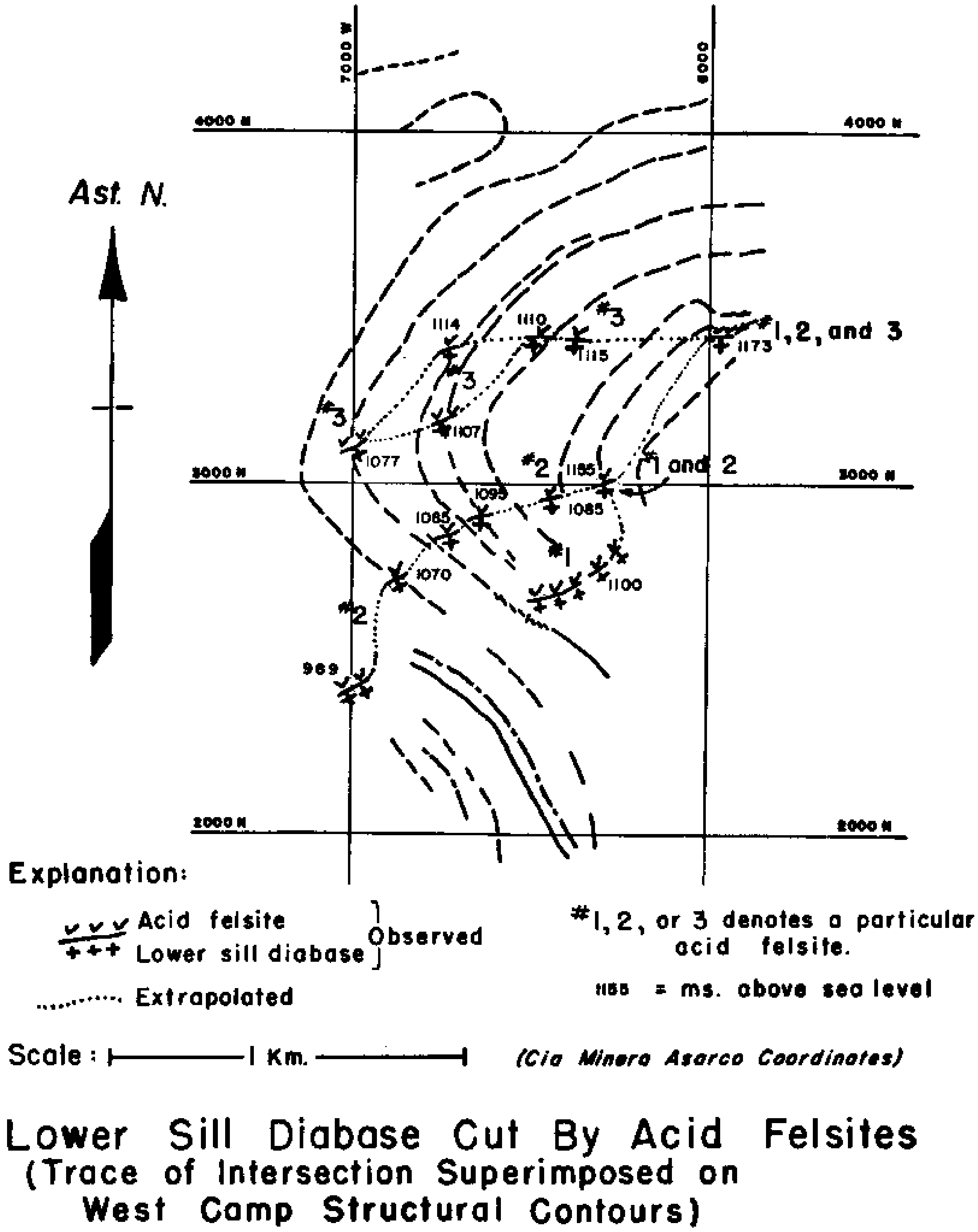



Figure 12. West Camp structural contours superimposed on ore bodies.




Figures 13. Lower Sill diabase cut by acid felsites: trace of intersection superimposed on West Camp structural contours.

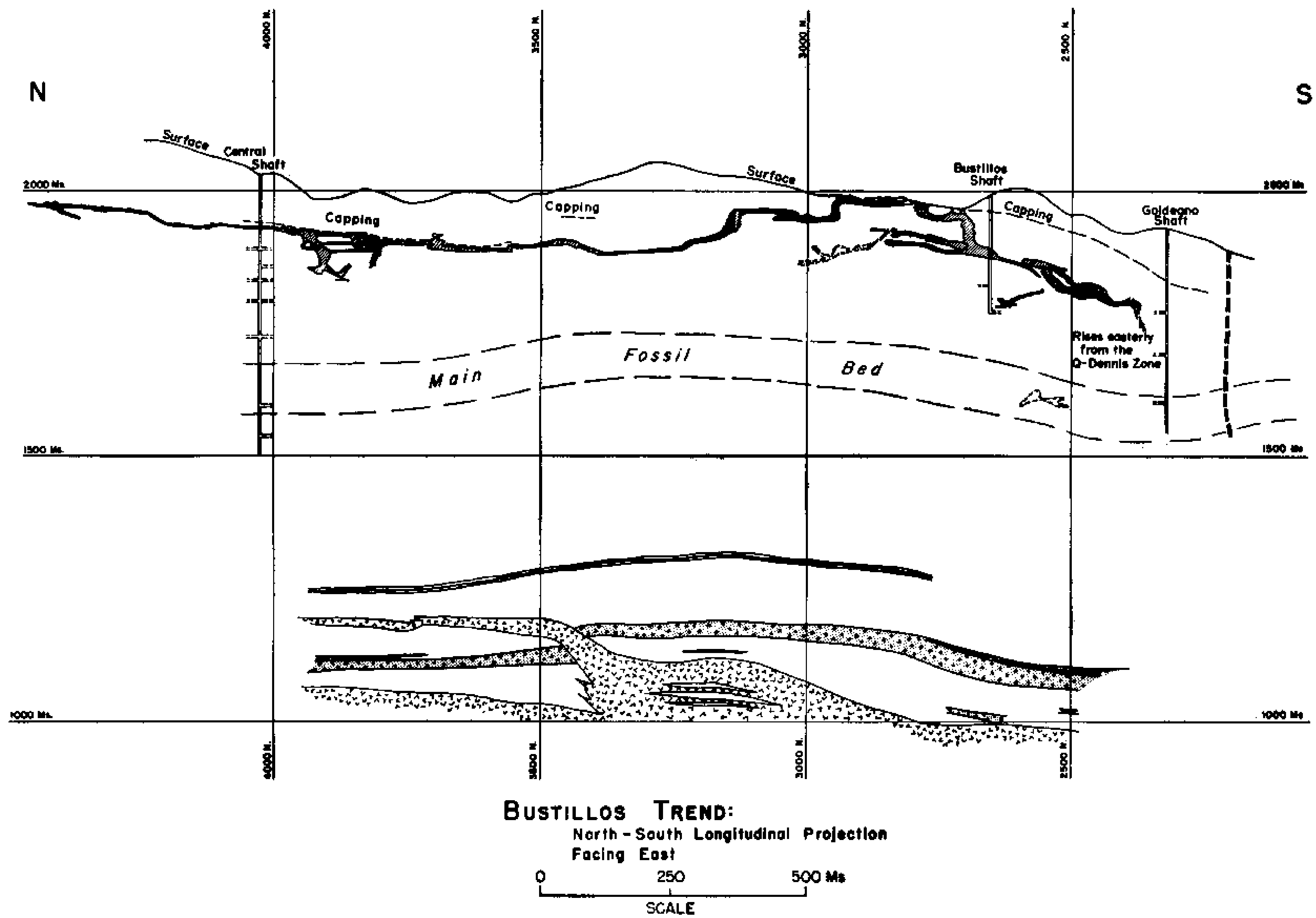



Figure 14. Bustillos trend: north-south longitudinal vertical projection facing east.

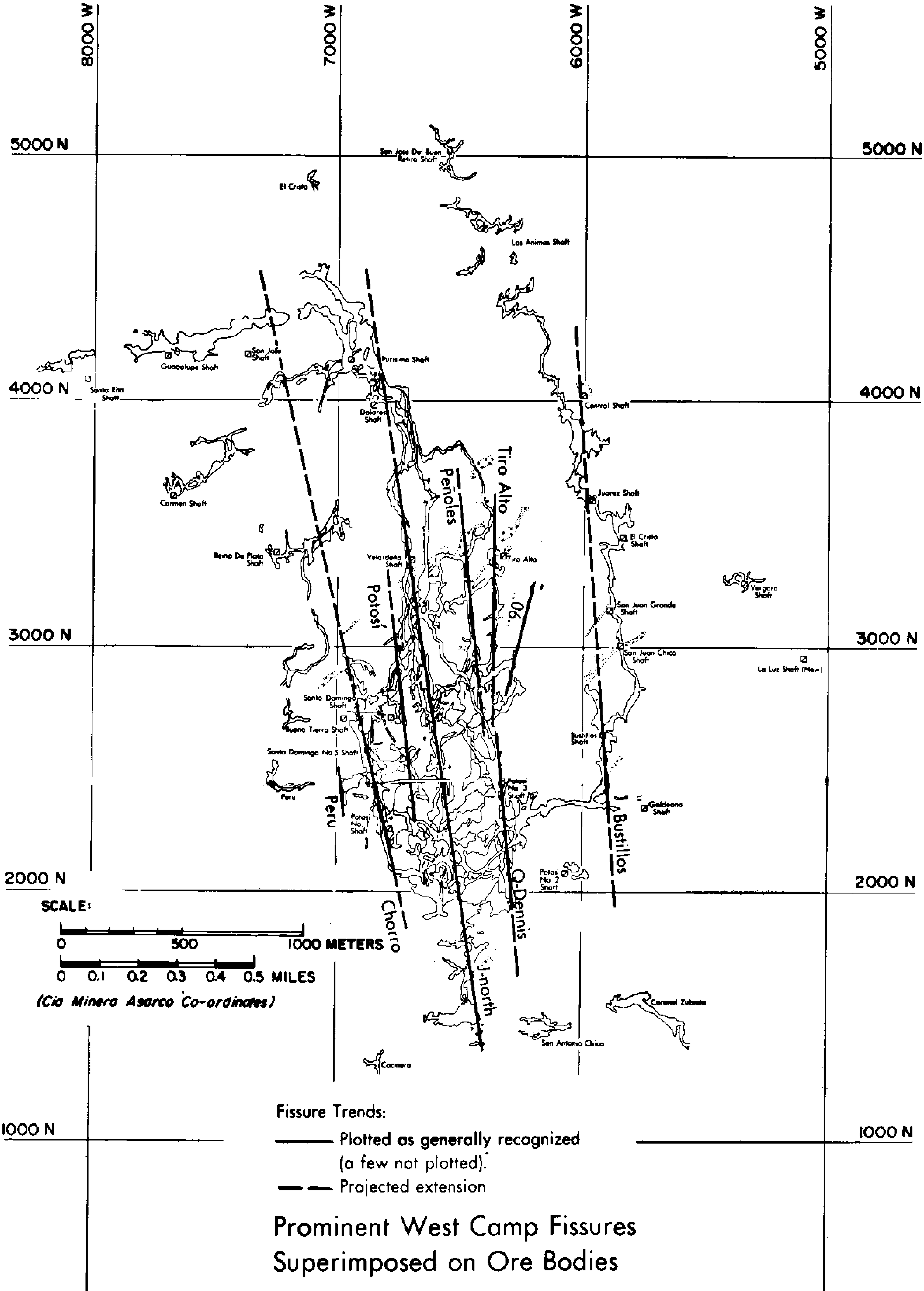



Figure 15. Prominent West Camp fissures superimposed on ore bodies.

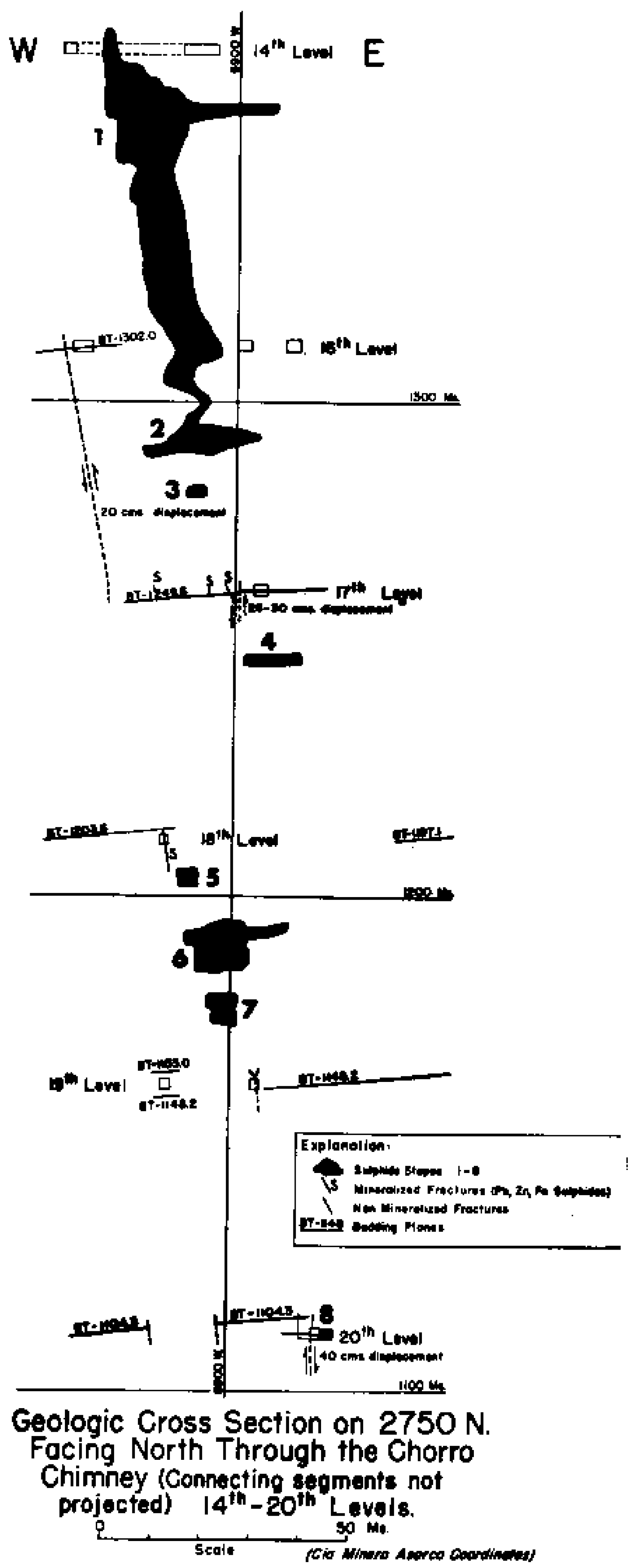



Figure 16. Geologic cross section facing N through the Choro Chimney.

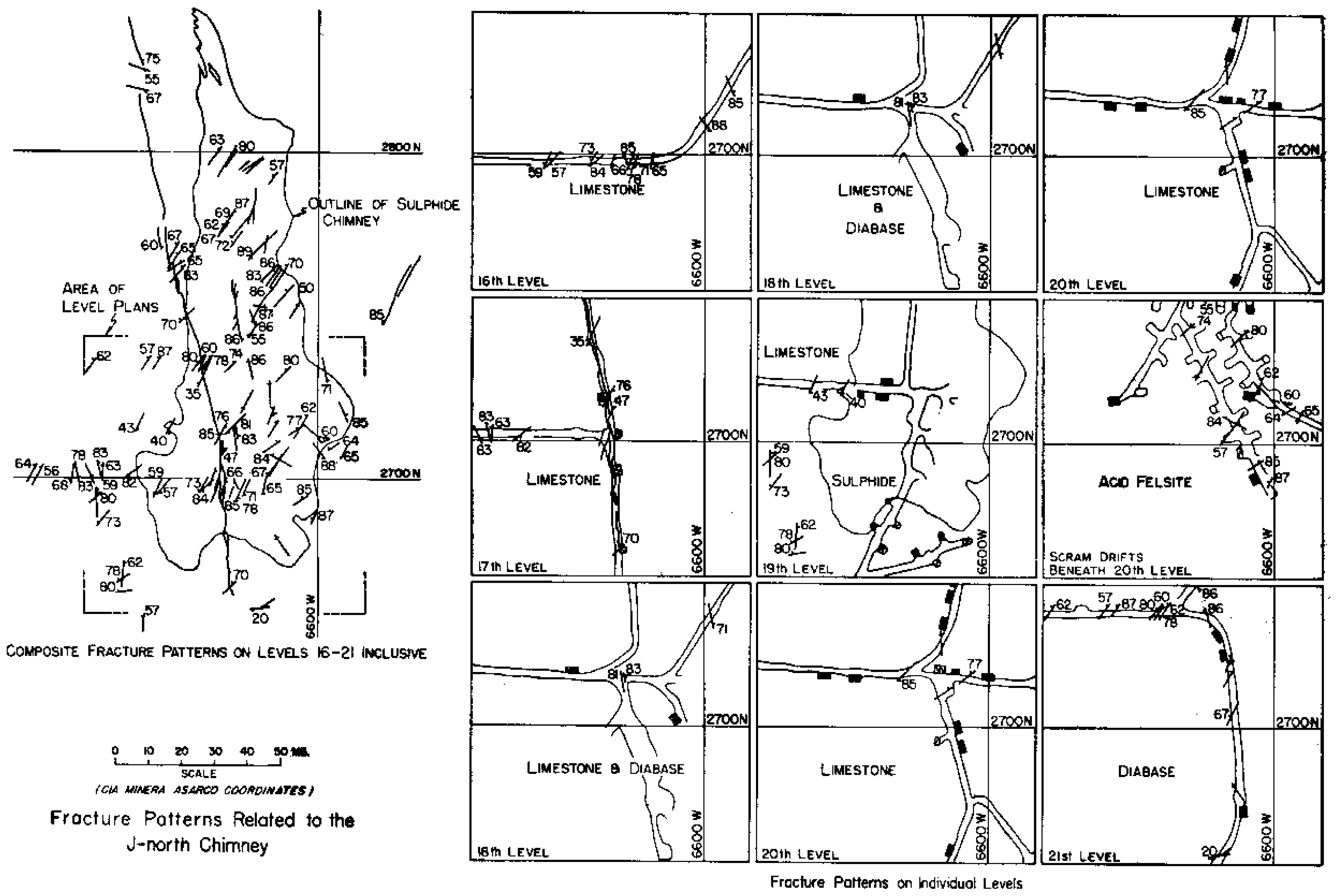
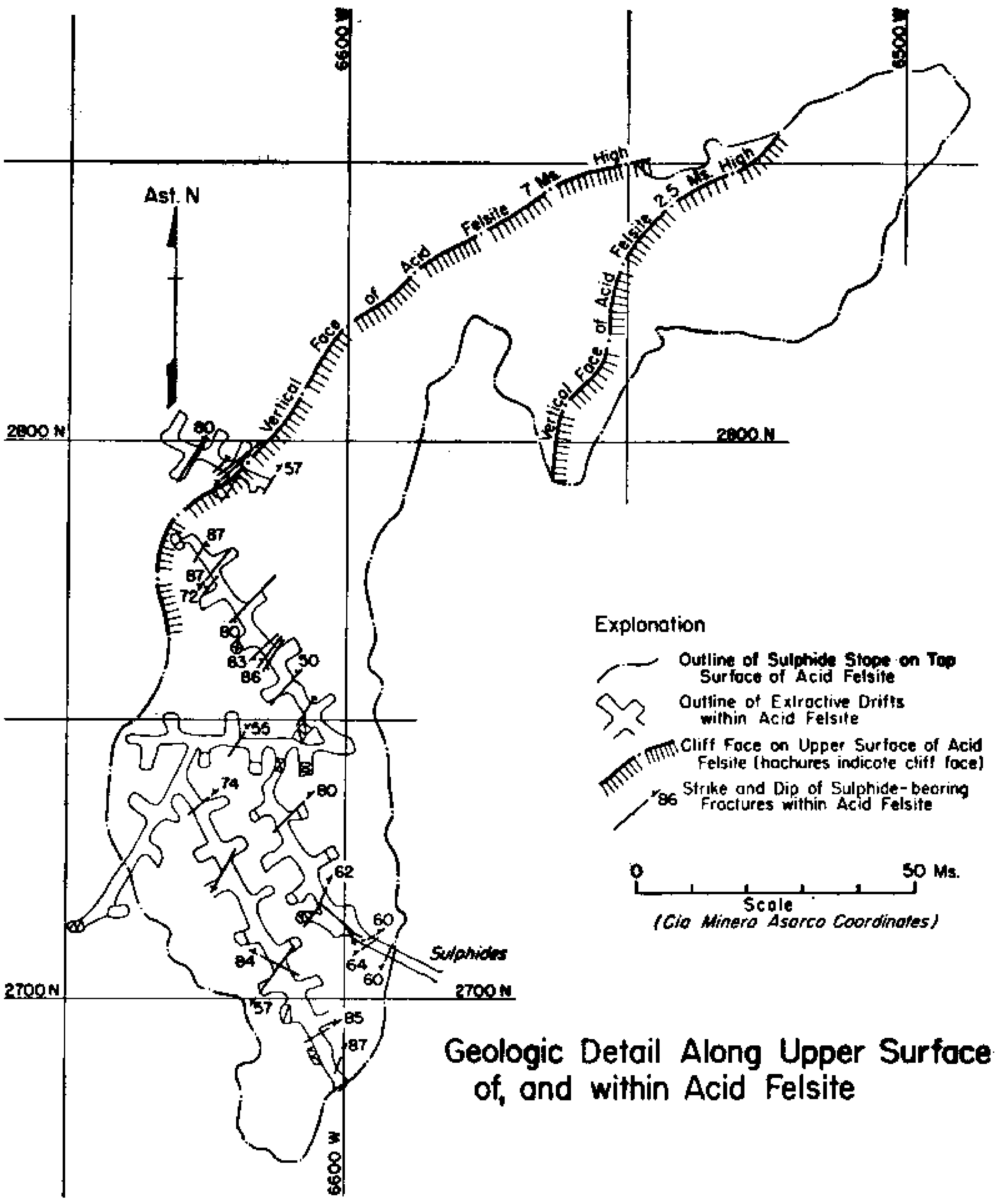



Figure 17. Fracture patterns related to the J-north Chimney.




J-north Chimney: northeast features associated with acid felsite.

Figure 18. J-north Chimney: northeast features associated with acid felsite.

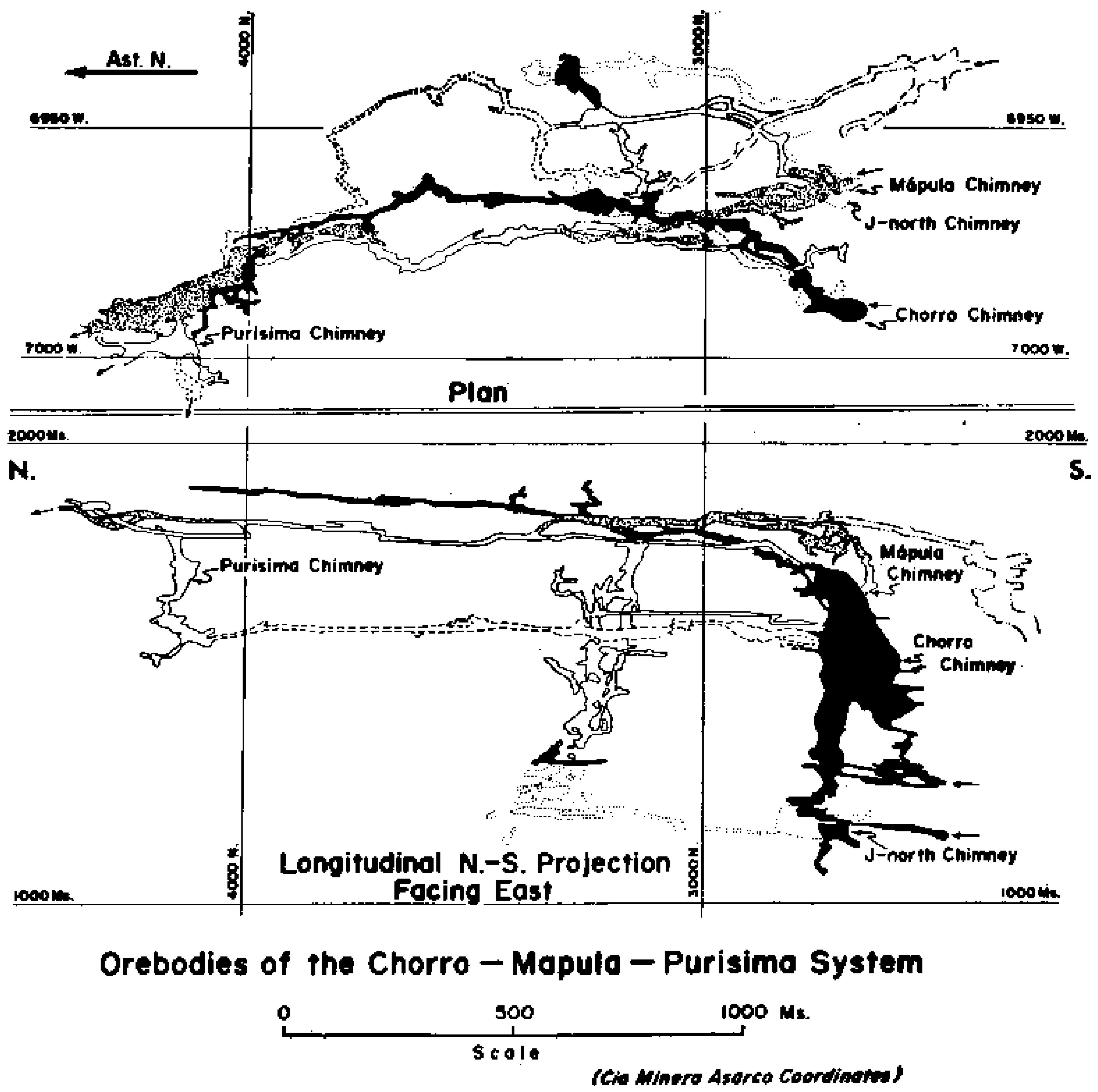



Figure 19. Ore bodies of the Chorro-Mápula-Purísima system.

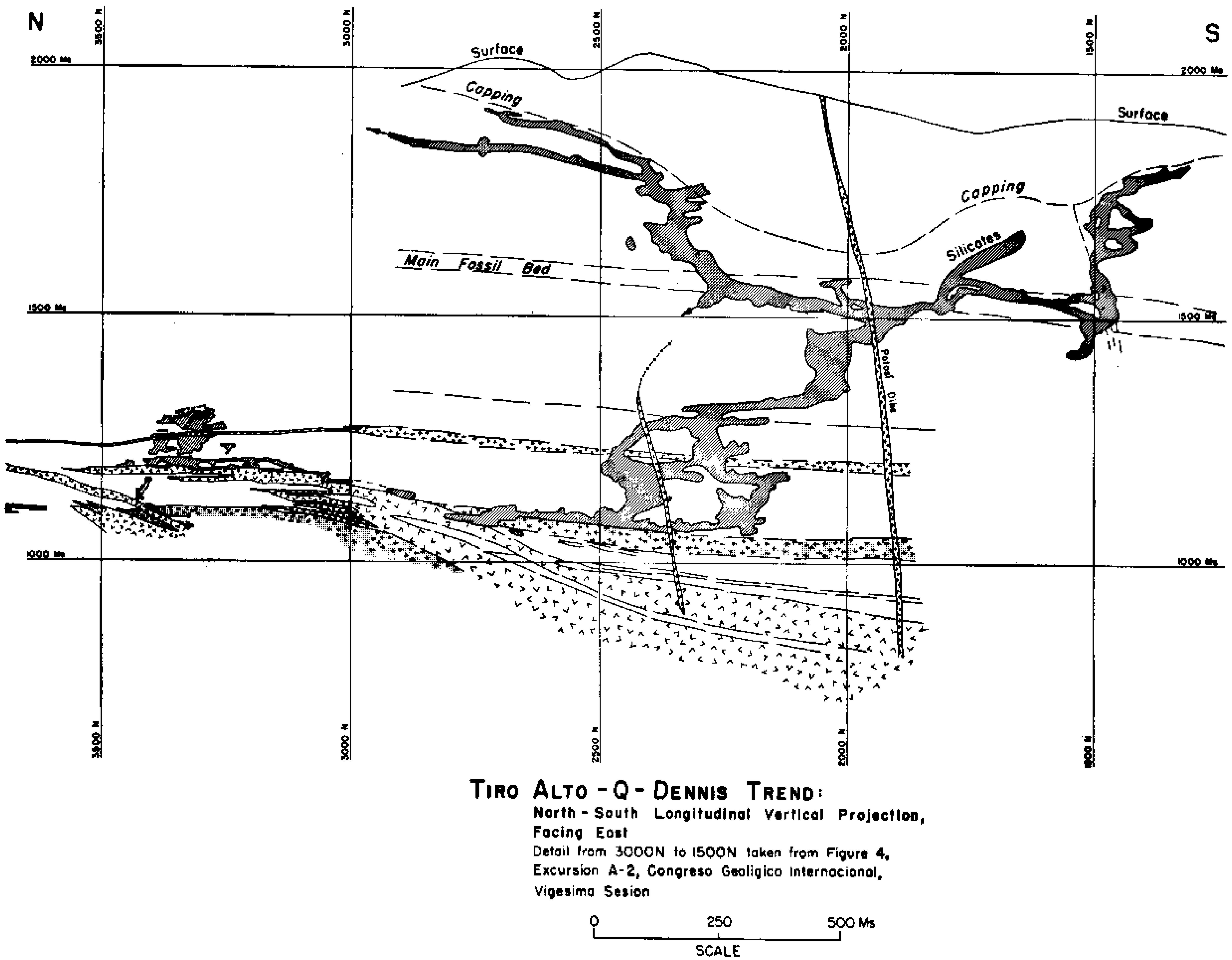



Figure 20. Tiro Alto - Q - Dennis Trend: north-south longitudinal vertical projection facing east.

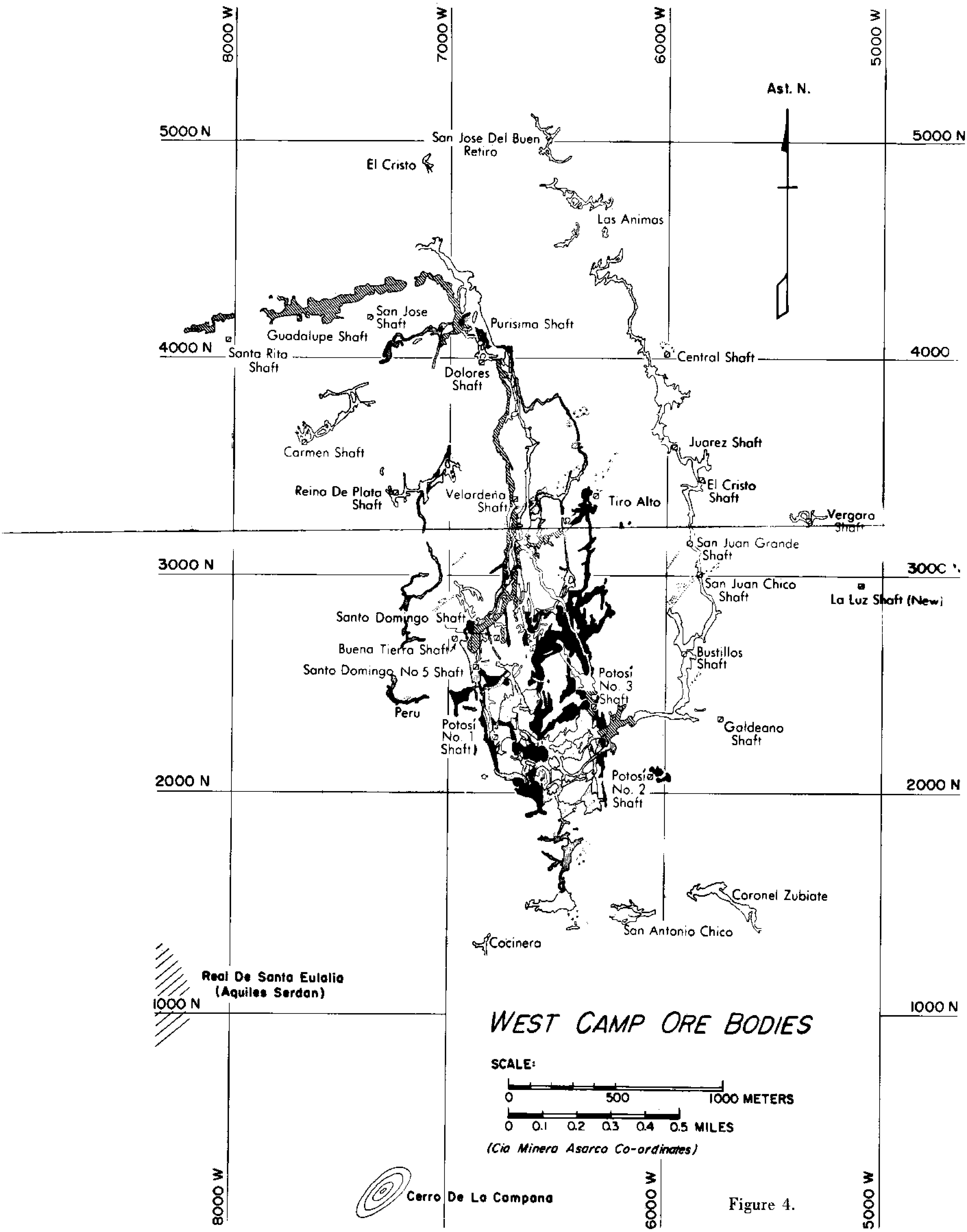

8000 W
7000 W
6000 W
5000 W
Ast. N.
5000 N
San Jose Del Buen Retiro
El Cristo
Las Animas
San Jose Shaft
Purisima Shaft
Guadalupe Shaft
4000 N
Santa Rita Shaft
Dolores Shaft
Central Shaft
4000
Carmen Shaft
Juarez Shaft
El Cristo Shaft
Reina De Plata Shaft
Velardeña Shaft
Tiro Alto
Vergara Shaft
San Juan Grande Shaft
3000 N
San Juan Chico Shaft
La Luz Shaft (New)
Santo Domingo Shaft
Buena Tierra Shaft
Bustillos Shaft
Santo Domingo No 5 Shaft
Potosi No. 3 Shaft
Peru
Potosi No. 1 Shaft
Galdeano Shaft
2000 N
Potosi No. 2 Shaft
Coronel Zubiate
San Antonio Chico
Cocinera
Real De Santa Eulalia (Aquiles Serdan)
1000 N
WEST CAMP ORE BODIES
SCALE:
0 500 1000 METERS
0 0.1 0.2 0.3 0.4 0.5 MILES
(Cia Minera Asarco Co-ordinates)
Cerro De La Campana

Figure 4.

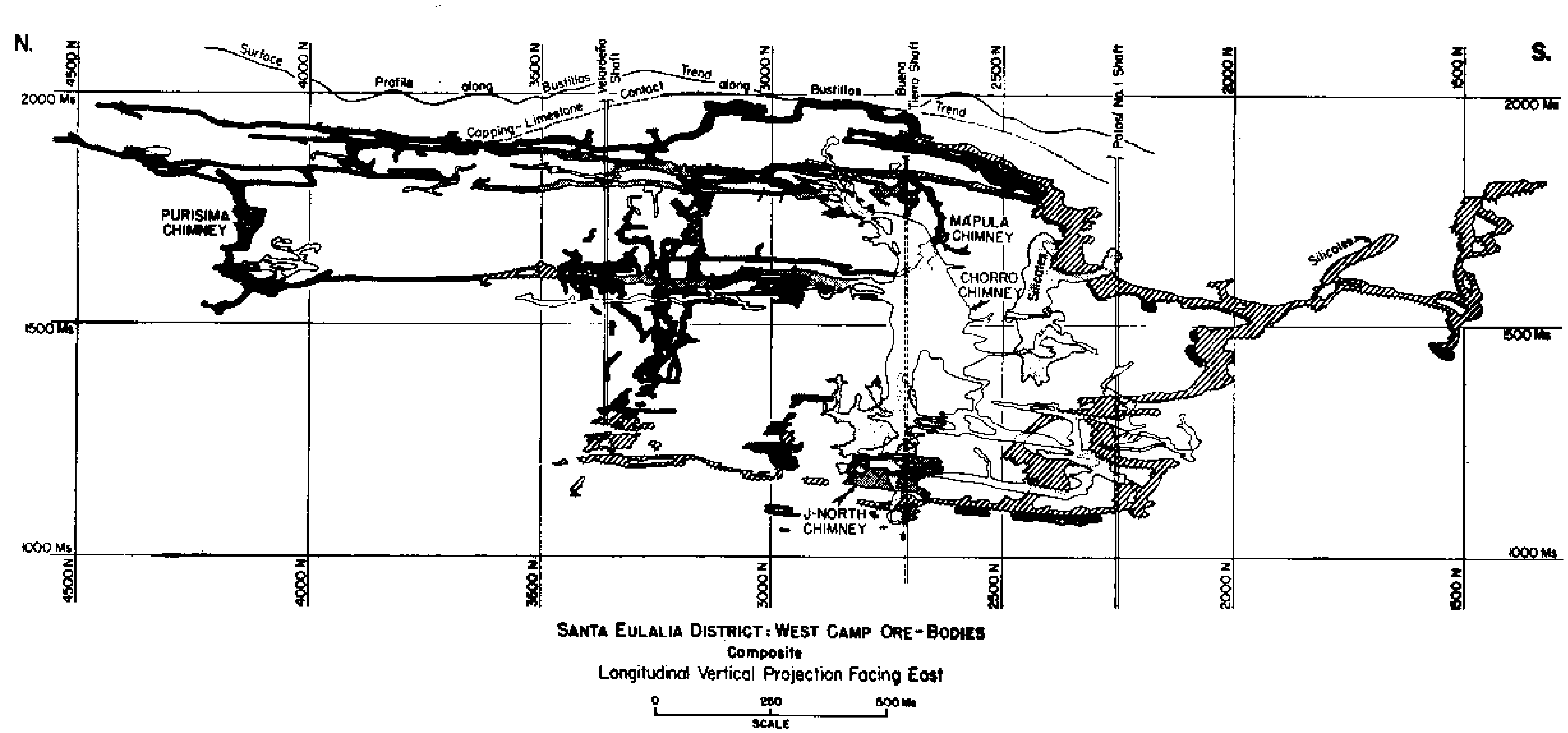



Figure 5. Santa Eulalia district: West Camp ore bodies, composite N-S longitudinal vertical projection facing E.

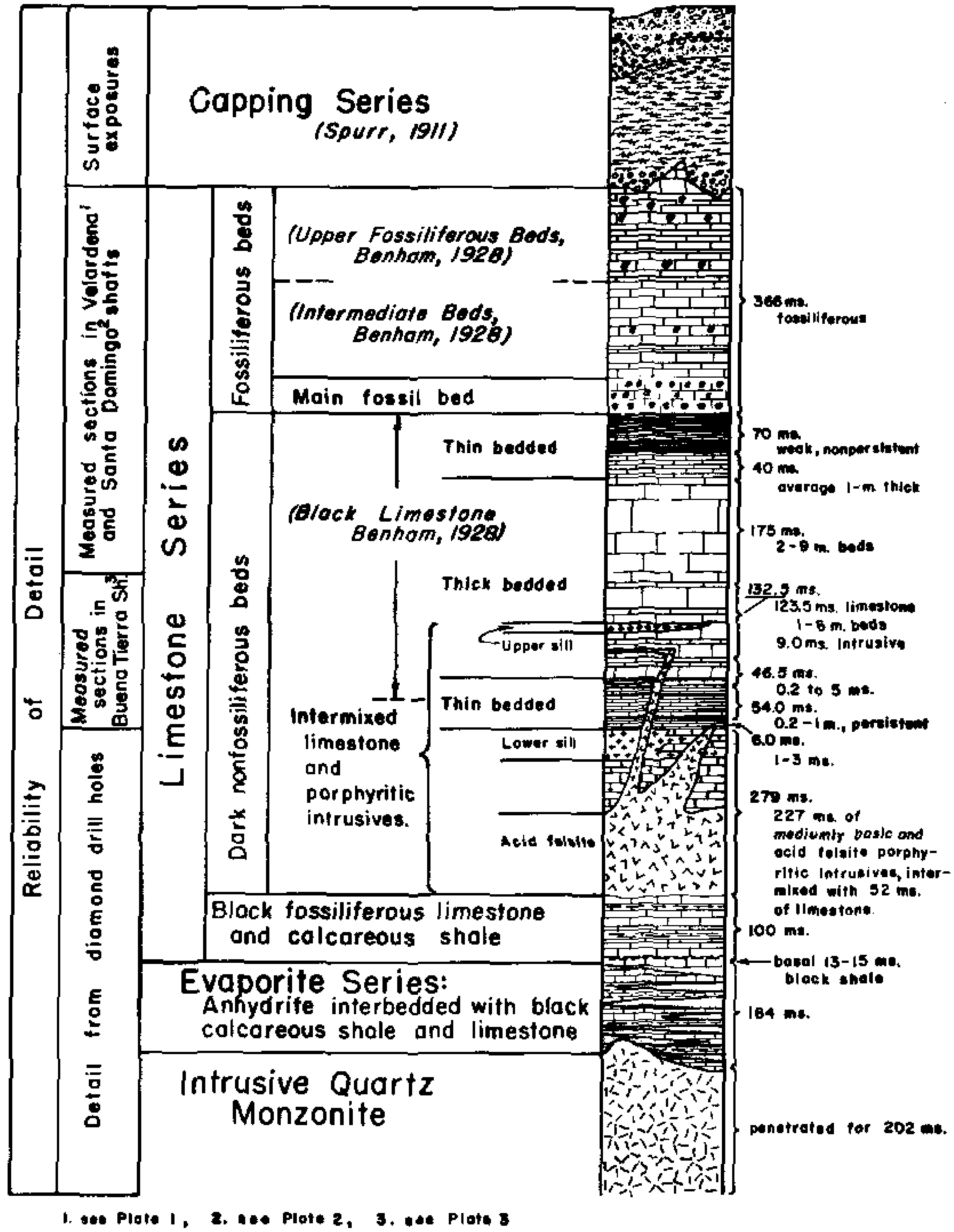



Figure 6. Columnar section.

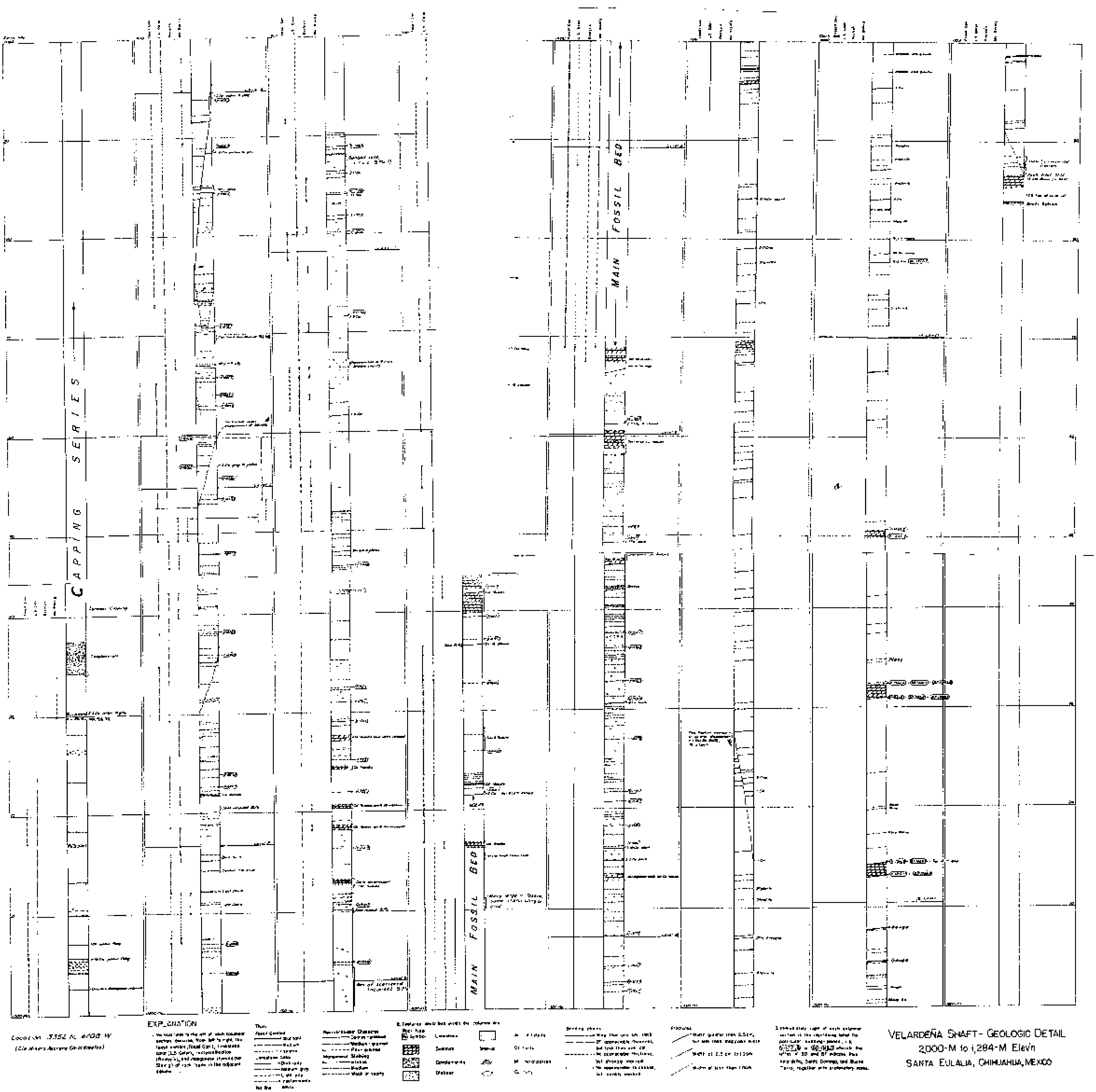



Plate 1. Velardeña Shaft - Geologic Detail.

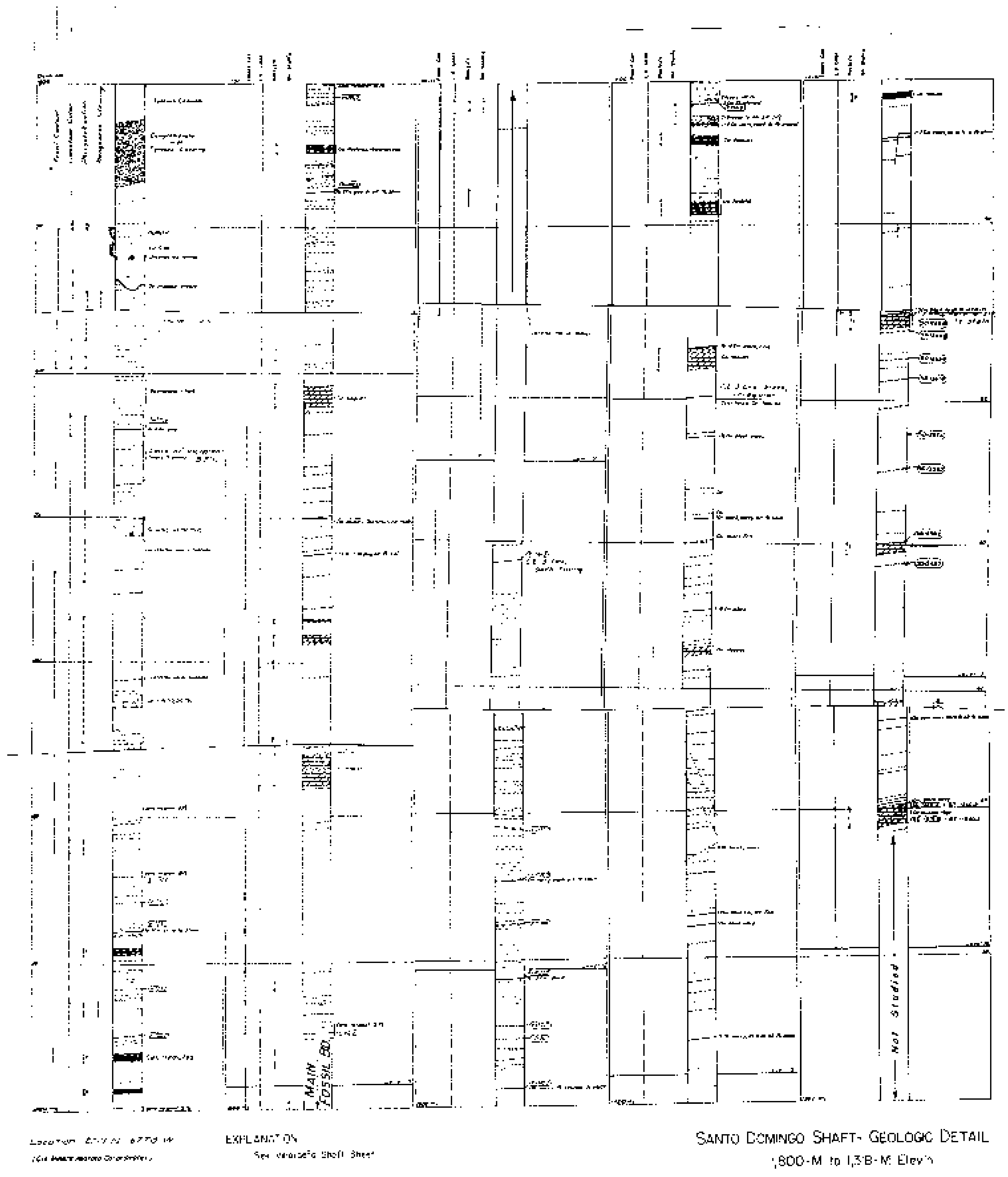



Plate 2. Santo Domingo Shaft - Geologic Detail.

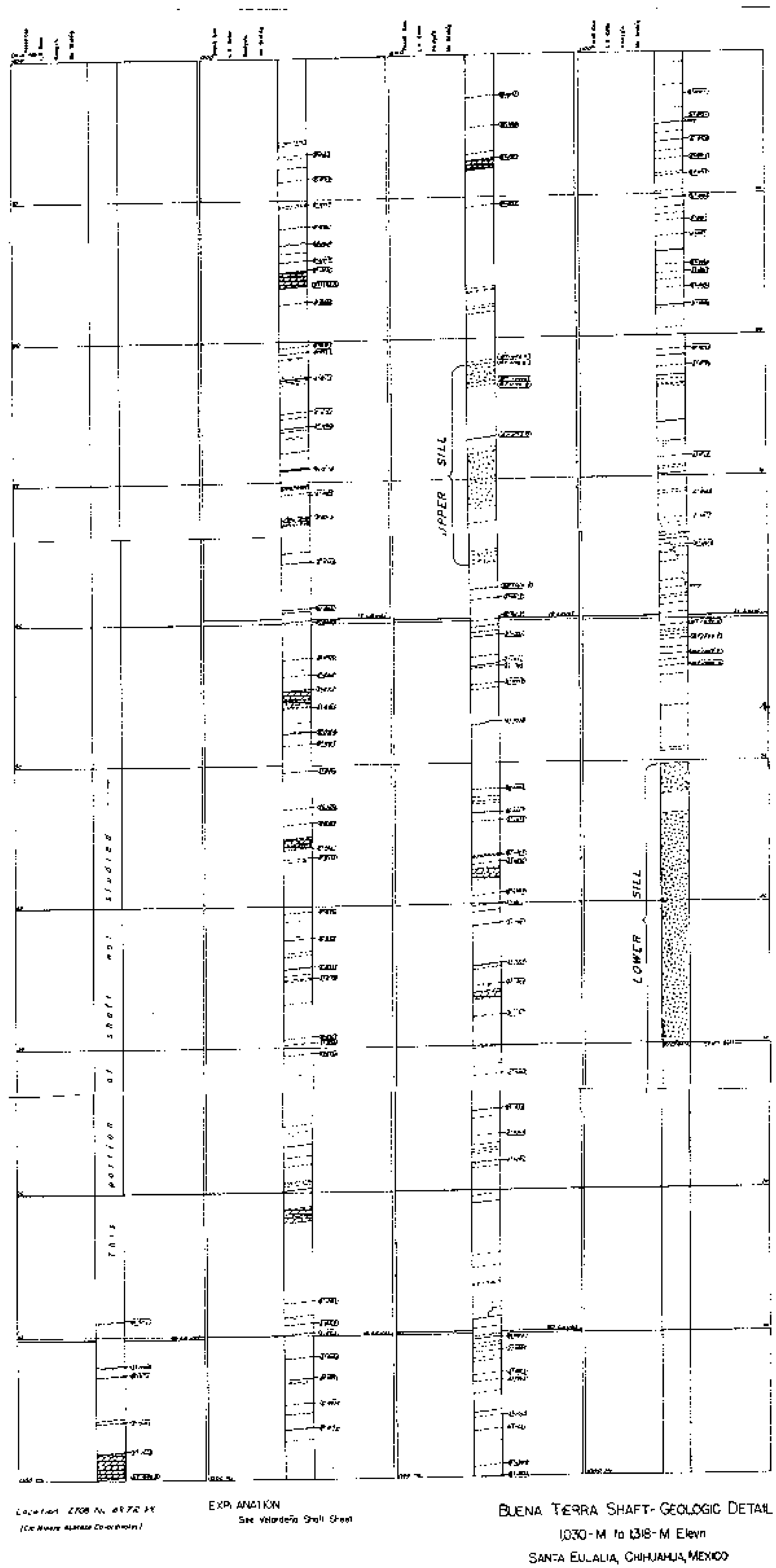



Plate 3. Buena Tierra Shaft - Geologic Detail.