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Investigation of the Principal Flour-
spar Districts of Mexico. by
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The attached manuscript on the fluorspar districts of Mexico lacks Figures 1-10, consisting of an index map and nine photographs. These illustrations were published in 1962 in the Spanish translation of the report, "Investigación de las principales distritos de fluorita en México," Boletín 62, Consejo de Recursos Naturales No Renovables, México, D. F., México.

The index map and a summary of the investigation were published in English in 1961 in U. S. Geological Survey Professional Paper 424-C, p. 212-215.

# Investigation of the principal fluorspar districts of Mexico

By

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Work done in cooperation with the Consejo de Recursos Naturales No Renovables, Secretaría del Patrimonio Nacional, México, D. F., and the Office of Minerals Mobilization, U. S. Department of the Interior.

U. S. Geological Survey
OPEN FILE REPORT
This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

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Abstract

As a result of the increasing need for fluorspar, especially in North America, the Mexican fluorspar industry expanded greatly in the 8-year period, 1952-1960. Since 1956, Mexico has been the world's largest producer and exporter of this commodity. From 1956 through 1959 Mexico exported about 90 percent of the fluorspar production to the United States; these exports averaged about 330,000 tons a year. Districts that yielded about 95 percent of the Mexican fluorspar production in 1959 were among those visited in the spring of 1960. Brief visits were made to 36 fluorspar mines in 9 states of Mexico. Measured, indicated, and inferred reserves in the fluorspar districts investigated total about 15 million tons of ore averaging about 65 percent $CaF_2$. These reserves and potential future sources indicate a long-continued production of fluorspar adequate to meet the domestic needs and to supply other North American requirements for many years.

[1] Publication authorized by the Director, U.S. Geological Survey

The fluorspar deposits are mainly in the Sierra Madre Oriental of eastern and central Mexico; in the Sierra Madre Occidental of western Mexico; and in the Sierra Madre del Sur southwest of Mexico City. More than two-thirds of the deposits examined are in limestone of Early Cretaceous age. The others are chiefly in shale or volcanic rocks that overlie the limestone, or within or next to intrusive Tertiary rhyolite. The deposits occur as nearly flat manto or blanket bodies or as steeply dipping veins, pipes, conical bodies, tabular and irregular replacement bodies, and filled sink hole and collapse breccias.

Mining and milling methods at the larger deposits are becoming more efficient. Problems that the Mexican fluorspar industry faces in the future include decreasing grade of ore in many deposits, greater depths of mining, increasing costs of labor, supplies, and transportation, and greater competition with Spanish and Italian fluorspar producers for the United States market.

## Introduction and acknowledgments

A survey of the principal fluorspar districts of Mexico was made in April, May and June 1960 by Ralph E. Van Alstine, U. S. Geological Survey, and Ing. Samuel Estrada and Ing. Ernesto de la Garza, both of the Consejo de Recursos Naturales No Renovables, Secretaría del Patrimonio Nacional, México, D. F. The brief visits to 36 fluorspar mines in 9 states of Mexico provided first-hand knowledge of the fluorspar deposits and their geologic environment.

Districts that yielded about 95 percent of the fluorspar produced in Mexico in 1959 were among those investigated. Tables 1 and 2 and Figure 1 show the districts, mining companies or mines,

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Figure 1. near here.

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and processing plants that were visited. Information about other fluorspar deposits of Mexico has been published (Gillson, 1960a; Prado, 1954, p. 75-85; and Williamson, 1961b).

Figure 1. Index map of part of Mexico showing fluorspar mining districts and processing plants visited, April - June 1960.

The Office of Minerals Mobilization, U. S. Department of the Interior, sponsored and financed R. E. Van Alstine's trip. The participation in the project by Ings. Estrada and de la Garza was financed by the Consejo de Recursos Naturales No Renovables.

The investigation was made with the cooperation of Sr. Ing. Salvador Cortes Obregon, Gerente, Consejo de Recursos Naturales No Renovables; Sr. Ing. Guillermo P. Salas, Director, Instituto de Geologia; Sr. Ing. Salvador Trevino, Gerente, Comision de Fomento Minero: and officers of the various fluorspar companies operating in Mexico. Ralph L. Miller, Chief of the U. S. Geological Survey mission to Mexico, helped greatly in arranging the cooperative study and accompanied the party in the northern Coahuila, Taxco, and Zacualpan districts.

Table 1.--Districts and mining companies visited

| State | District | Mining company or mine | Affiliate |
|---|---|---|---|
| ihuahua | Parral | Industrial de Fluorita | General Chemical Div., Allied Chemical Corp. |
| ahuila | El Tule | Minera Rosala | E. I. du Pont de Nemours & Co. |
| ahuila | Encantada-Buenavista | Fluorita de Mexico | Continental Ore Co. |
| ahuila | Encantada-Buenavista | El Camarón mine | ---------------- |
| ahuila | Encantada-Buenavista | Minera Rosala | E. I. du Pont de Nemours & Co. |
| ahuila | Paila-San Marcos | Minera Nacional | American Smelting and Refining Co. |
| ahuila | Paila-San Marcos | San Marcos y Pinos | Reynolds Metals Co. |
| ahuila | Paila-San Marcos | Minera Julieta | St. Lawrence Corp. of Newfoundland, Ltd. |
| ahuila | Paila-San Marcos | Minera La Valenciana | ---------------- |
| ahuila | Pico Etereo | La Domincia | Dow Chemical Co. |
| ahuila | Pico Etereo | Mal Abrigo mine | ---------------- |
| rango | Villa Union | Impulsora Minera | Mexus Minerals |
| anajuato | Rio Verde | Minera Rio Colorado | General Chemical Div., Allied Chemical Corp. |
| errero | Taxco | Restauradora de Minas | Minerales y Productos Derivados, Spain |
| errero | Taxco | Minas del Norte | La Consolidada |
| xico | Zacualpan | Mexicana de Minas y Beneficios | ---------------- |
| n Luis tosi | Zaragoza | Minera Las Cuevas | Noranda Mines, Ltd., and others |
| n Luis tosi | Zaragoza | Minerales Pennsalt | Pennsalt Chemicals Corp. |
| n Luis tosi | Rio Verde | Minera La Valenciana | ---------------- |
| San Luis Potosi | Rio Verde | Fluorita de Rio Verde | Continental Ore Co. |
| Sonora | Esqueda | Fluoresqueda | San Luis Mining Co. and Aluminium Limited of Canada |
| Zacatecas | Frio | Fluorita Industrial Mexicana | Aluminium Limited of Canada |

Table 2.--Processing plants visited

| . on g. 1 | Location | Operating company | Process | Approx. daily capacity (tons of concentrates) |
|---|---|---|---|---|
| 1 | Esqueda, Sonora | San Luis Mining Co. and Aluminium Ltd. of Canada | Flotation | 125 |
| 2 | Heath Crossing, Coahuila | Dow Chemical Co. | Flotation | 100 |
| 3 | Eagle Pass, Texas | Reynolds Metals Co. | Flotation | 100 |
| 4 | El Tule, Coahuila | E. I. du Pont de Nemours & Co. | Air separation pilot plant | 30 |
| 5 | Muzquiz, Coahuila | Fluorita de Mexico | Flotation | 200 |
| 6 | Agujita, Coahuila | American Smelting and Refining Co. | Flotation | 150 |
| 7 | Frausto, Coahuila | St. Lawrence Corp. of Newfoundland, Ltd. | Heavy Media | 100+ |
| 8 | Zaragoza district, San Luis Potosi | Minerales Pennsalt | Crushing and sizing | 300 |
| 9 | San Luis Potosi, San Luis Potosi | Noranda Mines, Ltd., and others | Crushing and sizing | 200 |
| 0 | Rio Verde, San Luis Potosi | Minera La Valenciana | Washing and sizing | 75 |
| 1 | Zacualpan, Mexico | Mexicana de Minas y Beneficios | Flotation | 70 |

## Fluorspar deposits

### Geologic environment

More than two-thirds of the fluorspar deposits examined are in limestone of Early Cretaceous age. The other deposits are mainly in shale or volcanic rocks that overlie the limestone, or within or next to intrusive Tertiary rhyolite.

The deposits occur as nearly flat manto bodies or as steeply dipping veins, pipes, conical bodies, tabular and irregular replacement bodies, and filled sink holes and collapse breccias. The manto deposits are generally smaller but contain higher grade ore than the veins, pipes, and conical bodies; they are abundant in several widely separated areas of limestone in northern and southern Coahuila.

## Mineralogy

Fluorspar is an earth material composed largely of the mineral fluorite ($CaF_2$). The deposits consist predominantly of fluorite, calcite, and quartz or chalcedony. The fluorite is highly variable in texture, grain size, and color. In some deposits the calcite content increases with depth; in others it decreases below a superficial caliche zone. Most of the ores contain small quantities of barite, celestite, gypsum, native sulfur, pyrite, sphalerite, galena, chalcopyrite, cinnabar, iron oxides, or manganese oxides. Bertrandite, $Be_4(OH)_2Si_2O_7$, has been reported in the Aguachile deposit of the Pico Etereo district, northwestern Coahuila (Rowe, 1961, p. 56; Levinson, 1962; and McAnulty, 1962).

## Grade of ore

Although detailed sample data were not available for most of the Mexican deposits visited, the average grade of ore, estimated at about 65 percent $CaF_2$, seems to be higher than that of fluorspar deposits in the United States. However, the overall range in grade from less than 40 to more than 90 percent $CaF_2$ is similar in the two countries. The silica content of the ore commonly is less than 10 percent and in some deposits is less than 1 percent; a few deposits contain more than 30 percent calcite. The high quality of fluorspar shipped from some Mexican districts results from selective mining of lower grade deposits and repeated hand-picking at the mines and mills.

## Reserves

The fluorspar reserves in the districts visited are estimated at about 5 million tons of measured and indicated ore and about 10 million tons of inferred ore averaging about 65 percent $CaF_2$. Fluorspar reserves generally are not blocked out systematically, and these estimates are based upon observations made by the writer and upon information supplied by the mining companies. Individual deposits containing these reserves range in size from less than 10,000 tons to more than 1,000,000 tons. An additional potential reserve of about 5 million tons of acid-grade fluorspar is contained in about 45 million tons of tailings that have accumulated from the flotation of zinc-lead-copper ore in and near the Parral district, Chihuahua. Undoubtedly other sources of supply will be found in Mexico, especially in Coahuila and San Luis Potosi. The most favorable sites for exploration are extensions of significant deposits, other mineralized structures within the known districts, and in many other parts of Mexico where Cretaceous limestone and silicic igneous rocks are found.

## Mining and milling

Shrinkage stoping, modified cut-and-fill system, room-and-pillar method, and benching in opencuts are the chief methods of mining fluorspar in Mexico. Some of the larger fluorspar mines are highly mechanized; at most of the small deposits, however, modern mining techniques are not used and only the highest grade, thickest, or most readily accessible ore is mined by hand and packed to the surface on the backs of the miners. High-grade ore in bodies as thin as 10 centimeters is mined profitably from one manto deposit. The deposits in the Encantada-Buenavista district, Coahuila, are worked mainly from adits in which the workings extend less than 15 meters below the surface and 100 meters from the portals. Water for mine use is hauled to most of the districts; nearly all the mines visited were dry. Because of this lack of water near the mines, ore is hauled as much as 250 kilometers to a mill.

Twenty companies control the mines visited. Fourteen of them are affiliated with United States companies, three are entirely Mexican, two are affiliated with Canadian companies, and one is Spanish. About 800 men were said to be employed in the mines in the fluorspar districts investigated.

Eleven fluorspar processing plants employing about 75 men were visited. Table 2 shows the operating company, type of process, and approximate capacity for each plant. Two of the 11 plants are inactive (Nos. 4 and 5 on Table 2). Two are new flotation mills that began operating in the summer of 1960 (Nos. 1 and 2 on Table 2).

Grades of fluorspar and production

Chemical and physical requirements of the three grades of fluorspar are summarized as follows:

Metallurgical-grade fluorspar

Fluorspar suitable for use in the production of steel is required to meet the following specifications for purchase by the United States Goverhment[1]:

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[1] Footnote near here

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a. Chemical requirements

| | Percent by weight (Dry basis) | |
|---|---|---|
| | Grade A | Grade B |
| Effective Calcium Fluoride[2] ($CaF_2$) Minimum | 70.00 | 60.00 |
| Sulfur (S) (as sulfide and/or free sulfur) Maximum | 0.30 | 0.30 |
| Lead (Pb) Maximum | 0.50 | 0.50 |

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[2] Footnote near here

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[1] [U. S.] General Services Administration, 1957, Defense Materials Service, National Stockpile Specification P 69b-R, Metallurgical-grade Fluorspar.

2/ The percent effective calcium fluoride shall be calculated by deducting from the contained calcium fluoride 2.5 percent for each 1 percent contained silica, fractions pro rata.

b. Physical requirements

All fluorspar shall pass a $1\frac{1}{2}$ inch sieve (3.8 cm opening), and not more than 15 percent by weight shall pass a U. S. Standard Sieve No. 16 (1.19 mm opening). Fine fluorspar is undesirable in making steel because it is lost in the furnace draft or floats on the surface instead of sinking into the melt.

Because of the above limitation on the amount of fine material, metallurgical-grade fluorspar generally undergoes less milling than the other grades, and the grade of crude ore commonly used for the production of metallurgical-grade fluorspar by jigs or Heavy Media process is higher than that used for making acid or ceramic grades by flotation.

Fluorspar suitable for making chemicals and artificial cryolite is required to meet the following specifications for purchase by the United States Government[1]:

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[1] Footnote near here

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a. Chemical requirements

1. Hydrofluoric acid grade

| | Percent by weight (Dry basis) |
|---|---|
| Calcium Fluoride ($CaF_2$) Minimum | 97.00 (See Note 1) |
| Silica ($SiO_2$) Maximum | 1.50 (See Note 1) |
| Sulfur (S) (as sulfide and/or free sulfur) Maximum | 0.03 |
| Calcium Carbonate ($CaCO_3$) Maximum | 1.25 |

Note 1. The calcium fluoride may be a minimum of 95.00 percent provided the available calcium fluoride is not less than 91.00 percent. The available calcium fluoride shall be calculated by deducting 4.00 percent from the calcium fluoride for each 1.00 percent silica, fractions pro rata.

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_/ [U. S.] General Services Administration, 1952, Emergency Procurement Service, National Stockpile Specification P-69a, Acid-grade Fluorspar.

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2. Cryolite grade

| | Percent by weight (Dry basis) |
|---|---|
| Calcium Fluoride ($CaF_2$) Minimum | 97.00 |
| Silica ($SiO_2$) Maximum | 1.10 |
| Sulfur (S) (as sulfide and/or free sulfur) Maximum | 0.03 |
| Iron oxide ($Fe_2O_3$) Maximum | 0.25 |
| Lead (Pb) Maximum | 0.20 |
| Zinc (Zn) Maximum | 0.20 |

b. Physical requirements

All acid-grade fluorspar shall be in the form of lump, filter cake, or dry fines. Dry fines shall have a moisture content of not more than 1.00 percent.

## Ceramic-grade fluorspar

Fluorspar suitable for use in the glass and enamel industries has no fixed specifications. It is generally a finely ground product and is intermediate in composition between the other two grades. Most ceramic-grade fluorspar contains 92-96 percent $CaF_2$ and less than 3 percent $SiO_2$, 2 percent $CaCO_3$, and 0.12 percent $Fe_2O_3$.

## Production

Since 1956, Mexico has been the world's largest producer and exporter of fluorspar. For this four-year period the annual production is considered to have averaged nearly 375,000 tons of metallurgical-grade and acid-grade fluorspar concentrates. The production of ceramic-grade fluorspar in Mexico has not been reported; however, some of the Mexican acid-grade concentrates have been used as ceramic-grade fluorspar in the United States.

In the four-year period 1956-1959 Mexico exported about 90 percent of its fluorspar production to the United States and about 6 percent to Canada; the remainder was consumed by Mexican industry or exported to Europe or Japan. Mexico supplied more than 60 percent of the fluorspar imported into the United States, averaging about 330,000 tons a year. About 35 percent of the Mexican fluorspar concentrates exported to the United States in this period contained more than 97 percent $CaF_2$ (McDougal and Foley, 1960a; McDougal and Roman, 1961). During 1960 this proportion of the higher-grade product dropped to about 25 percent, but it is expected to rise markedly as production from the two new flotation mills increases.

## Transportation

The transportation of fluorspar from mines to mills is difficult but is improving as better roads are being constructed. In parts of the Paila-San Marcos district, Coahuila, burros pack the ore down steep mountainsides. Trucks haul ore from most of the districts, however, over fair to poor gravel and dirt roads in rough terrain having a relief ranging from 150 to 600 meters. Railroads transport ore to the flotation mill of Reynolds Metals Co. on the border at Eagle Pass, Texas.

Travel over some of the mine roads is slow, unpredictable, and sometimes impossible. For example, the El Refugio deposit was reached from Rio Verde, San Luis Potosi, by driving about 70 kilometers over rough road that crossed streams and arroyos many times. This road was said to have been unsuitable for hauling ore during a 5-month rainy season. Trucks haul fluorspar from the Pico Etereo district of northern Coahuila across the Rio Grande, and fording is said to be impossible at times, especially during rainy periods in August, September, and October.

Most of the fluorspar concentrates are shipped by rail from the plants, and either cross the international border at points in Texas and Arizona or reach the United States after transfer to ocean freighters at Tampico. The freighters deliver the fluorspar to various ports along the Gulf of Mexico, Atlantic Coast, and Great Lakes via the St. Lawrence Seaway. Most of the concentrates arriving at Brownsville, Texas, opposite Matamoros, are shipped by barge, as far as Chicago and Pittsburgh. Trucks haul acid-grade concentrates from the new mill of the Dow Chemical Co. in northern Coahuila about 110 kilometers to the railroad at Marathon, Texas. Concentrates from the new flotation mill of the San Luis Mining Co. and Aluminium Limited of Canada in Sonora are shipped by rail through Douglas, Arizona.

## Costs and tariffs

The daily wages for miners range from a flat rate of 7 pesos (U. S. $0.56) to more than 30 pesos (U. S. $2.40) for contract work, as reported by various fluorspar producers. In many districts this cost covers labor for drilling, blasting, hand-picking, and back-packing ore to the surface; production per man-day ranges from less than 1 ton to more than 3 tons of fluorspar. Cost data on explosives and other supplies were not available. Truckers receive 15 pesos (U. S. $1.20) a day in one district, and in another district the cost of trucking more than 150 kilometers from mine to mill averaged $6 a ton of finished concentrates. Charges for removing moisture from filter cake from flotation plants are $4 to $8 per ton.

According to Gillson (1962a), the freight rate is about $3 a ton to the Brownsville-Matamoros area from Muzquiz or Nueva Rosita in Coahuila and also from San Luis Potosi and Rio Verde in the state of San Luis Potosi. From San Luis Potosi to Tampico the freight rate is about $1.50 a ton.

Prices for Mexican fluorspar at the international border were said to be \$25 a short ton for a metallurgical-grade product containing about 70 percent effective $CaF_2$ and \$30 to \$35 a ton for acid-grade wet filter cake. These prices include the Mexican export tax of \$1.20 - \$1.50 per ton for metallurgical-grade fluorspar and about \$2.00 per ton for acid-grade fluorspar.

The United States tariff rate on imported fluorspar containing not more than 97 percent $CaF_2$ is \$7.50 per short ton. On fluorspar containing more than 97 percent $CaF_2$ the rate is \$1.875 per short ton.

## Uses of fluorspar

The chief uses of metallurgical-grade fluorspar are as a flux in manufacturing steel; for the production of iron, magnesium, and aluminum castings; for making ferroalloys and nickel alloys; and for smelting secondary metals. About 4 pounds of fluorspar are used for each short ton of basic open-hearth steel produced in the United States (McDougal and Foley, 1960b).

Acid-grade fluorspar is used in making hydrofluoric acid, from which many fluorine chemicals are prepared and from which synthetic cryolite and aluminum fluoride are manufactured for the aluminum industry. About 2.4 tons of acid-grade fluorspar are consumed for each ton of HF produced. Each ton of aluminum manufactured from bauxite ores by methods using synthetic fluorides in the electrolytic process requires about 47 pounds of cryolite and 58 pounds of aluminum fluoride, having a combined equivalent of about 148 pounds of acid-grade fluorspar (Finger and others, 1960, p. 15). The use of fluorine chemicals is increasing rapidly, especially fluorocarbons for refrigerants, aerosol propellants, and plastics (Steuwe, 1958; Finger and others, 1960, p. 27-33; Williamson, 1961a; and Chemical and Engineering News, 1960b). Fluorine chemicals made from fluorspar are also used in etching glass; in the manufacture of high-octane fuels and fluorinated oils, greases, and waxes; in the production of uranium hexafluoride for the separation of uranium isotopes by thermal diffusion; and in certain kinds of fire extinguishers, insecticides, wood preservatives, antiseptics, tooth-decay preventatives, and water fluoridation processes.

Ceramic-grade fluorspar is consumed in the manufacture of certain types of glass, enamel, and tile; in making rock wool and welding-rod coatings; and in fluoridating water supplies.

## Outlook and conclusions

The use of fluorspar is increasing throughout the world as a basic raw material in the expanding steel, aluminum, and fluorine chemicals industries. The greatest increase in demand will be for acid-grade fluorspar for the aluminum and chemical industries.

The consumption of acid-grade fluorspar in Mexico is growing. In recent years small amounts of hydrofluoric acid have been made at Santa Clara a few kilometers northeast of Mexico City by Fluor-Mex, an affiliate of Stauffer Chemical Co. (Chemical and Engineering News, 1958 and 1959). This plant closed down, but Fluor-Mex is operating a new and much larger plant in San Luis Potosi for making hydrous and anhydrous hydrofluoric acid (R. M. Grogan, written communication, 1961). A plant to manufacture fluorocarbon products is being built on the Santa Clara site by Halocarburos, S. A., owned by Stauffer Chemical Co., E. I. du Pont de Nemours & Co., and Mexican investors (Chemical Week, 1960). In 1960, General Chemical Division, Allied Chemical Corp., provided technical information to Celulosa y Derivados for completing a plant in 1961 at Monterrey to make hydrofluoric acid and fluorinated hydrocarbons for Mexican needs and for marketing throughout Latin America (Chemical and Engineering News, 1960a).

The production of acid-grade fluorspar in Mexico is growing substantially because of the completion in 1960 of the two new flotation plants in Sonora and Coahuila (Nos. 1 and 2, Table 2), with a combined capacity of 225 tons per day. Cia. Minera Rio Colorado, an affiliate of General Chemical Division, Allied Chemical Corp., is completing a new flotation plant at Rio Verde, San Luis Potosi, with a capacity of 200 tons of ore per day (C. T. Pierson, written communication, 1961). Acid-grade fluorspar of Mexican origin is being shipped in increasing quantities to the United States Government under the U. S. Department of Agriculture's barter program; flotation plants of Fluoresqueda, S. A., in Sonora, Dow Chemical Co. in Coahuila, American Smelting and Refining Co. in Coahuila, and Reynolds Metals Co. in Eagle Pass, Texas, process this fluorspar.

Measured, indicated, and inferred reserves of fluorspar in the districts visited are adequate for many years of production. Continued exploration should result in the discovery of new deposits and significant extensions of known deposits. The production of metallurgical-grade fluorspar and hand-picked acid-grade fluorspar should decrease as the higher grade parts of many deposits are depleted and more lower grade ore is mined for the production of acid-grade fluorspar in flotation mills.

As a result of the increasing need for fluorspar, especially in United States, Canada, and Mexico, the Mexican fluorspar industry has expanded greatly and become very profitable within the last 8 years. The mining and milling methods at the larger deposits are becoming more efficient, and the industry is continuing to flourish, even though it is faced with greater depths of mining, decreasing grade of ore in many deposits, increasing costs of labor, supplies, and transportation, and greater competition for the east coast and Great Lakes markets of the United States from the Spanish and Italian fluorspar industries.

## Description of districts

### Chihuahua

#### Parral district

The main importance of the Parral district as a source of fluorspar is attributed to large tonnages of fluorspar that may be recovered from mill tailings resulting from the treatment of sulfide ores. In the zinc-lead-silver mines of the Parral district fluorite constitutes 10-20 percent of the vein material in most places (Lowther and Marlow, 1956, p. 86). Much of the fluorite is intimately intergrown with the sulfide minerals, but locally quartz-calcite-fluorite veins cut the sulfide ore. In the San Francisco del Oro and Santa Barbara districts, 18-25 kilometers southwest of Parral, the sulfide ores contain similar quantities of fluorite in the gangue (Koch, 1956, p. 115; Kierans, 1956, p. 102). In the northern part of the Santa Barbara district the amount of fluorite increases, and in places white to green fine-grained fluorite becomes the main component of the gangue (Scott, 1958, p. 1017).

Research in pilot plants is underway by several companies in the Parral district to attempt recovery of a fluorspar concentrate as a coproduct from the metal mines. If this work is successful, fluorspar flotation units may be added to the mills treating the sulfide ores. Acid-grade fluorspar may be recovered from the sulfide ores being mined and also from the large piles of mill tailings that contain 5-20 percent $CaF_2$. From data presented by A. A. Brown, Vice President, American Smelting and Refining Co., before the U. S. Tariff Commission in December 1959 and upon information given by several other mining companies, it is estimated that in the Parral district and adjacent San Francisco del Oro and Santa Barbara districts about 45 million tons of tailings represents a potential of about 5 million tons of acid-grade fluorspar concentrates.

The Parral district is in southern Chihuahua near the border between the Sierra Madre Occidental and the Central Plateau, in a region of low relief west and southwest of Parral. Two roads, two railroads, and the Parral River cross the district, which is very favorably located also with respect to the supply of labor. Ing. Marcial Vazquez, Dept. Geologico, Minas de Iguala, acted as guide to some of the fluorspar deposits.

In the Parral district Tertiary volcanic rocks consisting of basalt to rhyolite tuffs, breccias, and flows overlie gray and blue-black thin-bedded calcareous shales or argillites, probably of Cretaceous age (Schmitt, 1930; Lowther and Bell, 1956; and Lowther and Marlow, 1956). A stock of Tertiary quartz monzonite is intrusive into the shales, which are exposed on the flank of a broad dome and dip 30°-65° W. Normal faults, rhyolite dikes, and veins, all of which strike approximately north, cut the shales and younger rocks.

A fluorspar deposit without sulfides on the Perla claim was the source of most of the fluorspar produced from this district in 1944-45. This claim is about 2½ kilometers west of Parral and extends south from the Parral River, about 500 meters east of the active Esmeralda zinc-lead-silver mine. Near the contact of quartz monzonite and shales an epithermal vein of calcite, quartz, and fluorite is localized along a faulted rhyolite dike. The vein strikes approximately north and dips 65°-85° W. near the main opencut about 250 meters south of the railroad. The fluorite content is estimated to be less than 50 percent in the outcrop and to decrease in the workings below. The fluorite is white to yellowish brown where iron-stained, and is fine-grained and sugary; it is massive, nodular, and also lines cavities of boxwork quartz. Fluorite and calcite locally are interlayered with black manganese oxides.

The ore body averages about 4 meters in thickness in the opencut and continues downward at least 25 meters. The mineralized fault extends along strike for hundreds of meters north and south of the main cut, but the continuity of the fluorspar ore has not been demonstrated. According to Prado (1954, p. 75) four other claims are located along this vein north and south of the Perla claim. Between 1948 and 1952 Cia. Industrial de Fluorita and Cia. Metallurgica de Parral, affiliates of General Chemical Division, Allied Chemical Corp., acquired these claims.

In 1944-45 about 5,000 tons of fluorspar was mined from the Perla claim and about 2,000 tons from the Locomotora claim. The Locomotora claim is 2½ kilometers farther north along the vein where the fluorspar ore is about 2 meters thick, according to World War II records of Metals Reserve Co., Reconstruction Finance Corp. The fluorspar contained about 75 percent $CaF_2$ and 5 to 15 percent $SiO_2$. It went to El Paso, Texas, to the Alloy Metals Corp. flotation mill and to the Metals Reserve Co.'s metallurgical-grade stockpile.

## Encantada-Buenavista district

Major fluorspar production from the Encantada-Buenavista district started in 1951 with the discovery of many high-grade deposits, although fluorspar was mined from several deposits in the southern part of this district as early as 1943. The district is a very important source of fluorspar; from information provided by the mining companies it is estimated that nearly 1 million tons of ore from this district yielded about 500,000 tons of fluorspar concentrates in the last ten years. A publication describes the activities during the earlier years (Schulze, 1953). Sr. Francisco Cepeda of Fluorita de Mexico guided us to the nine mines visited in this area.

The Encantada-Buenavista district covers about 500 square kilometers in north-central Coahuila. Northwest-trending broad valleys and sharply dissected mountains and mesas of the Sierra Madre Oriental traverse this sparsely inhabited arid region, which is about 100 kilometers by gravel road northwest of Muzquiz. The deposits investigated on Buenavista Mesa are about 15 kilometers by road southeast of Encantada Mesa and about 150 meters higher.

The district is underlain by gently folded Cretaceous marine sedimentary rocks with fold axes trending northwest (King, 1947). Synclinal valleys and domal or anticlinal ridges are predominant; faults are not conspicuous. The host rocks are mainly the Georgetown Limestone of Early Cretaceous age and the overlying Del Rio Shale of Late Cretaceous age. The Del Rio Shale is overlain by the Buda Limestone or by the Eagle Ford Formation, both of Late Cretaceous age. The above stratigraphic sequence was reported (Imlay, 1944, Chart no. 100) for the area adjoining on the northeast between Serranias del Burro and the Rio Grande. Rhyolite plugs, dikes, and sills of Tertiary age cut the Cretaceous rocks and may be genetically related to the fluorspar deposits (McAnulty, 1956).

The Georgetown Limestone is a thick gray-black to chocolate-brown, medium- to thick-bedded, massive, cliff-forming reef limestone. Gray or yellowish-brown clay or thin-bedded mudstone of the Del Rio Shale fill irregular solution cavities and channels along the upper contact of the limestone. The Del Rio Shale is as much as 5 meters thick but locally is absent.

The fluorspar is found chiefly as nearly horizontal discontinuous manto or blanket deposits at or near the top of the Georgetown Limestone (fig. 2). It forms lenses and pockets in

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Figure 2. near here

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solution cavities in this limestone and replaces the limestone or the argillaceous rocks overlying the limestone; some deposits are as much as 15 meters below the top of the limestone. The mineralized zone is about 450 meters stratigraphically above the Cupido Formation that contains many lead-silver manto deposits southeast of the fluorspar area (Sanchez Mejorada, 1958). In the north part of the area low-grade siliceous fluorspar was deposited with skarn minerals at the contact of Georgetown Limestone with an intrusive rhyolitic or syenitic body (Gillson, 1960a, p. 370; Temple and Heinrich, 1960). In many places where the mineralized top of the resistant Georgetown Limestone is exposed on the upland surfaces of the mesas, residual fluorspar forms ore bodies in the soil and caliche, which locally is more than 6 meters thick.

Figure 2. Encantada-Buenavista district, Coahuila. Manto fluorspar deposit, showing nearly horizontal attitude and lenticular form. Photo by Ing. Samuel Estrada.

The thickness of the ore ranges from about ½ meter to 6 meters, possibly averaging 1½ meters, and the grade ranges from less than 60 percent to more than 90 percent $CaF_2$. The silica content, ranging from less than 1 to more than 15 percent, varies chiefly with the quantities of quartz intergrown with and coating the fluorite and with the extent of replacement of the argillaceous rocks by fluorite. Coarsely crystalline calcite is abundant in the ore, especially near the top of the ore bodies; locally more calcite than fluorite is present. Fine-grained calcite is interlayered in some of the ore, and scalenohedral crystals of calcite commonly coat fluorite crystals. Tiny crystals of selenite form a crust on specimens of fluorite collected from one of the ore bodies; sulfide minerals, barite, or strontianite were not observed. Schulze (1953, p. 10) noted the presence of yttro-fluorite and rare earth minerals in some of the ore.

The fluorite is generally brownish, gray-white, and purplish. The brownish fluorite and locally the adjacent limestone give off the odor of petroleum when freshly broken. The intensities of the brown color and odor seem to vary directly with the content of hydrocarbons which probably were derived from the associated sedimentary rocks. In Los Pinos deposit and several other deposits this brownish fluorite is especially common near the base of the ore zone. In El Camaron deposit coarse- to medium-grained brownish fluorite formed first and was followed by coarse gray-white fluorite and then veinlets and thin crusts of fine-grained cubic purplish fluorite.

Individual or bodies commonly contain only a few thousand tons of fluorspar and are not suited to modern, large-scale methods of mining. Many deposits are worked by short adits at the edge of the mesas and in canyon walls and by shallow pits dug in the soil. Mining is highly selective as only the richest, thickest, and most easily mined ore is extracted. In La Encantada deposit it is profitable to mine high-grade ore as little as ½ meter thick.

Fluorita de Mexico and affiliates of E. I. du Pont de Nemours & Co. and American Smelting and Refining Co. control most of the mines. The major part of the mining has been done by Fluorita de Mexico, which is controlled partly by a subsidiary of Continental Ore Co. (U. S. Bureau Mines Mineral Trade Notes, 1956). According to Prado (1954, p. 78) about 7,000 tons of fluorspar was being produced monthly; in 1956 about 600 miners were in camp at Encantada Mesa (Gillson, 1956). In May 1960, however, less than half this number of miners were said to be in the Encantada-Buenavista district producing about 6,000 tons of fluorspar a month.

Considerable hand-picking of the ore is done at the mine, both underground and at the portal. Hand-picking of the ore, without further processing, has yielded both acid-grade and metallurgical-grade fluorspar. At El Camarón mine 85 percent of the product was said to be of metallurgical grade, analyzing 78-80 percent effective $CaF_2$; the rest of the product was hand-picked material containing 95 percent $CaF_2$, which jigs made into acid-grade fluorspar at Muzquiz.

The mill of Fluorita de Mexico at Muzquiz processed most of the ore mined in the Encantada-Buenavista district. This Heavy Media and flotation plant began operation in 1953 (Denver Equipment Company, 1953), and increased in capacity in 1955 from 175 tons of feed per day to about 300 tons. The mill shut down in September 1959 when it was producing 200 tons of acid-grade concentrates a day (Adolfo E. Romo, oral communication, 1960), because much of the higher grade, readily accessible ore was mined, production and transportation costs were increasing, and fluorspar prices in the United States were decreasing. In 1960 most of the ore from this district was being processed in the flotation mill of American Smelting and Refining Co. at Agujita, Coahuila.

## El Tule district

El Tule district contains extensive manto deposits of fluorspar and by the end of 1958 had yielded probably in excess of 50,000 tons of crude fluorspar to flotation plants (Gillson, 1960a, p. 371). The district is in north-central Coahuila in the Sierra Madre Oriental, or in the Sierra Tamaulipecas (Humphrey, 1956, p. 25-26), about 67 kilometers north of Muzquiz. It covers an area of about 80 square kilometers and is accessible from Muzquiz by two routes. One route is about 100 kilometers long over gravel and dirt roads and necessitates a steep climb up the wall of El Tule canyon to the gently rolling mesa. Another route extends by paved road east from Muzquiz to the main highway north to Piedras Negras; thence north to Morelos and Zaragoza over paved roads; and west about 64 kilometers over a new dirt road to El Tule. This second route is about 192 kilometers long but is a much more gentle grade than the first.

Dr. Alan K. Temple, geologist of E. I. du Pont de Nemours & Co., showed us through the exploratory tunnel at the San Miguel fluorspar mine of this company. Several inactive mines of Fluorite de Mexico along the north and south edges of El Tule canyon also were visited. Mining methods that were used by Fluorita de Mexico are similar to those described above for the Encantada-Buenavista district to the west.

The fluorspar ore is found as discontinuous manto deposits generally near the top of the nearly horizontal Georgetown Limestone of Early Cretaceous age (Gillson, 1960a). This limestone is overlain by the Del Rio Shale, or directly by the Buda Limestone where the Del Rio Shale is absent. The manto deposits range in grade from less than 50 percent to more than 80 percent $CaF_2$ and in thickness from less than ½ meter to about 2 meters; the average thickness is perhaps only 60 centimeters (Gillson, 1960a). In several deposits coarsely crystalline celestite ($SrSO_4$) in layers as much as 2 meters thick overlies the fluorspar ore. Calcite, locally occurring as radial, concentric, and stalactitic growths, is found with barite and clay in the fluorspar ore.

Minera Rosala, the Mexican subsidiary of E. I. du Pont de Nemours & Co., has built an air separation pilot plant at the San Miguel mine for up-grading the crude ore before shipment. By this dry method fluorspar and celestite were partly concentrated, thus decreasing the tonnage to be hauled to a flotation plant where water is available.

## Paila-San Marcos district

Important fluorspar deposits in the Paila-San Marcos district are scattered through a mountainous region covering about 1,300 square kilometers centered around a point 125 kilometers northwest of Saltillo, southeastern Coahuila. Between 1953 and 1960 the six mines visited in this district yielded an estimated several hundred thousand tons of fluorspar. According to Humphrey (1956, p. 26, 31) the Sierra de la Paila is in the Meseta del Norte province, and the Sierra de San Marcos is in the Coahuila Ridge and Basin province. The deposits in these two ranges are accessible from the main highway between Saltillo and Piedras Negras by travelling over gravel and dirt roads extending west at junctions respectively about 6 kilometers north of Guadalupe and a few kilometers south of Santa Teresa.

The Aurora Limestone and the Cuchillo Formation contain the fluorspar veins and manto deposits. In this area the Aurora Limestone, which is the equivalent of the Georgetown Limestone and Fredericksburg Group of Texas (Imlay, 1944, p. 1028), is underlain by the Cuchillo Formation, consisting of limestone, dolomite, and gypsum, and is overlain by the Indidura Formation (equivalent to the Eagle Ford Formation), made up of shale and limestone (Imlay, 1938, figs. 5 and 6). The first two formations are of Early Cretaceous age, and the Indidura Formation is of Late Cretaceous age.

Canalones-Voladero deposit

According to the statement that Mr. A. A. Brown, Vice President, American Smelting and Refining Co., made before the U. S. Tariff Commission in December 1959 this company has in excess of 2,000,000 tons of fluorspar reserves in Mexico, including their important Canalones-Voladero deposit at the north edge of the Sierra de la Paila. This deposit of Cia. Minera Nacional, a Mexican subsidiary of American Smelting and Refining Co., is about 35 kilometers by gravel and dirt road west of the main highway between Saltillo and Piedras Negras. According to James A. Heinrichs, Mine Superintendent, the chief mine workings are along one of several parallel veins in the Aurora Limestone of Early Cretaceous age. The vein zone is more than 1 kilometer long and is exposed in the workings through a vertical range of about 150 meters. The main vein is lenticular along strike and in depth and is as much as 12 meters thick; lenses of ore 30-50 meters long are common.

The vein occupies a fault striking approximately N. 80° W. and dipping 80° S. to vertical. The limestone walls are slickensided, and polished grooves are nearly horizontal. Similarly oriented grooved and slickensided surfaces cut the ore. The ore commonly shows a foliation parallel to these faults and also parallel to a few steep cross faults and flat bedding-plane faults that displace the vein a few meters.

The main vein minerals are calcite and fluorite; locally they are intergrown and appear difficult to separate without fine grinding and flotation. The fluorite forms more than 55 percent of the vein; it is generally grayish-white and translucent, and locally is purplish. Small quantities of barite, celestite, and chalcedony were seen.

The mine operated between 1954 and 1958 and produced metallurgical-grade fluorspar, which was trucked about 100 kilometers north to Castaños and shipped by rail to Eagle Pass and Brownsville, Texas. Ore to be made into acid-grade fluorspar was hauled about 250 kilometers north of the mine to the company's flotation mill at Agujita, between Sabinas and Nueva Rosita. Mr. W. A. Conley, Superintendent, showed us through the mill, which treats about 200 tons of custom ore daily, mainly from small mines in the Encantada-Buenavista district.

## El Aguijón and "77" deposits

Fluorspar is produced from manto deposits and persistent veins in the Cañon Vacas area about 25 kilometers by gravel and dirt road southwest of the Canalones-Voladero mine described above. El Aguijon mine and the "77" mine are owned by Cia. Minera Julieta, a Mexican subsidiary of St. Lawrence Corp. of Newfoundland, Ltd. Mr. Walter E. Seibert, Jr., of this company showed us these deposits.

El Aguijón ore body is a small manto deposit about ½ meter thick and contains more than 85 percent $CaF_2$. The dark crystalline Cretaceous limestone, locally dolomitic, strikes N. 10° E. and dips 15° W. The fluorite is white and violet; when freshly broken it commonly has the odor of hydrogen sulfide.

The vein at the "77" mine, striking east-west and dipping vertically to 80° S., occupies a fault about 1 kilometer long in limestone of Cretaceous age. Slickensides and nearly horizontal grooves are along the walls; similarly oriented fault surfaces and grooves were seen within the ore. Some gash veins branching to the southeast in the hanging wall also yield ore. The vein minerals are mainly coarsely crystalline white fluorite and calcite. The fluorite content is about 75 percent, and the silica content is less than 5 percent. Ore, 1-15 meters thick, is exposed in stopes through a vertical range of 60 meters.

Trucks haul the fluorspar from El Aguijón mine and the "77" mine about 58 kilometers east to the main highway between Saltillo and Piedras Negras and then 40 kilometers south to Frausto, where Cia. Minera Julieta has a mill along the railroad 1 kilometer east of the highway. The ore is made into metallurgical-grade fluorspar by washing, screening, and sink-float processing.

## Nieves Tres deposit

Minera La Valenciana is working an extensive manto deposit as much as 2½ meters thick at the Nieves Tres mine, a few kilometers southeast of the mines of Cia. Minera Julieta described above. The deposit strikes N. 65° E. and dips 70° NW. at the outcrop. To the northwest the dip of the deposit and Cretaceous limestone decreases to about 15° NW. The ore consists of fluorite and calcite and contains about 75 percent $CaF_2$. The fluorite generally is coarsely crystalline dark brown, gray, and white; some is iron stained and yellowish. The brown variety gives off a strong odor of hydrogen sulfide when freshly broken. Ore from this deposit is hauled south about 70 kilometers along the west side of Sierra de la Paila to the railroad.

## Leon Dos, Esperanza, and Fortuna deposits

In the Sierra de San Marcos two major centers of fluorspar mining have yielded more than 70,000 tons of fluorspar since 1953 and contain substantial reserves. The Leon Dos, or San Marcos y Pinos, deposit of Reynolds Fluorspar, a Mexican affiliate of Reynolds Metals Co., is near the South end of the range. The second center, containing the Esperanza and Fortuna deposits of Cia. Minera Julieta, is about 25 kilometers to the northwest.

The Leon Dos deposit is about 32 kilometers by gravel and dirt road west of the main highway between Saltillo and Piedras Negras. Mr. Blas Narro and Mr. Fernando Riojas guided us through the mine. The fluorite-calcite vein occupies a fault in the nearly horizontal dolomitic Aurora Limestone of Early Cretaceous age; it strikes N. 65° E. and dips 80° NW. (figures 3 and 4). Some flat bedding-plane

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Figures 3 and 4 near here

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faults displace the vein as much as a meter.

The ore occurs in the vein as lenses and gently plunging shoots as much as 7 meters thick. It consists of massive white fluorite, calcite, and a little chalcedony and clay; sulfide minerals, barite, and celestite were not seen. It is estimated that the ore contains about 50 percent $CaF_2$.

Figure 3. Leon Dos deposit, Coahuila. Open stope on nearly vertical vein in Cretaceous limestone; view northeast.

Figure 4. Leon Dos deposit, Coahuila. Steeply dipping vein about 1 meter thick between grooved and slickensided walls of Cretaceous limestone; view northeast. Photo by Ing. Samuel Estrada.

The fluorspar is mined by shrinkage stoping through a vertical distance of about 70 meters and a strike length of about 300 meters. Hand-picking of some of the vein calcite and limestone increases the grade of the mined product to about 65 percent $CaF_2$. Trucks haul the ore east to the main highway and about 70 kilometers north to Castaños. From Castaños it is shipped by rail about 200 kilometers to the Reynolds Metals Co. mill at Eagle Pass, Texas. According to Mr. Ernest Ovitz, Mill Superintendent, who conducted us through this flotation plant, it has a daily capacity of 150 tons of mill feed and 100 tons of acid-grade fluorspar. About half of the mill feed comes from the Leon Dos mine, and the rest originates with other companies mining fluorspar in Mexico.

The Esperanza and Fortuna deposits of Cía. Minera Julieta are about 55 kilometers by dirt road west of Santa Teresa on the main highway between Saltillo and Piedras Negras. They are high in the Sierra de San Marcos and are reached from the end of the road by climbing about 300 meters above the canyon bottom.

The Esperanza deposit is a large vein in the nearly flat Cretaceous limestone, probably the Aurora limestone, which strikes N. 60° E. and is vertical. This fluorite-calcite vein is more than 1 kilometer long and is exposed in numerous trenches, adits, and a shaft about 30 meters deep. It is about 4 meters thick in a stope west of the shaft. Most of the fluorite is white; some brown fluorite gives off the odor of hydrogen sulfide when freshly broken. The ore contains 75-80 percent $CaF_2$, which is raised in grade to more than 85 percent by selective mining and hand-picking (W. E. Seibert, Jr., oral communication, 1960). Burros pack the ore down the side of the canyon, and trucks haul it to the company's mill at Frausto, where it is blended with lower grade material or shipped without further processing as metallurgical-grade fluorspar.

The Fortuna vein appears to be of lower grade and narrower where exposed in a trench a short distance east of the Esperanza shaft. This fluorite-calcite vein is several kilometers long but has not yet been mined or explored at depth.

## Pico Etereo district

The Pico Etereo district contains several large fluorspar deposits, including the beryllium-bearing Aguachile deposit, and covers more than 100 square kilometers in northwestern Coahuila east of Big Bend National Park, Texas. More than 250,000 tons of fluorspar, nearly all of metallurgical grade, was shipped from this district to the railroad at Marathon, Texas, from 1953 through the first half of 1960. The district is in an arid area between Sierra del Carmen on the west and Serranias del Burro on the east. The deposits are accessible from Marathon, Texas, by driving about 120 kilometers south to Heath Crossing on the Rio Grande and continuing another 42 kilometers southeast to the mines. Four deposits were visited with Mr. Frank Daugherty, geologist with La Dominicia, S. A. de C. V., a subsidiary of Dow Chemical Co. This company owns three of these deposits (Cuatro Palmas, La Facil, and Aguachile), and the other, the Mal Abrigo deposit, was said to belong to Mr. Bishop Bailey of El Paso and Marfa, Texas.

The main fluorspar ore bodies are in gently folded Georgetown Limestone of Early Cretaceous age next to rhyolite porphyry intrusives of Tertiary age. Some smaller bodies are in the rhyolite porphyry or in the adjacent Buda Limestone and limestone of the Boquillas Flags, both of Late Cretaceous age. The fluorspar is found chiefly in tabular bodies, veins, and an inverted cone-shaped body; it replaces brecciated limestone and fills spaces between the walls and breccia fragments.

## Cuatro Palmas deposit

The large Cuatro Palmas deposit is about 42 kilometers by gravel and dirt road southeast of the flotation mill at Heath Crossing, which is approximately 20 kilometers northeast of Boquillas. The deposit is about 8 kilometers south of Pico Etereo, a conspicuous mountain of intrusive rhyolite porphyry for which the district is named. The fluorspar is found at the contact of the upper part of the Georgetown Limestone with a rhyolite porphyry dike. The deposit is cone-shaped, tapering downward, and is about 90 meters in diameter in the outcrop. The ore body contains blocks and smaller fragments of unreplaced limestone and chert and a few stringers of rhyolite porphyry. Locally the fluorspar has preserved the nearly horizontal bedding of the replaced Georgetown Limestone (fig. 5).

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Figure 5. Near here

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The ore contains about 70 percent $CaF_2$; the chief gangue mineral is calcite. The fluorite is generally purplish gray and fine grained. Botryoidal structures and fine interlayering of fluorite with calcite were observed. Some of the calcite crystals are rhombohedral, and some calcite is intergrown with fluorite in tubular structures.

Figure 5. Cuatro Palmas deposit, Coahuila. Opencut in fluorspar replacing Georgetown Limestone of Cretaceous age; view northwest.

The ore is mined in benches about 4 meters high in an opencut, where the miners pick out much of the unreplaced limestone, chert, and rhyolite porphyry. The resulting metallurgical-grade product in the past has been trucked mainly to the railroad at Marathon, Texas; however, the ore is now hauled to the new flotation plant at Heath Crossing. This mill of the Dow Chemical Co., situated on the Mexican side of the Rio Grande (fig. 6), has a daily capacity of 100 tons of acid-grade fluorspar.

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Figure 6. Near here

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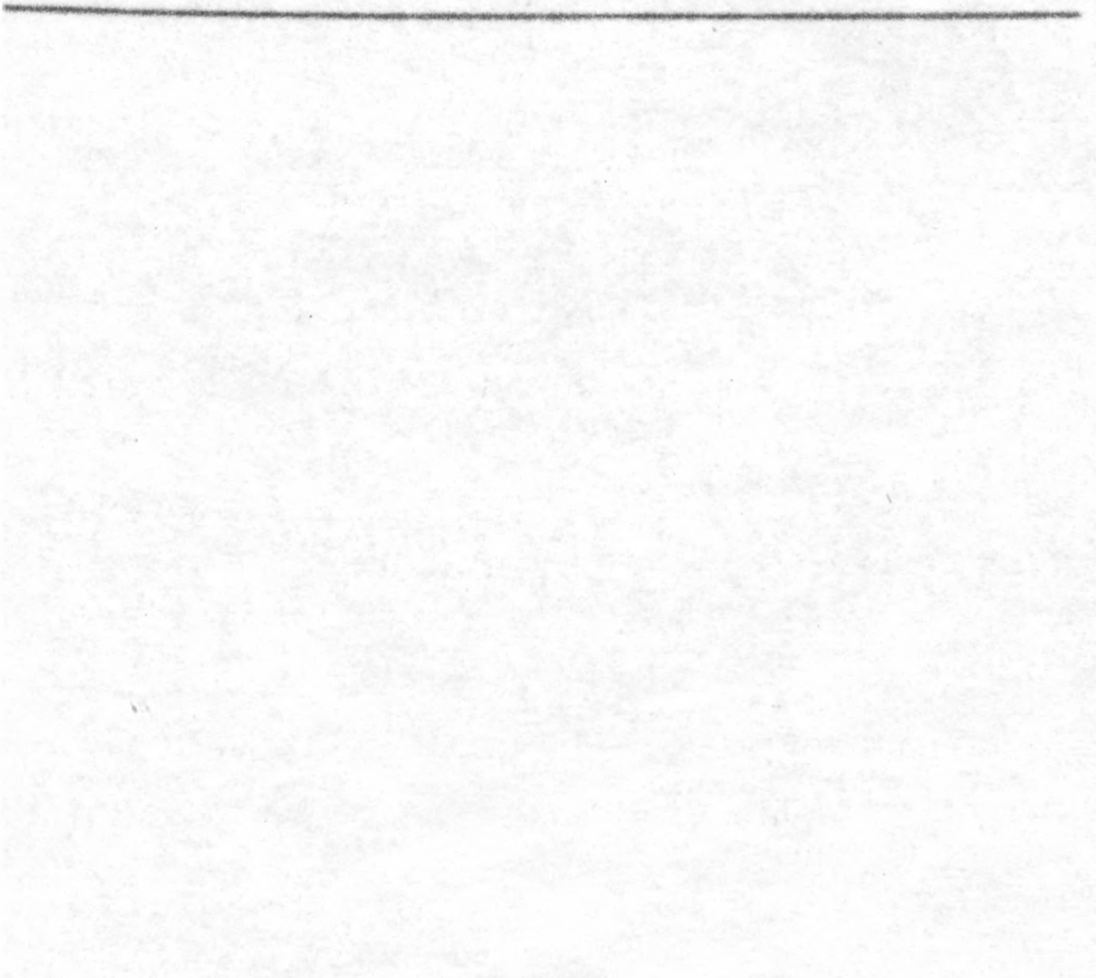
## La Facil deposit

La Facil deposit, about 1 kilometer east of the Cuatro Palmas deposit, is a relatively small but high-grade tabular body along the faulted contact of the gently dipping Georgetown Limestone with a rhyolite porphyry dike. The ore body strikes about N. 35° E. and dips approximately 75° SE. It is about 60 meters long in an opencut and as much as 15 meters thick. The ore is estimated to contain about 85 percent $CaF_2$ and 15 percent combined $SiO_2$ and $CaCO_3$. The fluorite is mainly a dark purple fine-grained variety; a few cubes and botryoidal and mammillary structures were observed. Some coarse greenish, yellowish, and pinkish fluorite has a fibrous radial structure. Veinlets of the coarse fibrous yellowish fluorite cut a sill branching from the main dike of rhyolite porphyry.

Figure 6. Fording Rio Grande (Bravo) at flotation mill of Cia. La Domincia. Photo by Ing. Samuel Estrada.



## Aguachile deposit

The Aguachile deposit, which was discovered in 1955 and has not yet been mined extensively, is a bertrandite-bearing fluorspar deposit of major size (Rowe, 1961, p. 56). It is about 3 kilometers southeast of the Cuatro Palmas deposit described above, in Cerro Aguachile, which is an elliptical dome elongated northwest and composed of Cretaceous sedimentary rocks cut by rhyolite porphyry and quartz-riebeckite microsyenite (McAnulty, 1962, and Levinson, 1962). The Cretaceous sedimentary rocks exposed around the flank of the dome are, from oldest to youngest, Edwards Limestone, Kiamichi Formation, Georgetown Limestone, Del Rio Shale, Buda Limestone, and the Boquillas Flags. The roof of the dome was faulted down at least several hundred meters, forming a central basin about 2 kilometers in diameter. Along the fault and on the inward facing slope of the basin a vertical ring dike of rhyolite porphyry 5 to 100 meters thick was intruded. A conspicuous plug of quartz-riebeckite microsyenite cuts the central part of the basin.

The main fluorspar deposits at Cerro Aguachile crop out intermittently for several kilometers along the lower or basinward side of the ring dike of rhyolite porphyry (fig. 7). The epithermal

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Figure 7. Near here.

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fluorspar replaces brecciated Georgetown Limestone, which dips northward 50° to 70° on the north side of the basin, and fills fractures in it. Other deposits are in brecciated Buda Limestone and Boquillas Flags next to the dike and replace limestone xenoliths in the dike. The ore bodies are vertical, tabular, and locally more than 50 meters thick; the average thickness is about 15 meters. The ore is estimated to contain 60-85 percent $CaF_2$, 10-20 percent $CaCO_3$, 5-10 percent $SiO_2$, and less than 10 percent iron oxides. The BeO content is about 0.3 percent (Levinson, 1962, p. 67).

Figure 7. Aguachile deposit, Coahuila. Most of the fluorspar workings extend intermittently along the lower contact of a rhyolite porphyry dike cutting Cretaceous sedimentary rocks. Photo by Ing. Samuel Estrada.

The fluorite is mainly reddish gray, but later generations are colorless, white, gray, dark purple, or faintly purple, blue, green, or yellow. Examination with a binocular microscope shows that the fluorite crystals in vugs are cubes; cubes modified by octahedrons and dodecahedrons; octahedrons combined with dodecahedrons; and trapezohedrons. The fluorite generally is very fine grained and locally finely layered; elsewhere it is coarser and friable or fibrous. Some of the replacement ore is sugary and shows relict breccia structure, relict bedding, and unreplaced chert nodules. Cracks and vugs in the fluorite contain chiefly quartz, hematite, limonite, clay, scalenohedral calcite, and bertrandite, $Be_4(OH)_2Si_2O_7$; in places these minerals cement brecciated fluorite. Some of the bertrandite forms a coating on euhedral crystals of colorless fluorite and gray fluorite with areas that are faintly purple, blue, or green; these fluorite crystals are as much as 8 mm across. According to Bowe (1961, p. 56) and Levinson (1962) the bertrandite is an extremely fine grained, gray to flesh-colored to yellowish white mineral resembling clay in appearance but harder, and it occurs as a matrix for fluorite grains, as veinlets and radial aggregates, and as linings or fillings of tiny vugs. Other minerals associated with the bertrandite are adularia, kaolinite, aragonite, and a lithium-bearing sericite (Levinson, 1962).

Some open pit mining has been done along the north side of the basin at Cerro Aguachile. The miners picked limestone, chert, and rhyolite porphyry from the ore; about half of the product was metallurgical-grade fluorspar, and about half was acid-grade fluorspar.

## Mal Abrigo desposit

The Mal Abrigo deposit, which is a persistent vein that has yielded an estimated minimum of 50,000 tons of fluorspar, is about 18 kilometers by gravel and dirt road northeast of Cuatro Palmas and La Facil deposits described above. The vein is along the faulted contact of a rhyolite prophyry intrusive on the north with Georgetown Limestone of Early Cretaceous age on the south. The limestone dips about 15° S. The ore is generally gray, fine grained, layered, and vuggy; cubes of fluorite commonly line cavities. Some of the ore is coarser and botryoidal. Very coarse rhombs of greenish calcite are especially abundant near the east end of the workings.

The Mal Abrigo deposit is being mined for about 300 meters along the vein in stopes accessible from adits and winzes; the ore in the opencuts has been largely removed. Some stopes are more than 10 meters wide and 15 meters high. Selective mining and sorting yield a product of metallurgical grade.

## Villa Union district

The Villa Union district, which has produced high quality fluorspar and is currently being explored, is in an area of low relief east of Durango near the east margin of Sierra Madre Occidental. It is accessible by driving to the village of Villa Union, which is 35.5 kilometers over paved roads northeast of Nombre de Dios on the main highway between Durango and Fresnillo; thence about 10 kilometers north over dirt roads to the Niagara fluorspar mine owned by Impulsora Minera. Mr. Eric Brit, geologist for Impulsora Minera, a subsidiary of Mexus Minerals, Inc., of Houston, Texas, helped with the investigation of the deposit, which was said to be typical of several nearby deposits not yet developed.

Basalt of Pliocene or younger age (Sanchez Mejorada, 1960) crops out at the Niagara mine, and an underlying, fine-layered silicified grayish-white volcanic tuff is the wallrock of the fluorspar vein. Examination of a thin section of this rock shows fragmental and vesicular structures and a fine-grained clay mineral, quartz, fluorite, chlorite, and pyrite. Layering in the tuff is almost vertical at the shaft, which was sunk on an eastward-trending mineralized fault zone. At the surface the fluorspar forms small veins and fills irregular cavities in a brecciated zone more than 20 meters long. In a short drift at a depth of 19 meters the fluorspar appears to be concentrated into a nearly vertical ore body about 2 meters thick and containing approximately 50 percent $CaF_2$. Continued exploration should result in a better understanding and evaluation of this deposit.

The fluorite is mainly green and violet; octahedral crystals are common. Quartz is the most abundant gangue mineral and locally forms layers of crystals on the fluorite. Coating some of the quartz and fluorite crystals are small crystals of cinnabar, pyrite, and gypsum. The presence of mercury in a specimen containing films of a soft red mineral was established by Joseph J. Fahey, U. S. Geological Survey, by a mercury fluorescence technique. The pyrite was identified by X-ray by Mary E. Mrose, U. S. Geological Survey. Sulfur was deposited last and is found as tiny crystals on most of the other minerals.

The Niagara mine has been worked sporadically since 1942, and a trench, now inaccessible, yielded an estimated minimum of 10,000 tons of fluorspar, which was shipped to the United States. The fluorspar was chiefly metallurgical-grade, but an acid-grade product also resulted, as much of the fluorite is coarse grained and separates cleanly from the wallrock and gangue minerals when miners break the ore with hammers. Hand-picking, washing, and rough hand-jigging at the mine give a high-quality metallurgical-grade product containing more than 90 percent $CaF_2$. Trucks haul the fluorspar to the railroad at Poanas, about 23 kilometers south of the mine, from where it is shipped to Tampico for transportation by water.

## Guerrero

### Taxco district

The Taxco district contains reserves of several hundred thousand tons of fluorspar; between 1939 and 1948 this district yielded more than 100,000 tons of fluorspar, chiefly from the two mines visited, La Azul and El Gavilán (González Reyna, 1956, p. 399). The fluorspar district is in a mountainous area along the boundary between the Balsas-Mexcala Basin of the Sierra Madre del Sur on the south and the Neovolcanic Plateau on the north (Raisz, 1959). It is about 10 kilometers by road northeast of Taxco, north-central Guerrero, and extends north from Kilometer 151 on the paved road between Puente de Ixtla and Taxco.

The fluorspar deposits are found near the contact of the Morelos Formation of Early Cretaceous age with the overlying Balsas Clastic Group of Eocene and Oligocene age and the Tilzapotla Rhyolitic Series of Oligocene or younger age (Fries, 1956a, p. 34; 1956b, p. 48). The Morelos Formation consists chiefly of limestones and dolomites. The Balsas Clastic Group is composed of red conglomerate, mainly with fragments of limestone and shale, interstratified with sandstones and siltstones (Edwards, 1955, p. 173-177). The Tilzapotla Rhyolitic Series is made up of lavas, tuffs, and breccias. Several systems of vertical faults cut these rocks at the mines, and an anticline and several series of sink holes are found nearby in the limestone (Foshag, and others, 1946, num. 7, p. 6). Zones of faults, zones of sinkholes, and the contact between the Tertiary volcanic rocks and Cretaceous rocks trend north; the fluorspar deposits are in breccias along this trend extending north more than 6 kilometers from La Azul deposit (Fries, 1956a, p. 34).

La Azul deposit

La Azul deposit is a large deposit of fluorspar owned by Cia. Restauradora de Minas, a Spanish company. It is less than 1 kilometer by road east of Kilometer 151 on the paved road between Puente de Ixtla and Taxco, and it crops out as an oval-shaped ore body about 200 meters long, 150 meters wide, and 30 meters deep (Fernández, 1956, fig. 8). The deposit is bounded on the south by Cretaceous limestone, on the west by Tertiary red conglomerate, and on the north and east by alluvium (Edwards, 1955, pl. 47). Tertiary rhyolitic volcanic rocks overlie the red conglomerate to the west. The ore body contains unreplaced fragments and larger blocks of volcanic rocks and limestone. Locally the contacts of the ore body are faulted, and two sets of faults striking northeast and northwest divide the deposit into numerous blocks (Foshag and others, 1946, núm. 8, p. 4). The mineralized breccia at La Azul deposit has been attributed to replacement of Cretaceous limestone and Tertiary rhyolitic volcanic rocks where they are faulted down against the limestone (Foshag and others, 1946, núm. 7, p. 7; núm. 8, p. 4); to replacement of fragments of limestone and other rocks in a volcanic chimney (Osburne, 1956, p. 88-89); and to replacement of limestone fragments in Tertiary volcanic ash in a buried sinkhole in Cretaceous limestone (Gillson, 1960b). According to Fries (1956a, p. 34), solution of the Cretaceous limestone and collapse of the overlying clastic and pyroclastic rocks into the sinkhole occurred later than the mineralization.

Massive and nodular types of ore were mined from La Azul deposit. The massive ore is fine grained to microcrystalline, locally is faintly layered, and generally contains about 90 percent $CaF_2$; little of this type of ore was seen in the workings. The nodular ore consists of rounded masses of fluorspar irregularly distributed in a clayey matrix; the grade of the nodular material appears to range from less than 50 percent $CaF_2$ to about 90 percent $CaF_2$. The fluorite is purple, pink, gray, white, and colorless. Cubes with edges truncated by dodecahedra, with edges bevelled by tetrahexahedra, and with corners modified by hexoctahedra line vugs in the ore; specimens of fluorite hexoctahedra also were observed. The main gangue minerals are quartz and calcite, which are interlayered and intergrown with fluorite and also occur in vugs. Chalcedony, barite, clay, hematite, and limonite are locally present, and gearksutite, $CaF_2 \cdot Al(F,OH)_3 \cdot H_2O$, occurs with fluorite as greenish and white compact masses, earthy nodules, and grains (Foshag and others, 1946, núm. 7, p. 7).

La Azul deposit, which has not been mined since 1948, was developed mainly by an opencut on the hillside. Ore was mined in three terrace levels, each one as much as 10 meters high, and was also extracted from several short trenches, adits, and a shaft. The shaft, now inaccessible, reportedly was sunk in ore to a depth of about 45 meters; extending from the shaft are two levels totaling about 120 meters in length, at depths of 16 and 36 meters (Fernández, 1956, p. 92).

In a mill that formerly adjoined the mine, the ore was crushed, washed, and screened. Trucks hauled the concentrates, chiefly metallurgical grade, about 36 kilometers to the railroad at Puente de Ixtla. Estimates of production from this deposit range from a total of 70,000 tons (Fernández, 1956, p. 91) to 93,711 tons by 1946 (Gonzalez Reyna, 1956, p. 399); additional production in 1947 and 1948 increases the second estimate of the total production to approximately 100,000 tons.

Between 1939 and 1942 a Japanese company mined and shipped fluorspar from La Azul deposit; about 55,000 tons went to Japan before the Mexican Government acquired the property and made it part of Reservas Mineras Federales (Foshag and others, 1946, núm, 8, p. 4, 6). In 1943 Cia Nacional Minera de Taxco leased the property. Shipments during the next 5 years went mainly to Laredo, Texas, for the U. S. Government stockpile and for the metallurgical-grade fluorspar market in the United States.

Fluorspar reserves remaining at La Azul mine have been estimated at more than 200,000 tons (Fernández, 1956, p. 91). An earlier estimate of about 1 million tons (Foshag and others 1946, núm, 8, p. 3-4) was divided into 500,000 tons of ore containing 85 percent $CaF_2$ and 500,000 tons of lower grade siliceous ore that might be treated by flotation to make an acid-grade product. The greater estimate was made in 1942, and much of the higher grade ore has been mined since then. A new estimate of reserves could be made after extensive sampling of exposures in the workings and additional exploration of the deposit at depth, possibly by drilling.

## El Gavilán deposit

Cía. Minas del Norte, a subsidiary of Cía. Fundidora La Consolidada, which is an American-owned steel company in Mexico City, mined the small but high-grade El Gavilán deposit sporadically for about 10 years during and after World War II. The deposit is about 4 kilometers north of La Azul deposit described above, and about 1 kilometer by dirt road west of Kilometer 147 on the paved road between Puente de Ixtla and Taxco.

As shown on the geologic map by Fries (1956a, fig. 5; 1956b, pl. 4), El Gavilán deposit is along the contact of the Morelos Limestone of Early Cretaceous age with the Tilzapotla Rhyolitic Series of Oligocene age or younger. The fluorspar deposit is localized near this contact in a fault block of altered rhyolite on the northeast edge of a sinkhole in the limestone (Foshag and others, 1946, núm. 7, p. 7-8). The fluorspar is concentrated chiefly along a steep north-trending zone about 100 meters long and 5 meters thick.

The flourspar ore resembles the nodular ore at La Azul deposit except that it contains fewer fragments of unreplaced limestone. The fluorspar nodules range in diameter from several centimeters to more than 3 meters; some contain as much as 98 percent $CaF_2$. The matrix of the rhyolite next to the nodules is partly replaced by grains of fluorite, but the quartz and feldspar phenocrysts are unreplaced (Foshag and others, 1946, núm. 7, p. 8). The fluorite is fine grained and is gray, black, brown, or red. The main impurities are clay, calcite, quartz, and unreplaced rhyolite. Much of the clay, containing quartz and well-formed crystals of biotite, was formed by the alteration of rhyolite.

Mining was done chiefly in benches in an opencut. The nodular ore was mined by hand, broken with hammers, sorted by hand, screened, and trucked to the railroad at Puente de Ixtla (Foshag and others, 1946, núm. 7, p. 8). The product was mainly of metallurgical grade and went to steel plants in Mexico City and Piedras Negras and to the U. S. Government stockpile. Production to the beginning of 1946 amounted to 7,900 tons containing 84-94 percent $CaF_2$ and 1-4 percent $SiO_2$ (González Reyna, 1956, p. 399). Reserves were not estimated in 1960 because the workings are badly slumped and little evidence of the fluorspar mineralization can be seen; the approximate reserves at this deposit previously were estimated at 7,600 tons (Prado, 1954, p. 83).

## Zacualpan district

The Zacualpan fluorspar district, which contains sizable deposits and has been the source of more than 100,000 tons of acid-grade fluorspar since 1938, is about 30 kilometers northwest of Taxco and in the Balsas-Mexcala Basin of the Sierra Madre del Sur (Raisz, 1959) in the extreme southern part of the State of Mexico. It is about 10 kilometers west of the village of Zacualpan, which is accessible from the railroad at Puente de Ixtla over about 100 kilometers of paved and gravel road via Nueva Ixtapan. Mr. Ernest Ground and Mr. Fernando Gutierrez of Cía. Mexicana de Minas y Beneficios helped with the visits to the flotation plant and to the General Escobedo and El Perpetuo Socorro mines of the company.

The Zacualpan district was active mainly during two periods. In the earlier period, 1938 to 1944, acid-grade fluorspar concentrates resulted from hand-picking, washing, and jigging; a small part of the product was of metallurgical grade. The current period of production started in 1951, when the first acid-grade fluorspar flotation plant in Mexico began operating at Zacualpan, about 25 kilometers by road from the mines. Trucks haul acid-grade concentrates from the mill to the railroad at Puente de Ixtla. Most of the fluorspar reaches the United States and Canada, but some early shipments from this district went to Japan.

The two fluorspar mines are along a steep fault zone in sericite schist and sedimentary rocks, both probably of Mesozoic age, which are cut by a variety of igneous rocks, probably of Cenozoic age (Prado, 1954, p. 83-84). The rocks of this area are shown mainly as of Early Cretaceous age on the recent geologic map of Mexico (Sanchez Mejorada, 1960). A specimen of the greenish-gray wallrock of the veins proved to be an impure quartzite that breaks across the quartz grains. In thin section, the rock shows interlocking grains of recrystallized quartz with smaller quantities of sericite, chlorite, biotite, pyrite, and tiny patches of fine-grained calcite.

## General Escobedo deposit

At the General Escobedo mine, which has supplied most of the fluorspar produced in the Zacualpan district, several nearly parallel lenticular veins occupy a northeast-trending fault zone exposed in the northeast side of an arroyo. On some levels the company is mining fluorspar from three veins 10 or more meters apart. The mineralized fault zone contains ore bodies intermittently through a strike length of more than 300 meters and a vertical range of more than 200 meters. Ore bodies locally are more than 60 meters long and as much as 9 meters thick. Some contain about 60-65 percent $CaF_2$, 12-15 percent $SiO_2$, 3-6 percent $BaSO_4$, and 2-3 percent $CaCO_3$ (Prado, 1954, p. 84); the balance is made up chiefly of iron oxides and the constituents of breccia fragments and clay.

Much of the ore consists of coarsely crystalline green fluorite; some of the fluorite is violet, white, or colorless. Well-formed fluorite crystals in vugs commonly are cubes, some with the corners modified by trapezohedrons. Barite crystals, several centimeters long, and crystals of quartz, calcite, and pyrite accompany fluorite in vugs. Pyrite forms veinlets in fluorite and occurs as tiny cubes within fluorite cubes, arranged parallel to some of the faces of the fluorite crystals. Very small quantities of sphalerite are locally present in the ore; one selected specimen shows sphalerite associated with pyrite, chalcopyrite, galena, and quartz. A soft green mineral common in the ore was identified by X-ray by Mary E. Mrose, U. S. Geological Survey, as palygorskite (attapulgite), $(Mg,Al)_5(Si,Al)_8O_{20}(OH)_2 \cdot 8H_2O$. In a deposit in Nevada, fluorite locally is interlayered with thin sheets of a fibrous mineral, which is probably a member of the palygorskite group according to G. T. Faust, U. S. Geological Survey (Thurston, 1946, p. 3).

Workings at the General Escobedo mine extend through a vertical range of more than 200 meters. Adits were driven to the northeast on eight levels, and ore bodies were stoped on these levels. The upper part of the mine is largely worked out, and mining is now being directed toward the lower part.

El Perpetuo Socorro deposit

At El Perpetuo Socorro deposit ore bodies extend along a steep fault at least through a vertical range of 100 meters and a horizontal distance of 200 meters. The mine is across an arroyo from the General Escobedo mine and is localized along the southwest extension of the mineralized fault zone described above. The ore is similar in composition to that at the General Escobedo mine, except that barite and silica appear to be more abundant. Several lenticular veins were followed in an opencut and adits. Much of the ore in the upper workings has been mined, and current production is coming from stopes above an adit about 10 meters above the arroyo level.

San Luis Potosi - Guanajuato

Rio Verde district

The Rio Verde district contains several large deposits of fluorspar and yielded more than 100,000 tons of metallurgical-grade fluorspar from 1956 to 1960, chiefly from El Refugio and El Zapote mines. The fluorspar district is in the Sierra Madre Oriental and extends approximately 25-45 kilometers south-southwest of Rio Verde, San Luis Potosi. El Refugio deposit is in Guanajuato about 10 kilometers by road south of the border between that State and San Luis Potosi; the other three deposits to be described are in San Luis Potosi. The deposits are accessible from Rio Verde over gravel and dirt roads. The drive to El Refugio deposit covered 68 kilometers and took nearly 3½ hours. The route crosses and follows stream beds, and travel is unpredictable and often impossible during the usual 5-month rainy season. The field examinations were made with the help of Mr. Roque Gañez at El Refugio mine, Mr. Arnoldo Gonsalez at El Zapote mine, and Mr. Rolf Rossbach and Mr. Fred Garcia at La Ilusion and La Rosita mines.

As shown on a recent geologic map (Sanchez Mejorada, 1960) Tertiary volcanic rocks overlie Lower Cretaceous rocks in the Rio Verde district. Near the fluorspar deposits pink to gray rhyolitic flows and tuffs are distributed irregularly over an erosion surface developed upon cherty gray limestone of Early Cretaceous age, probably the Georgetown Limestone. The ore at the four deposits visited is in steeply dipping, elliptical pipelike bodies that trend N. 20°-45° W. in the gently folded limestone. Fluorspar replaces limestone and fills voids in brecciated limestone beneath and next to the volcanic rocks. It also forms small seams and pockets in the adjacent volcanic rocks.

El Refugio deposit

El Refugio deposit is a large fluorspar ore body about 45 kilometers south-southwest of Rio Verde, near the village of Alamos de Martinez and about 65 meters southeast of the Santa Maria River. This elliptical pipelike ore body is elongated about N. 20° W., approximately parallel to the strike of the adjacent limestone. It plunges steeply northeast, whereas the limestone dips 20°-50° NE. The ore body is 30 meters or more thick and widens in depth. The fluorite is gray, yellow, pink, and purple and locally is interlayered with coarse calcite and fine silica, hematite, and limonite. Small fluorite cubes, scalenohedral calcite, and clay partly fill vugs in some of the ore.

Minera Helios mined El Refugio deposit from an opencut (fig. 8)

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Figure 8. Near here.

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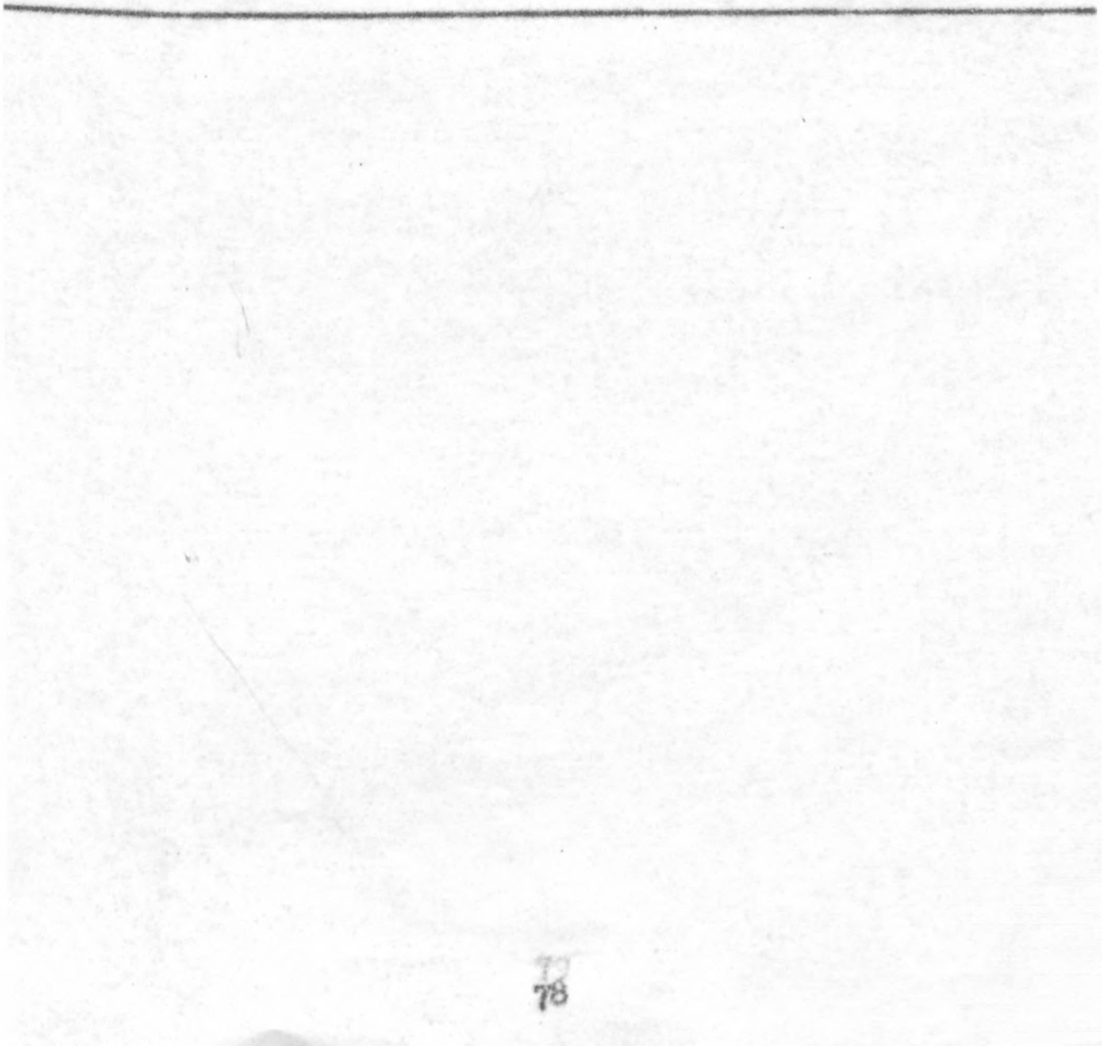
for several years. In 1958 the approximate annual production rate was 55,000 tons assaying 85 percent $CaF_2$, 4 percent $SiO_2$, 5-10 percent $CaCO_3$, some $Al_2O_3$, and some iron (U.S. Bureau Mines Mineral Trade Notes, 1958). Trucks hauled the ore to Rio Verde, where it was hand-sorted mainly into metallurgical-grade products. The fluorspar was shipped by rail to Brownsville, Texas, and Tampico for water transportation by barge and ocean steamer, respectively, to markets chiefly in the United States. In 1959 Mineral Rio Colorado, an affiliate of General Chemical Division, Allied Chemical Corp., acquired the deposit and was exploring and developing it in 1960. In 1961 this company was building a new flotation plant at Rio Verde, with a capacity of 200 tons of ore per day (C. T. Pierson, written communication, 1961).

La Rosita deposit

Fluorita de Rio Verde, an affiliate of Continental Ore Co., is working La Rosita fluorspar deposit. The mine is about 38 kilometers south-southwest of Rio Verde, approximately half a kilometer east of Rio Bagres. The route from Rio Verde is about 52 kilometers long.

Figure 8. El Refugio deposit, Guanajuato. Opencut in fluorspar ore replacing limestone of Cretaceous age; view east.



The deposit is an elliptical pipelike body elongated N. 30° W. and dipping steeply east in gently folded Cretaceous limestone; rhyolitic volcanic rocks of Tertiary age crop out about 300 meters north of the mine and across an arroyo. The ore body widens with depth to as much as 15 meters at a depth of 30 meters, and is estimated to contain about 60 percent $CaF_2$. The fluorite is purple, gray, and locally very friable; it is intergrown with abundant calcite. Very little silica and no sulfide minerals were seen in the ore, which contains unreplaced fragments of brecciated limestone. Trucks haul about 25 tons of ore a day to the railroad at Rio Verde.

## El Zapote deposit

El Zapote deposit, owned by Minera La Valenciana, is an important source of fluorspar about 25 kilometers south of Rio Verde. It is accessible from Rio Verde by driving about 32 kilometers along dirt roads in the mountainous terrain. The deposit is an elliptical pipelike body in Cretaceous limestone, overlain to the southwest by Tertiary rhyolitic volcanic rocks. The ore body is elongated about N. 45° W. It is vertical near the surface, and on the 77-meter level the walls locally dip outward 60° and the ore body is approximately 60 meters thick. Adjoining this ore body on the south is a second ore body, possibly a filled sinkhole in the limestone adjacent to the volcanic rocks, from which about 80,000 tons of metallurgical-grade fluorspar was extracted, mainly in 1955-56.

The ore consists chiefly of fluorite and calcite. The fluorite is generally pinkish gray, very fine grained, and fine layered. Calcite is intergrown with fluorite and is found also as scalenohedral crystals lining vugs in the ore; it is estimated to form more than 25 percent of the ore exposed in some of the working faces. Copper carbonates stain some of the fluorspar in the lower workings. The ore locally contains seams of slickensided red clay gouge.

El Zapote deposit is being mined below a 77-meter level, and development of a 107-meter level is underway. The miners pick some of the unreplaced limestone and coarse calcite from the ore; picking is done also at the plant at Rio Verde, where the ore is screened, sized, and washed to remove the clay. Production was said to be at the rate of about 14,000 tons of metallurgical-grade fluorspar a year, containing 70-90 percent effective $CaF_2$, 2-15 percent $CaCO_3$, 2-5 percent $SiO_2$, and 1-5 percent combined $Fe_2O_3$ and $Al_2O_3$. The concentrates are shipped by rail to Brownsville, Texas, and Tampico for further transportation by water.

## La Ilusión deposit

Fluorita de Rio Verde, an affiliate of Continental Ore Co., is exploring and developing La Ilusión deposit. This deposit is about 1 kilometer northwest of El Zapote deposit, described above, and the geologic environment is similar at the two deposits. The main deposit, a vertical pipelike ore body (fig. 9) in Cretaceous

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Figure 9. Near here

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limestone, is next to Tertiary rhyolitic volcanic rocks. The contact of the limestone and overlying volcanic rocks is very irregular, and near the east edge of the ore body a fault striking N. 20° E. and dipping 75° E. displaces this contact. The ore body, which is about 10 meters in diameter at the edge of the pit, contains some unreplaced fragments of limestone and volcanic rocks; fluorite, calcite and chalcedony form small seams and pockets in the wall rocks. Specimens of ore show that gray fluorite replaced brecciated limestone and was coated in turn by calcite crystals and clay. It is estimated that La Ilusión deposit yielded a few thousand tons of metallurgical-grade fluorspar during the exploration work. An adit is being driven to explore and develop the ore body at a lower level.

Figure 9. La Ilusión deposit, San Luis Potosi. Pipelike ore body of fluorspar is about 10 meters in diameter; view north.

## Zaragoza district

In 1960 the Zaragoza district was producing more fluorspar than any other district visited in Mexico. Several hundred thousand tons of fluorspar has come from this district since 1954, chiefly metallurgical-grade material from two mines; production in 1959 is estimated to have exceeded 150,000 tons. The district is in the Sierra Madre Oriental, about 40 kilometers southeast of the city of San Luis Potosi. It is accessible from San Luis Potosi by driving 25 kilometers east over a paved road toward Rio Verde and about 32 kilometers southeast over a dirt road via Zaragoza. Investigation of the deposits was facilitated by C. Almazan and Alfonso Lopez Callada of Minera Las Cuevas, an affiliate of Noranda Mines, Ltd., and associates, and by P. J. Cutting and Robert Guerling of Minerales Pennsalt, an affiliate of Pennsalt Chemicals Corp.

Tertiary rhyolitic volcanic rocks are faulted down against gray limestone of Early Cretaceous age, probably the Georgetown Limestone. The volcanic rocks are pink to brown rhyolitic flows, breccias, and tuffs with conspicuous layering and phenocrysts of quartz and potash feldspar. Rhyolite plugs form abrupt hills east of the mines. Steep faults at the two mines strike northwest; nearly horizontal limestone shows on the northeast walls, and volcanic rocks comprise the southwest walls. The fluorspar replaces and fills cavities in limestone, rhyolite, and breccia zones along the faults between these two types of rock.

Las Cuevas deposit

Las Cuevas deposit has been the source of more than 100,000 tons of fluorspar. In 1955-57 Ralph Miner mined the deposit before it was acquired by Noranda Mines, Ltd., and associates. Two ore bodies about 100 meters apart are being exploited in workings extending from a shaft sunk to a depth of 70 meters in Cretaceous limestone, about 100 meters from the fault contact with Tertiary rhyolitic volcanic rocks. The ore bodies are in brecciated, slickensided, and altered volcanic rocks and dip about 80° E. They are elongated north-south and are as much as 100 meters long and 50 meters thick. The ore contains some unreplaced fragments of volcanic rocks and limestone, a small quantity of clay, and a soft manganese oxide mineral in small cavities. It is estimated to average more than 60 percent $CaF_2$; channel samples were said to contain as much as 90 percent effective $CaF_2$. The fluorite generally is massive or finely layered. Fine-grained pinkish and gray varieties of fluorite are most common; some coarse yellow fluorite shows radial growth.

The fluorspar is mined at Las Cuevas deposit by a modified room-and-pillar system. The miners pick out some of the waste, and trucks haul the ore to the railroad at San Luis Potosi, where it is crushed, screened, and sorted. The products are high quality and lower quality metallurgical-grade fluorspar, both containing at least 70 percent effective $CaF_2$, and smaller quantities of acid-grade lump fluorspar. The concentrates are shipped by rail to Brownsville, Texas, for loading on barges, and also to Tampico for shipment to East Coast ports of the United States and Great Lakes ports via the St. Lawrence Seaway.

## La Consentida deposit

La Consentida deposit, which is the site of the largest open-pit fluorspar mine in Mexico (fig. 10), is about 800 meters northeast

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Figure 10. Near here

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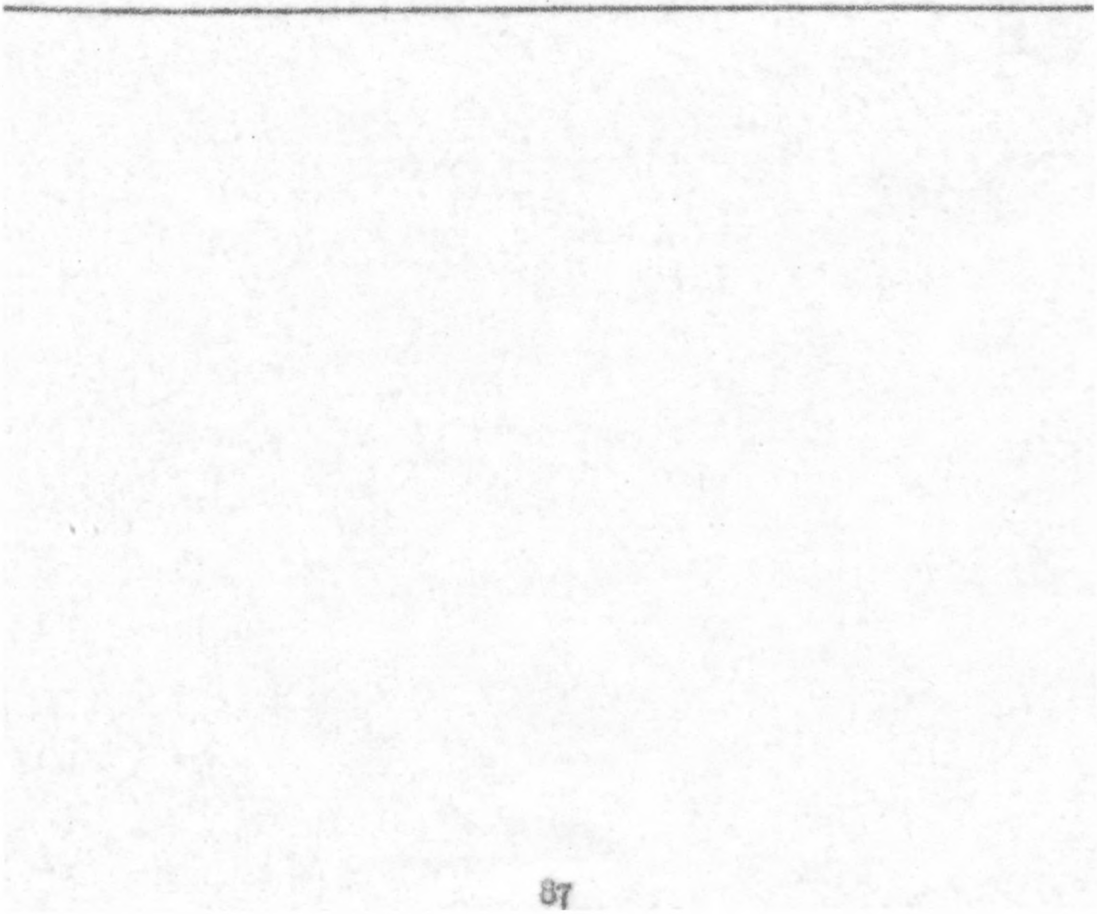
of Las Cuevas deposit, described above. The fluorspar is localized along a steep fault between Tertiary rhyolitic volcanic rocks and Cretaceous limestone and replaces the adjacent limestone to the northeast. The ore body contains many fragments of unreplaced volcanic rocks and limestone, some large enough to leave in place during mining operations, and several seams of gouge as much as 2.4 meters thick. Fluorspar is exposed through a vertical range of more than 100 meters and for a strike length of about 300 meters. Through these distances the ore body ranges in thickness from less than 1 meter to nearly 100 meters. According to the mining company, the ore ranges in grade from 55 to 85 percent effective $CaF_2$ (Engineering and Mining Journal, 1956). Silica forms several percent of the ore where rhyolite fragments or clay are present.

Figure 10. La Consentida deposit, San Luis Potosi. Mining fluorspar in benches in large open pit; view northwest.



The ore consists chiefly of very fine-grained, fine-layered gray, pink, and purplish fluorite; some yellow fluorite with radial growth also is present. Concretionary, crustiform, botryoidal, and stalactitic structures are common. Vuggy fluorspar locally contains manganese and iron oxides and crystals of scalenohedral calcite. Calcite also forms layers, alternating with fluorite, as much as 1 centimeter thick.

Mining began in 1955, and by mid-1960 the pit was more than 60 meters deep and 100 meters long. Mining is done in benches 8-15 meters high. Miners pick out some of the limestone from the ore, which passes next through a crushing and screening plant at the mine. Trucks haul the ore to San Luis Potosi, where it is again upgraded by hand-picking and sized. Two metallurgical-grade fluorspar products, which are based upon size specifications, are shipped by rail to Tampico and Brownsville, Texas, for further shipment by water. Much of the fine material is shipped by rail from San Luis Potosi to the flotation plant of Reynolds Metals Co. at Eagle Pass, Texas.

## Esqueda district

The Esqueda district, which contained extensive, thick veins and has been the source of more than 50,000 tons of fluorspar, is in the Sierra Madre Occidental of northeastern Sonora. The fluorspar deposits are about 15 kilometers by road southeast of the village of Esqueda, which is on the railroad about 70 kilometers south of Agua Prieta, Sonora, and Douglas, Arizona. The district is accessible by a gravel road extending south from the international border. Ing. Robert Morel of Fluoresqueda, S. A., a subsidiary of San Luis Mining Co. and Aluminium Limited of Canada, guided us through La Barra mine.

The fluorspar at La Barra deposit occupies a vein in a fault in volcanic rocks, probably of Tertiary age. Pinkish-gray felsitic rhyolite, green volcanic breccia, and red volcanic conglomerate were seen at the mine. The volcanic rocks in a road cut north of the mine strike about N. 20° W. and dip 40° E.; the vein has a similar strike but dips about 70° E. Slickensided and grooved surfaces are conspicuous along the footwall of the vein and within the ore.

Ore shoots along the vein are as much as 20 meters thick and 200 meters long. The ore is estimated to contain more than 50 percent $CaF_2$ and about 10 percent $SiO_2$, which is present as quartz and in inclusions of volcanic rocks. The rest of the vein material is mainly calcite, which is locally brown, manganiferous, and very abundant. Hematite, limonite, and wad in some places form coatings on the other vein minerals. The fluorite is commonly coarse grained and green; white, pink, and dark gray varieties also were found. Most of the fluorite is massive, but some forms botryoidal growths and small cubes modified by hexoctahedrons. Fluorite crystals, with the cube, hexoctahedron, and the other five holohedral isometric forms, coat polybasite crystals in rich silver ore from a vein in rhyolite near Arizpe, Sonora, which is about 50 kilometers southwest of the Esqueda district (Desautels, 1960). Possibly silver mineralization will be found with fluorite at depth in the volcanic rocks in the Esqueda district.

Mining is done by shrinkage stoping where the vein is narrow, and elsewhere by a cut-and-fill method. The south part of the vein was worked from an adit and a shaft, and stopes extend to the surface. On the north part a new shaft reached a depth of about 100 meters, and extensive drifting and crosscutting developed the ore body. Several similar veins also are being explored in the district.

Almost all the fluorspar from La Barra mine was metallurgical grade and was produced before 1953, when the San Luis Mining Co. acquired the mine from R. S. Clinch of Esqueda. Production was small during the next two years, and in 1955 the mine was closed. Operation of the mine started again in 1960; trucks haul the ore to Esqueda to Fluoresqueda's new flotation plant, which has a daily capacity of 125 tons of acid-grade concentrates. Some of the concentrates are shipped to the United States under the U. S. Department of Agriculture's barter program.

## Zacatecas

### Frio district

The Frio district, which is inactive but has yielded more than 50,000 tons of fluorspar, is about 10 kilometers east of Sombrerete, Zacatecas. The deposits are in low hills near the east edge of Sierra Madre Occidental and about 2 kilometers southeast of the railroad station at Frio. They are reached by driving about 7 kilometers over a dirt road extending south from the main highway between Durango and Fresnillo. The Josefina mine, which is now owned by Fluorita Industrial Mexicana, S. A., a subsidiary of Aluminium Limited of Canada, has been the source of most of the production from the Frio district.

The fluorspar deposits are along persistent fault zones in greenish-gray silicified shale and siltstone, probably of Early Cretaceous age (Sanchez Mejorada, 1960). The main mineralized fault zone strikes N. 60°-80° E. and dips about 65° S. Although it is more than 10 meters wide and has been traced in outcrops, trenches, and shafts for about 4 kilometers, ore bodies are limited in size and irregularly distributed over this length.

At the inaccessible Josefina mine the ore body is reportedly developed by several vertical and inclined shafts with drifts and stopes along a section of the vein said to be about 150 meters long (E. W. Greig, oral communication, 1961). The east shaft was sunk to a depth of 90 meters where the ore is nearly 2 meters thick; locally the ore is more than 4 meters thick. The grade is estimated at about 65 percent $CaF_2$. The grade of the vein is lower where blocks and smaller fragments of silicified wallrock, masses of red clay, and quartz are abundant.

The fluorite is generally grayish-white, massive or faintly layered, and fine grained. A late generation of ore is composed of alternating layers of white and brown fluorite ranging in thickness from about 1 millimeter to 1 centimeter; quartz crystals and fluorite cubes, many in combination with tetrahexahedra, line vugs in this type of ore. Cubes of coarser green fluorite are grouped in parallel position and form pseudo-octahedra. Some of the crystal habits of fluorite are well preserved by chalcedonic quartz deposited on the fluorite. The late quartz locally contains tiny grains of pyrite. Small quantities of white clay, limonite, and black manganese oxide were deposited last.

Fluorspar was discovered in the Frio district in 1944 and was produced intermittently until 1953. Cía. Minera Josefina y Anexas of Durango and Durango Fluorspar mined about 60,000 tons of fluorspar averaging approximately 60 percent $CaF_2$ (E. W. Greig, written communication, 1961). Almost all the product was metallurgical-grade fluorspar and went to the United States. A small quantity of the ore was hand-picked to yield a ceramic-grade fluorspar containing about 95 percent $CaF_2$. In 1956 Aluminium Limited of Canada purchased the Josefina mine and has been exploring the mineralized fault zone. In an explored section about 1 kilometer long mainly east of the mine, nearly all of the exposures contain fluorspar.

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