UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Colombia Investigations
(IR) CO-14

ECONOMIC GEOLOGY OF THE ZIPAQUIRA QUADRANGLE AND ADJOINING AREA, DEPARTMENT OF CUNDINAMARCA, COLOMBIA

by

Donald H. McLaughlin, Jr.
U. S. Geological Survey

and

Marino Arce H.
Instituto Nacional de Investigaciones Geologico-Mineras

Prepared on behalf of the
Government of Colombia and the
Agency for International Development
U. S. Department of State

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

70-208

1970

(200)
In 3 tool

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Colombia Investigations
(IR) CO-14

ECONOMIC GEOLOGY OF THE ZIPAQUIRA QUADRANGLE AND ADJOINING AREA, DEPARTMENT OF CUDINAMARCA, COLOMBIA

by

Donald H. McLaughlin
I. S. Geological Survey

ECONOMIC GEOLOGY OF THE ZIPAQUIRÁ QUADRANGLE AND ADJOINING AREA, DEPARTMENT OF CUNDINAMARCA, COLOMBIA

by

Donald H. McLaughlin, Jr.
U. S. Geological Survey

and

Marino Arce H.
Instituto Nacional de Investigaciones Geológico-Mineras

CONTENTS

CONTENTS (continued)

CONTENTS (continued)

ILLUSTRATIONS

TABLES

FIGURES

FIGURES (continued)

PLATES

(Plates are in pocket except as noted)

ECONOMIC GEOLOGY OF THE ZIPAQUIRA QUADRANGLE AND ADJOINING AREA, DEPARTMENT OF CUNDINAMARCA, COLOMBIA

by

Donald H. McLaughlin, Jr.
U. S. Geological Survey

and

Marino Arce H.
Instituto Nacional de Investigaciones Geológico-Mineras

ABSTRACT

At least four evaporite sequences are interbedded with Cretaceous strata in the Bogotá area of the Cordillera Oriental of Colombia. The easternmost and oldest evaporite interval is of probable Berriasian-Valanginian age; the next oldest is of probable late Barremian-early Aptian age, and is followed by a possible late Aptian sequence. The westernmost and best known sequence is Turonian-early Coniacian in age, in the Sabana de Bogotá. This youngest sequence contains the thickest known salt deposits and is probably the most widespread geographically.

Three gypsum deposits of probable Barremian-Valanginian age are in the eastern part of the area under investigation. These deposits may have been leached from former salt accumulations. No other evaporites are exposed, but numerous brine springs are known. That the sources of these brines are neither deep not distant is suggested by the generally high concentration of the brines, the local presence of rute (leached salt residue), and the commonly significant amounts of H_2S gas emitted at these springs.

The rock salt exposed in three accessible mines commonly has a characteristic lamination caused by alternating layers of relatively pure halite and very argillaceous halite. Ubiquitously scattered throughout all salt deposits are small clasts of black, commonly pyritic, marly claystone. This lithology is also present as large claystone bodies conformably interbedded in the salt strata. Anhydrite is rare and is apparently more abundant at the Zipaquirá mine that at the Nemocón and Upín mines

Paleontologic evidence in the Sabana de Bogotá demonstrates that the salt-claystone series, hematite impregnated strata, and carbonaceous to locally coaly claystone are coeval. The salt-claystone facies may have been deposited in shallow evaporite pans that were separated within the overall evaporite interval by barriers on which the locally hematitic strata were deposited. The carbonaceous facies may also have formed in barrier areas or on the edges of the evaporite basins. Whether or not this facies relationship prevails in the older evaporite intervals is not known; meager evidence suggests that it does.

Nonmetallic mineral resources other than the evaporite minerals are phosphate rock, limestone, kaolinite, and emeralds. Metallic mineral deposits present in the Zone include hematite at Pericos, La Caldera, Tibirita, Nueva Vizcaya, and Cerro de Montecristo; chalcopyrite at Cerro do Cobre and at Farallones de Medina; galena in several places along the Río Farallones and Río Gachetá; and spahlerite in the Junín district.

INTRODUCTION

The mineral deposits described are in the middle latitudes of the Cordillera Oriental, as shown on figure 1, in an area designated as Zone IV by the Instituto Nacional de Investigaciones Geológico-Mineras (Ingeominas) of the Colombian Government. All deposits were studied in conjunction with a program of geologic mapping of the Zipaquirá and part of the Guavio Quadrangles (fig. 1) within Zone IV over a period of about 3½ years. The work was done cooperatively by Ingeominas and the U. S. Geological Survey (USGS), sponsored by the Colombian Government and the Agency for International Development, U. S. Department of State.

Acknowledgments

The writers wish to acknowledge the helpful collaboration of Francisco Zambrano O., Fernando Pachón P., Enrique Aya C., Pedro Mojica G., Carlos Ulloa M., Erasmo Rodríguez M., Ricardo Escobar R., and Luis Ernesto Castillo P., all geologists with Ingeominas. Surveyors Mario Forero C., Luis Ramírez L., Luis Castañeda V., and Vicente Grijalba M. made detailed topographic and mine maps. Srta. Diana Gutiérrez P., Dr. Hans Bürgl, Mr. Edward Fritz, and Father Eduardo Acosta provided the writer with paleontologic determinations.

Earl M. Irving, Tomas Feininger, and Charles M. Tschanz, all of the U. S. Geological Survey, gave helpful advice during the course of the study. Dr. C. D. A. Dahlstrom, of the Chevron Oil Company, was instrumental in advising the writer on various aspects of the salt geology of the Zipaquirá mine. Prof. Louis F. Dellwig, of the University of

Kansas, shed some light on some of the more complicated features encountered in the salt of the accessible mines. The writer wishes to thank Dwight E. Ward, Earl M. Irving, Robert J. Hite, and Tomas Feininger for the thoughtful critiques of the manuscript.

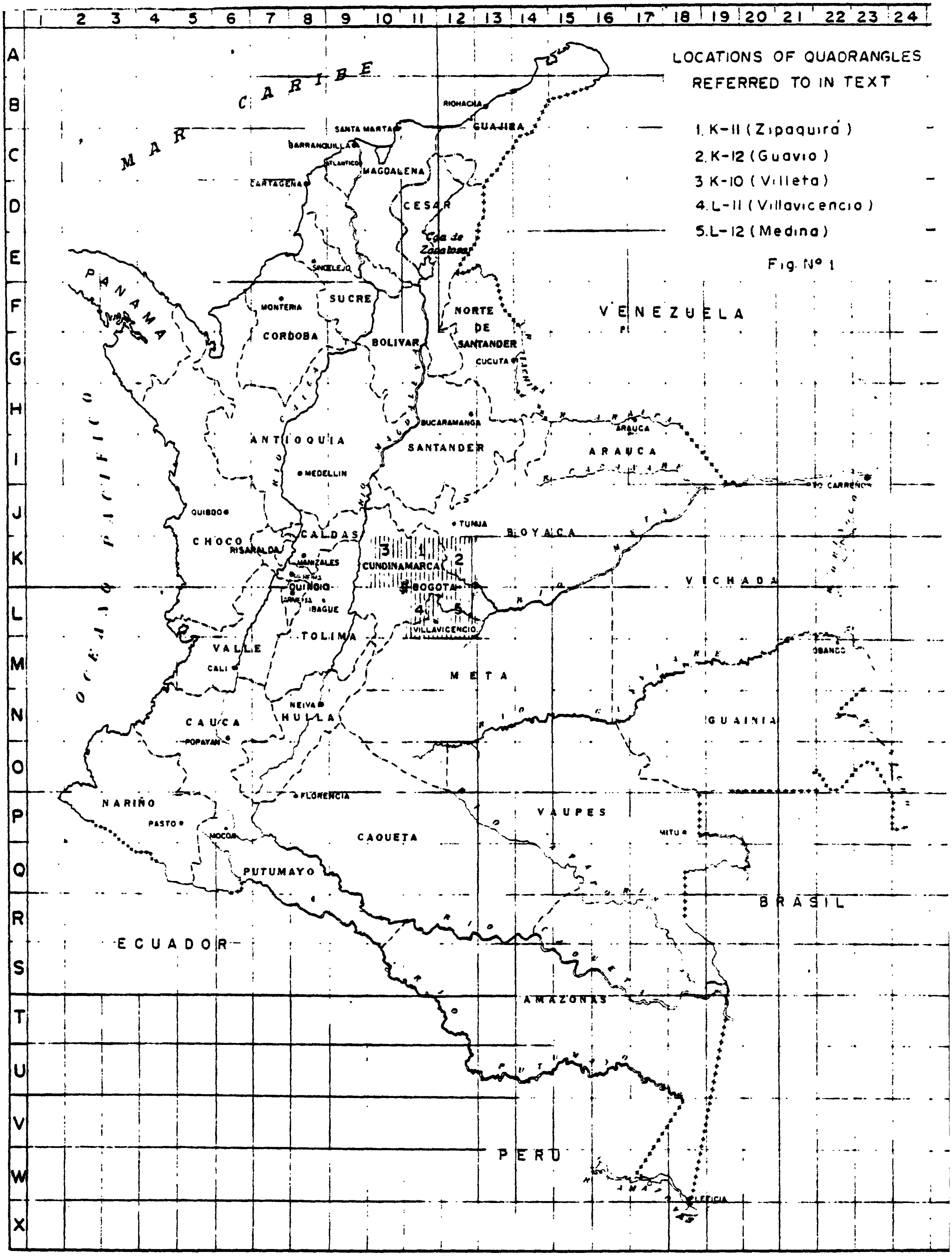


Figure 1. Index map of Colombia showing location of quadrangles referred to in text.

GENERAL GEOLOGY

Regional tectonic and depositional framework

The Colombian Andes consist of three major ranges, of which the Cordillera Oriental is the easternmost. Further to the east are the Llanos, a lowland in fault contact with the Cordillera Oriental (Campbell and Bürgl, 1965, pl. 1). The faults bounding the Cordillera Oriental on the east are considered by most geologists to be west dipping, high-angle reverse faults. The western boundary of the Cordillera Oriental at the latitude of the present study is a series of east-dipping high-angle reverse faults that form the eastern margin of the half-ramp Magdalena Valley (Raasveldt and Carvajal, 1957; Campbell and Bürgl, 1965, pl. 1). West of the Magdalena Valley, the Cordillera Central is bounded on the west throughout much of its extent by the Cauca Valley. West of this valley is the Cordillera Occidental, limited on the west by the Pacific coastal lowlands in the region south of approximately 5°18' N. latitude. North of this parallel, along the Pacific coast, are the low coastal ranges, generally referred to as the Cordillera de Baudo or the Cordillera de la Costa. These tectonic elements are illustrated in figure 2. With the exception of the single reported saline spring in the Cordillera Central south of Medellín, all the known salt is in the middle latitudes of the Cordillera Oriental.

Miogeosyncline sedimentation, the locus of which was the present-day Cordillera Oriental, deposited a maximum thickness of about 12,500 m (41,000 ft) of strata at the latitude of Bogotá. The section thins abruptly to the south and less abruptly to the north (Bürgl, 1962, fig. 18). Cretaceous eugeosynclinal sediments were deposited in the area of the present-day Cordillera Occidental. Here the Cretaceous section is not well known but Bürgl (1962, p. 27) states that these eugeosynclinal strata are on the order of 10,000 m (32,800 ft) thick. These two depositional facies are now separated by the mainly crystalline Cordillera Central which was intermittantly emergent during the Cretaceous, and may have formed a median belt through the Cretaceous geosyncline, forming a barrier between the two depositional facies. The saline horizons are in the miogeosynclinal facies of the Cretaceous Andean geosyncline.

Stratigraphy

The stratigraphic section of the Cordillera Oriental in the latitude of the Bogotá area consists of three major assemblages of sedimentary rocks. The oldest, of Paleozoic age, comprises the Quetame, Floresta, and Farallones Groups. These strata are overlain by more than 12,000 m of Upper Jurassic and Cretaceous rocks, which in turn are overlain by about 1,500 m of Tertiary strata. (See pl. 1).

The Paleozoic strata form the core of the Quetame uplift in the eastern part of the Cordillera Oriental. The Tertiary rocks are in the Sabana de Bogotá and the Cretaceous strata are present from the Sabana de Bogotá eastward, locally over the Quetame uplift, to the structural border of the Cordillera Oriental. Cretaceous strata are also widespread throughout the entire Cordillera Oriental, but this study is limited to that area where these strata are known to be markedly salt-bearing. Regional correlations of Cretaceous strata and the stratigraphic positions of salt beds are shown in figure 3.

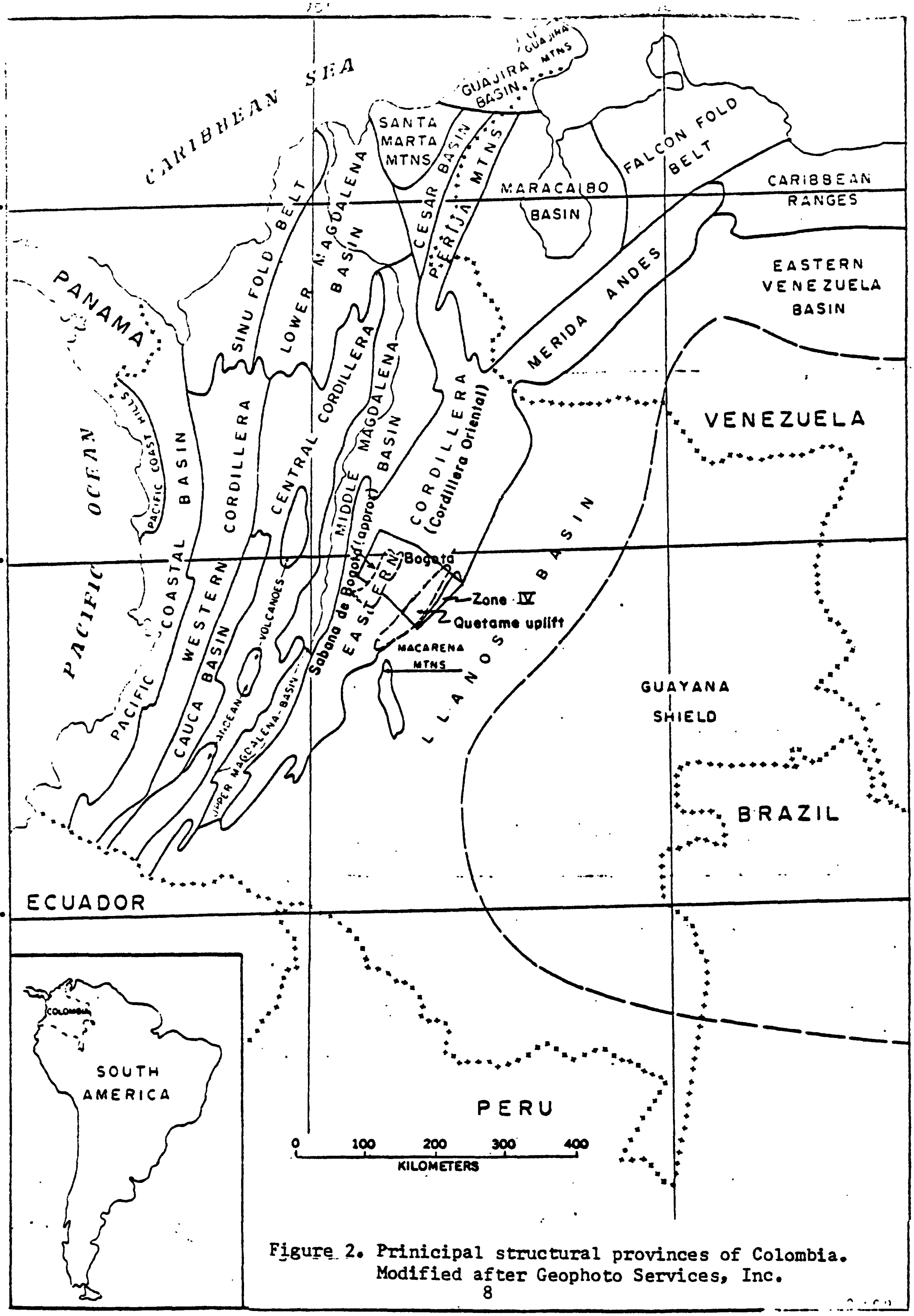


Figure 2. Prinicipal structural provinces of Colombia. Modified after Geophoto Services, Inc.

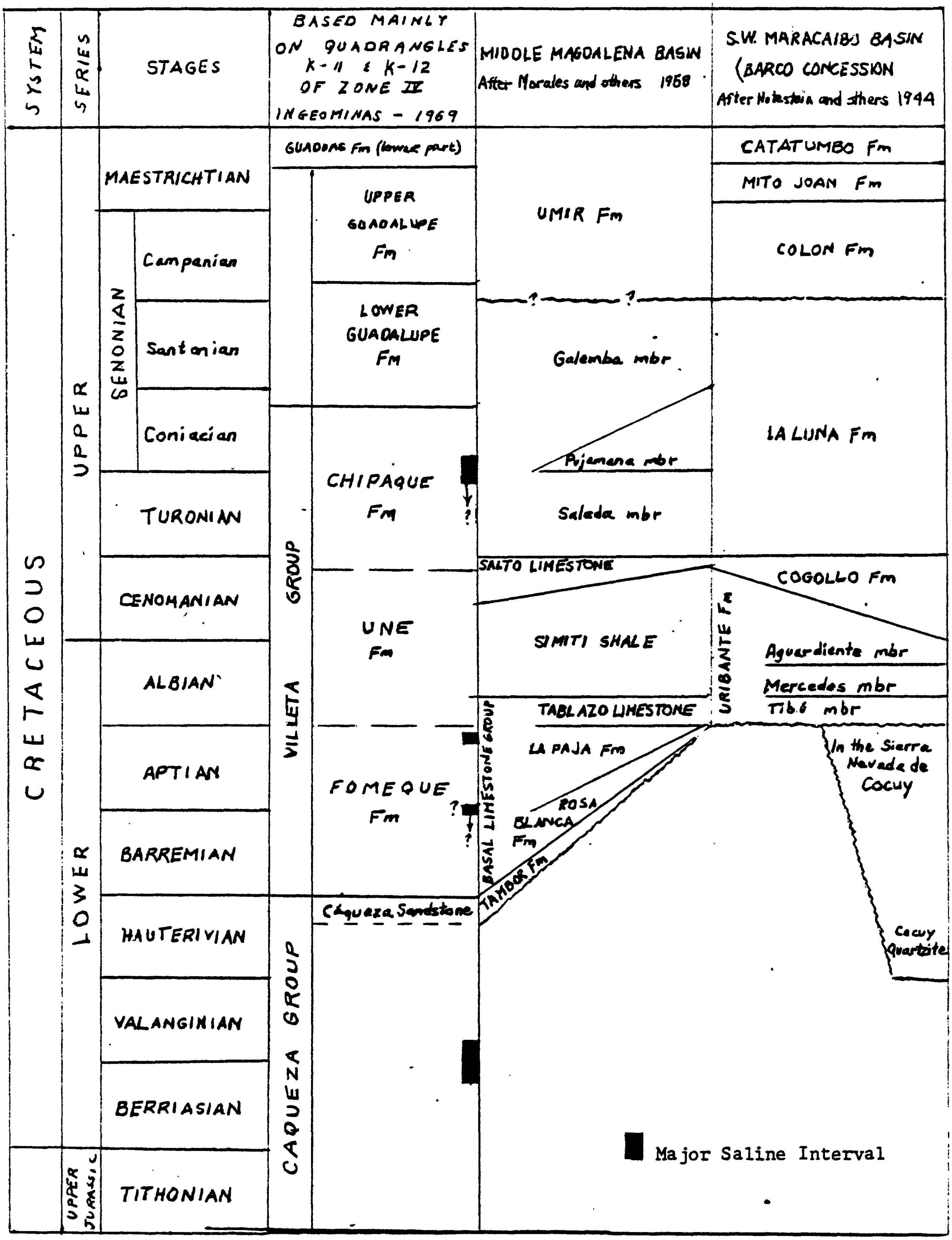


Figure 3. Regional correlations of Cretaceous formations. - (Modified from Thompson, 1966)

Cretaceous rocks

<u>Cáqueza Group</u> - The Cáqueza Group is the lowest stratigraphic unit within the Cretaceous system. Cáqueza strata lie with disconformity and local unconformity on the Quetame, Floresta, and Farallones Groups.

The Cáqueza Group crops out along the eastern margin of the Cordillera Oriental. The unit is thin where still present over the Quetame uplift which was a neutral area during Early Cretaceous time, and probably did not contribute detritus to the Cáqueza.

Predominantly the Cáqueza Group is dark-gray, commonly hard, silty, blocky to shaly, locally micaceous claystone that contains numerous interbeds of gray to dark-gray, locally micaceous siltstone. Pyrite and limonitic pseudomorphs after pyrite are common throughout much of the Cáqueza section. Iron oxide derived from pyrite has locally discolored the predominantly dark rock. Low in the section are brownish-gray to gray, locally conglomerate sandstone; dark-gray, massive, locally sandy limestone overlies the basal claystone. At least one intraformational unconformity occurs in these lower strata. Fine-grained, gray and tan, hard, massive quartz sandstone lenses are locally interstratified in Cáqueza claystone. The top of the Cáqueza Group is formed by a fine-grained, micaceous, gray, locally silty, hard, commonly thickly bedded quartz sandstone. Evaporites are present in the middle of the group, although structural complications and poor exposures preclude more definite knowledge of the precise stratigraphic location of the evaporites.

The area of Cáqueza outcrop ranges from locally subdued topography to rugged slopes and steep -walled canyons.

The Cáqueza Group ranges in age from Tithonian, here included with the Cretaceous system, to Hauterivian. Thickness ranges from about 2100 to as much as 4200 meters. Structural complications as yet unresolved limit the preciseness of these figures.

Fómeque Formation - The Fómeque Formation, conformably overlying the Cáqueza, forms the lowest unit of the Villeta Group and is composed of silty, dark-gray, commonly carbonaceous claystone, which ranges from blocky to shaly. Dark brownish-gray marls are very common and range to several meters in thickness. Interbedded locally are micaceous siltstone, fine-grained sandstone, and locally coquinoid limestone lenses which range from gray through black. Pyritic concretions are present throughout the unit but are more common in the upper part. Coaly strata and carbonaceous fragments are locally present. Salt appears to be present at two horizons, the lower about 1600 meters above the base and the upper some 900 meters below the top of the formation.

Topography formed by the Fómeque is generally much more subdued than that of the underlying Cáqueza Group. The contrast in topography between the two units is generally well expressed along the contact. The Fómeque Formation has a characteristic ribbed weathering habit caused by the interbedded, more resistant marls forming small ridges throughout much of the area of outcrop.

The Fómeque Formation is generally considered to be of Barremian to Aptian age although the actual time boundaries are yet to be determined with precision. Thickness ranges from about 1500 to some 3200 meters. The formation thins to the south in the area northeast and east of Bogotá.

Une Formation - The Une Formation conformably overlies the Fomeque, and the contact between the two units is generally well defined. The Une Formation is composed of hard, very light gray, fine- to medium-grained quartz sandstone. Muscovite is locally abundant and the sandstone is slightly glauconitic in some places. Bedding is commonly massive in the southern part of Zone IV; beds become thinner toward the northeast, and more argillaceous interbeds are present toward the north. Coal crops out locally.

The Une Formation is everywhere topographically prominant and the uppermost sandstone forms large dip slopes in several places. The Une Formation ranges from Albian to late Cenomanian in age and from 450 to 800 meters in thickness.

Chipaque Formation - The Chipaque Formation, the uppermost unit in the Villeta Group, is everywhere conformable above the Une. The Chipaque is characterized by dark-gray to black, locally pyritic, massive to shaly claystone, much of which is slightly silty and relatively soft. Lenses of siltstone and fine-grained, silty quartz sandstone are present and some are impregnated by hematite in the Sabana de Bogotá area. Salt is common in the lower part of the formation but appears to be restricted to one interval.

The Chipaque Formation is characterized by a subdued, slumped topography. The unit is common in the axial regions of anticlines in the Sabana de Bogotá where it is commonly very structurally deformed.

The Chipaque Formation weathers to a subdued topography and landslides are common. The age of the Chipaque ranges from latest Cenomanian to late Coniacian. Thickness, commonly difficult to determine, ranges from about 400 to 700 meters.

Lower Guadalupe Formation - The Chipaque is conformably overlain by the Lower Guadalupe Formation. The contact between these two units is placed at the base of the first prominant sandstone that overlies the Chipaque Formation. In addition to the lower sandstone member, the Lower Guadalupe Formation is composed of light-gray to locally dark-gray siltstone and silty claystone with thin interbeds of fine-grained, very light gray, quartz sandstone.

Topographic expression of the Lower Guadalupe Formation is generally subdued and commonly slumped. Where they are significantly thick, the lower sandstone heads form scarps, the most prominant of which lies a few kilometers east of Choachí on the road to Bogotá.

The age of the Lower Guadalupe Formation ranges from late Coniacian to early Campanian. Thickness ranges from a pinch-out in the west to about 750 meters in the east. As the Lower Guadalupe is lithologically transitional between the underlying Chipaque and overlying Upper Guadalupe Formation, separation of the unit is difficult in areas of structural complication or where the lower sandy facies is missing or not exposed.

Upper Guadalupe Formation - The Upper Guadalupe Formation is made up of three members. The lowest is a lenticular, mainly medium-grained, very light gray to light brownish-gray quartz sandstone. Bedding locally is massive and hard. Overlying the lower sandstone is a thinly bedded, locally hard, commonly siliceous siltstone which carries abundant Foraminifera in many places. The upper sandstone is everywhere prominantly exposed in the Sabana de Bogotá area. This member is commonly hard, locally friable, medium- to locally coarse grained, and slightly pebbly. Bedding is commonly massive and crossbedding locally conspicuous. Minor interbeds of siltstone and silty claystone, in places cemented by silica, are common.

The Upper Guadalupe Formation is well expressed topographically, forming prominant dip slopes on many of the anticlines in the Bogota area and steep scarps both within the Sabana de Bogotá and along the margins of this high valley.

The Upper Guadalupe Formation is of Campanian to early Maestrichtian age. Thickness ranges from 600 to 1000 meters.

Guaduas Formation - The Guaduas Formation overlies the Upper Guadalupe conformably, although locally evidence of an erosional break between the two units is present.

Except in a small area south of Bogotá, the Guaduas Formation is a nonmarine sequence of silty claystone, generally light-gray in the lower parts of the formation and reddish in the upper. Argillaceous, friable quartz sandstone members form two intervals which are locally prominant. Coal is present throughout the formation, particularly in the lower part where it is exploited in small mines.

The Guaduas Formation weathers to gentle hummocky topography and is commonly slumped.

Most of the Guaduas Formation is of Maestrichtian age, but the upper part of the formation is probably Paleocene. Thickness of the Guaduas Formation varies widely, ranging from 25 to slightly more than 1000 meters.

Tertiary rocks

Cacho Sandstone - Conformably overlying the Guaduas Formation is the Cacho Sandstone, a sequence of coarse-grained to locally conglomeratic, friable, cross bedded quartz sandstone. The coarsely clastic strata are commonly separated by a light-gray to brownish-gray, silty claystone. The Cacho Sandstone is commonly well expressed topographically, forming low but easily discernible hills and ridges.

A Paleocene age for the Cacho has been indirectly established by palynology. Thickness ranges to 400 meters. West of Zipaquira, however, the unit is probably missing, due to a local unconformity between the overlying Bogotá Formation and underlying units.

Bogotá Formation - The Bogotá Formation, completely continental in origin, lies conformably on the Cacho Sandstone, except in the area cited above.

The formation is composed of grayish-red, locally purplish, commonly greenish-gray, generally poorly stratified mudstone and silty claystone. Sandstone lenses, ranging from fine- to medium-grained, generally friable and variegated, are local constituents. Carbonaceous material is present as thin beds of low-grade argillaceous coal north of Bogotá.

The incompetent Bogotá Formation underlies gentle topography and is subject to much slumping, landsliding, and gravitational overturn. Palynologic data suggest that the Bogotá Formation ranges from late Paleocene to early Eocene age. True thickness of the Bogotá Formation is difficult to assess because of the incompetent nature of the unit. Cross sections made through areas of Bogotá outcrop suggest thicknesses ranging from 450 to 800 meters.

Younger Tertiary strata - The mainly coarsely clastic strata overlying the Bogotá Formation are nonmarine and may be as much as 650 m thick. As these units, including the Regadera, Tilatá Formations, are not directly involved with salt anticlines in the Bogotá area, they are not summarized in this report.

EVAPORITE MINERALS

The salt deposits within Zone IV form only a small part of the evaporates present in the Cordillera Oriental. Salt springs, indicating the presence of salt, extend from Girardot on the southwest to the Málage-Guaca area in the northeast, as illustrated in figure 4. All salt mines and former salt mines, however, are within Zone IV.

Detailed underground mapping in all accessible salt mines and related surface areas was done to determine the mode of occurrence and age of the deposits, to obtain information about the possibility of increasing salt production, and to assess the potassium potential of the deposits.

Location of deposits

Salt mines - The Zipaquirá and Nemocón mines are 50 to 60 km, respectively, north of Bogotá on the margins of the high valley, the Sabana de Bogotá. The Sequilé mine, about 37 km north-northeast of Bogotá, has been abandoned for many years and is inaccessible because of caving. The Upín mine is 22 km north-northwest of Villavicencio, on the eastern limits of the Cordillera Oriental. All mines are located on figure 4.

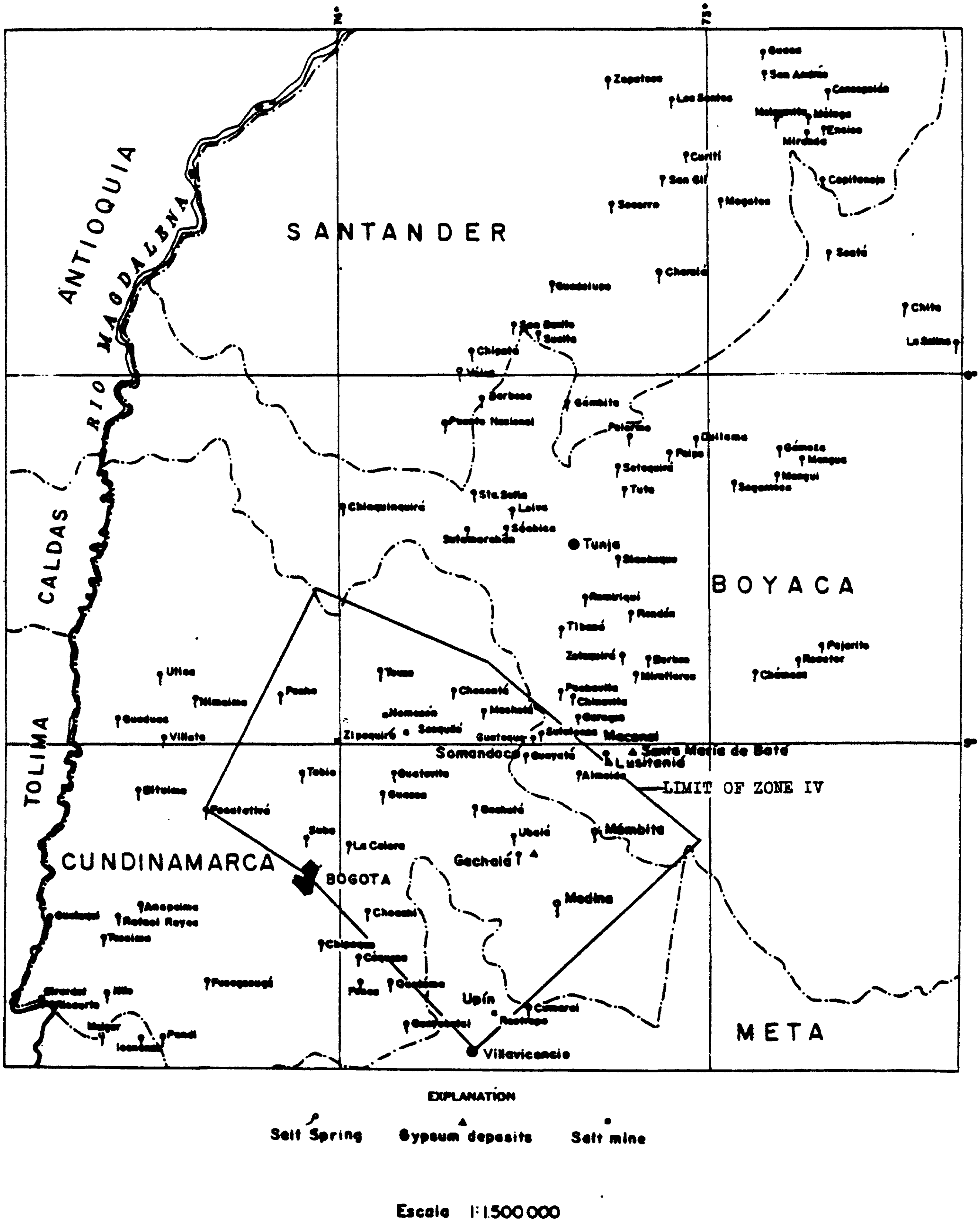


Figure 4. Location of known salt springs, salt mines, and gypsum deposits in central Cordillera Oriental, Colombia

Salt springs - Salt springs (salinas) are known in Cretaceous strata of the central latitudes of the Cordillera Oriental, from Girardot on the southwest to the eastern limits of the range. The southernmost salt spring is in the Icononzo- Pandi district along the southeastern border of the Department of Cundinamarca; the northernmost springs are in the Málaga-Guaca region in the Department of Santander. The majority of the salt springs are east and north of Bogotá, and are beyond the area under investigation, as may be seen from figure 4. Because of the time limitations not all salt springs in the area were visited.

Within the area investigated only two of the salt springs are currently being exploited. The more important of these is about 5 km north of Gachetá; the other spring is at El Salitre, near Somondoco. The Gachetá spring serves mainly local needs and that at Somondoco is only a source of salt for cattle. Another spring is at Mámbita, near the eastern front of the Cordillera Oriental, about 90 km east-northeast of Bogotá.

Gypsum deposits - Three gypsum deposits, each interbedded with the claystone in the lower part of the Cáqueza Group, are known in the central part of the Cordillera Oriental. These are located as follows (fig. 4): (1) A few kilometers north of the Santa Maria de Bartá. (2) At Lusitania on the Río Batá (Garagoa). (3) About 4 km east of Gachalá.

Stratigraphic occurrences and ages of evaporites

Berriasian- Valanginian

The three gypsum deposits, the salt providing the brine in the spring near Mámbita, and the salt deposit at Upín are probably all correlative. Berriasian-Valanginian fossils are found in marly claystone at the Lusitania deposit (D. Gutiérrez, written commun., 1969).

Valanginian fossils have been found several hundred meters stratigraphically above the gypsum deposit near Gachalá. Hubach (1957b, p. 110) states that the Upín salt is probably Valanginian but gives no evidence. Campbell and Bürgl (1965, p. 576) consider that the Cretaceous strata near Villavicencio are of Berriasian age.

This evaporite sequence lies deep within the Cáqueza Group, but its exact position is not yet known.

Late Barremian- early Aptian

Results of regional mapping suggest that the salt spring at El Salitre, near Somondoco, is probably derived from salt of late Barremian-early Aptian age, although no definite paleontologic evidence is yet available. This salt spring is in the lower part of the Fómeque Formation of middle Barremian to late Aptian age (Hubach, in Kehrer, 1933).

Late Aptian

The Salinas de Gachetá lies on strike with strata which to the south contain a late Aptian fauna. A poorly preserved and stunted fauna found in the immediate vicinity of the salinas supports this age assignment. Regional mapping suggests that the source salt of the salinas is in the upper part of the Fómeque Formation.

The salt spring near Choachi (fig. 4) is probably also derived from salt of late Aptian age in the upper part of the Fómeque Formation (Renzoni, 1965).

Turonian-late Coniacian

The salt sequence of the Sabana de Bogotá region is most likely of Turonian-early Coniacian age. A Turonian ammonite was collected from strata immediately under the Zipaquirá deposit (Bürgl, oral commun., 1965). A late Coniacian fauna has been collected within the weathered salt residue at the Salinas de

Tausa, and the same fauna was found in beds adjacent to the Nemocón salt mine. Near La Pradera and about 11 km west of Zipaquirá, late Coniacian fòssils are associated with salt residue interbedded in black, shaly claystone.

All evidence to date suggests that the salt deposit in the Sabana de Bogotá area is in the Chipaque Formation, but precisely what stratigraphic position within the Chipaque is difficult to state because of poor exposures, structural complications, and thickness variations.

These four evaporite sequences are the best known. All are in Cretaceous black claystone and siltstone below the Lower Guadalupe Formation (late Coniacian to early Campanian). The aggegate thickness of this claystone-siltstone section is between 10,000 and 12,000 m.

Structure of salt-bearing beds

Regional structural grain in the area under discussion trends from N.35° E. to N. 40° E., with local exceptions. The entire area has undergone tangential compression that formed numerous folds and several relatively extensive, high-angle reverse faults that are related to the folds. Salt deposits are everywhere associated with anticlines, and evidence of salt is commonly present along fault traces. Characteristic of compressional tectonism in the area of bedded salt is the common dynamic opposition of structural elements. Dynamic opposition is best exemplified in the Sabana de Bogotá where exposures are more prevalent and structures well delineated by the sandstone of the Upper Guadalupe Formation.

All significant salt deposits are in the Sabana synclinorium and the Farallones anticlinorium in the central and eastern part of the Cordillera Oriental. The Sabana synclinorium forms the central highlands in the region of the Sabana de Bogotá. In this same latitude the Farallones anticlinorium comprises the generally lower regions to the east and is the easternmost structural province of the Cordillera Oriental. The eastern limits of the Farallones structural province are formed by large, high-angle reverse faults that constitute the eastern front of the Cordillera Oriental. Both structural provinces contain numerous folds and faults but those of the Sabana synclinorium have much greater lateral extension than do those of the Farallones anticlinorium. Plate 2, a section through the Cordillera Oriental, illustrates these and other structural provinces and their interrelationships.

The Turonian-lower Coniacian salt deposits are limited to the Sabana synclinorium; all other salt deposits are within the Farallones anticlinorium.

Upín - The salt deposit at Upín is in a sliver of Cáqueza strata that lies between two major high-angle reverse faults that here mark the southeastern structural front of the Cordillera Oriental. The western fault, several kilometers west of the salt mine, forms the southwestern boundary of the core of the Farallones structural province and places the Farallones Group (mainly late Paleozoic age) in contact with Cáqueza strata. The eastern fault, passing a few hundred meters east of the salt mine, probably has a greater vertical displacement than the western, as the Cáqueza Group is presumably in fault contact with the Tertiary strata of the Llanos. Extensive brush cover and colluvial deposits obscure the structure. The relationship between the salt deposit and surrounding geology is shown on plate 3.

The regional grain in this area is northeast-northwest. Much of the salt in the mine and the Cáqueza strata along the Río Upín strike at varying angles to this grain, suggesting that strike-slip movements may have occurred along one or both faults, rotating the salt deposit and enclosing strata.

Gachetá - Regional mapping indicates that this salt spring is near the crest of the Gachetá anticline along the Chorrera-Salinera reverse fault into which the anticline appears to merge. This is illustrated on plate 1 in areas d-5 and d-6. Lack of exposures precluded more detailed strucutral knowledge in this area.

Zipaquirá - The Zipaquirá salt deposit lies in an anticlinal trend which has a mapped extension of about 129 km. At Zipaquirá the salt-bearing facies of the Chipaque Formation apparently lies in an upfaulted wedge in the crestal regions of the anticline. This crestal area and the western flank have moved over the eastern flank of the anticline along a pronounced high-angle reverse fault, the trace of which lies directly east of the deposit (fig. 5 and pl. 4). The cross section (fig. 5) also suggests that the Chipaque claystone has flowed plastically into the axial part of the anticline. The northern limit of the Zipaquirá deposit, shown on plate 4, is formed by a left-lateral tear fault which is probably a splay from the main reverse fault east of the deposit. The southern limit is not definitely known, in the absence of drill data.

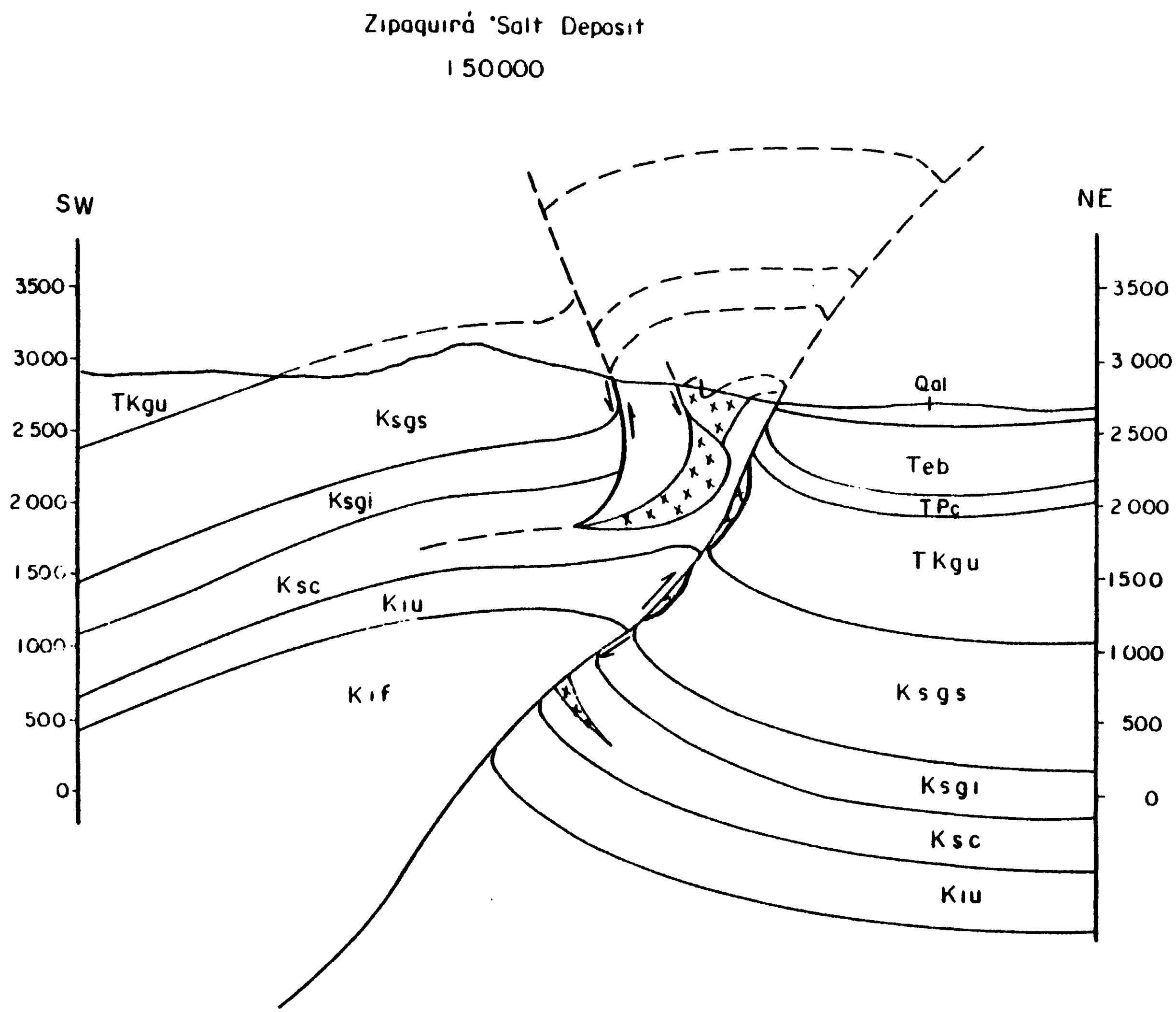


Figure 5. Diagrammatic cross section showing structure of Zipaquirá salt deposit.

Nemocón - The anticlinal trend that contains the Nemocón deposit has a known axial extent of about 148 km. The surface geology of the Nemocón area can best be considered as comprising two anticlinal plunges which were previously in wider right-lateral en echelon relationship than they are now, and have been moved together by lateral compression. The salt deposit is in the northeast plunge of the South Nemocón anticline; salt may have been present where the North Nemocón anticline plunges southwest where a large depression is floored by Chipaque claystone. The strucutral development of the Nemocón region is shown in figure 6. A remnant of the original syncline which separated the two plunges still exists, as may be seen from the figure. The present structural configuration of the area is suggested in figure 7 and on plate 1, area b-3.

The Nemocón salt deposit is probably anticlinal and plunges to the south, as is shown on the mine map (pl. 5). As the deposit is in the northeast plunge of the northeast-trending anticline, the salt bed may have rotated, probably counter-clockwise, about 45° as the two anticlinal plunges were moved together. The rotation and plunge of the folded salt suggests that the northeast plunge of the South Nemocón anticline moved in relation to the southwest plunge of the North Nemocón strucutre. Further suggestive of movement to the southeast are the northwest-dipping reverse faults that bound the southeast flank of the southern extension of the North Nemocón anticline. The latter fault is a regional feature and has a trace of about 17 km. See plate 1, area b-3.

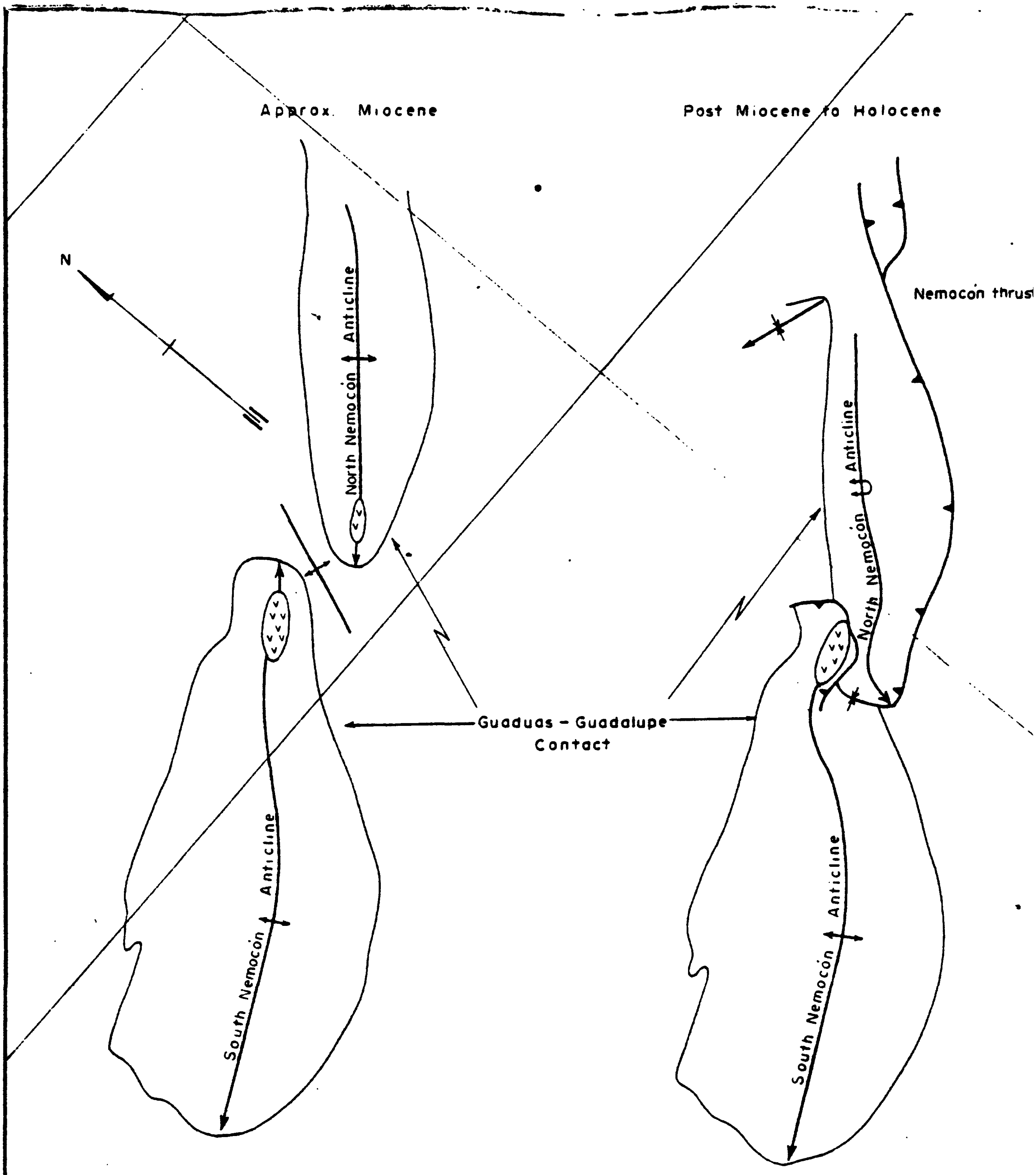


Figure 6. GENERALIZED PALINSPASTIC RECONSTRUCTION OF NEMOCON AREA

Scale 1:100,000

Salt

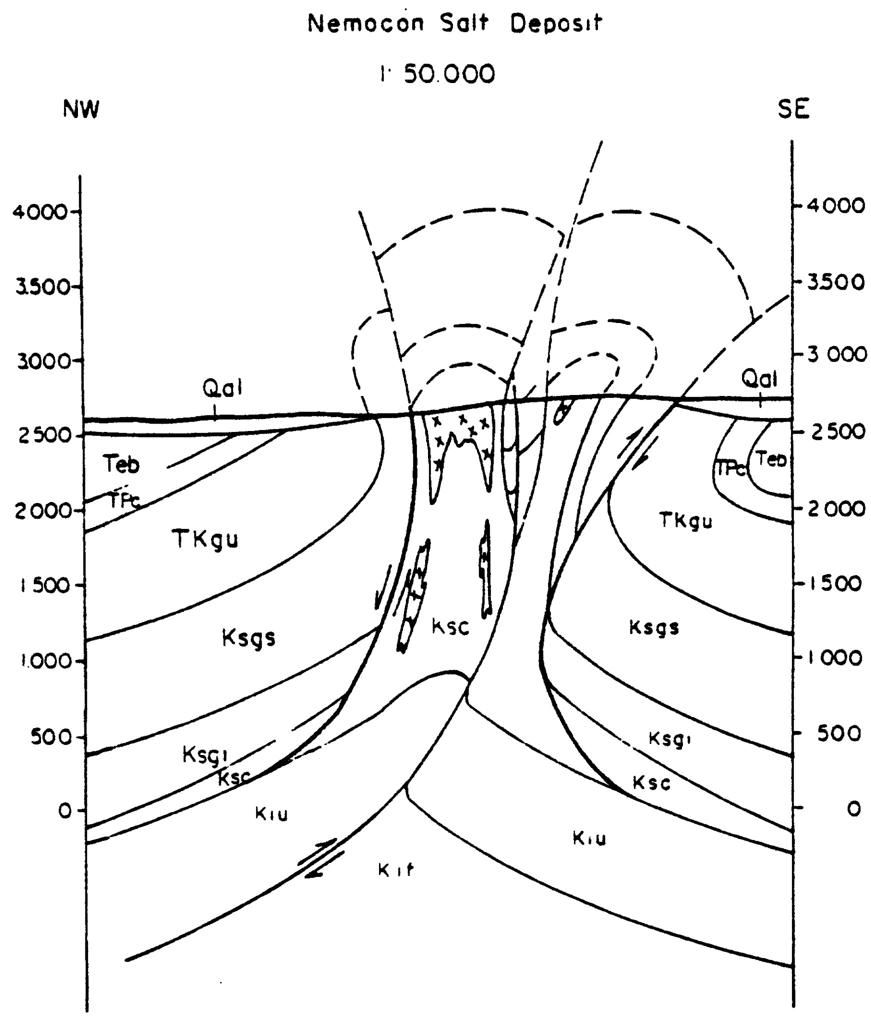


Figure 7. Diagrammatic cross section of the Nemocón salt deposit.

Tausa - The Tausa salt spring is on an anticlinal trend that has a mapped southerly extension of only 39 km. Further mapping to the north, however, will increase this figure considerably. The deposit from which the brines are derived lies in a salt-bearing wedge in the axial part of the Tausa anticline. The wedge has been upfaulted, placing the Chipaque Formation topographically and structurally higher than the adjacent Lower Guadalupe Formation (late Coniacian to Campanian). These relations are shown on figure 8 and plate 1.

Southwest of the former salt works, the northwest limit of the Tausa anticline is formed by a southeast-dipping reverse fault which extends at least 10 km to the southwest. About 4 km south of the salt works the reverse fault completely cuts out the northwest flank of the anticline, as illustrated on plate 1, areas b-2 and a-2. Small streams which are occasionally salty are reported in this region, suggesting that the Tausa deposit may extend further southwest than the salt residue that crops out 2 km southwest of the former salt works. The reverse fault may continue, veering to the south, across an alluviated valley, and reappear along the southeast border of the Cerros de Cogua, where the fault dips to the northwest and movement has been to the southeast. These relations are illustrated on plate 1, areas b-2, a-2, and a-3.

Sesquilé - The anticlinal trend that contains this deposit has a mapped axial extension of about 96 km. A former salt mine is located in the southern end of an upfaulted wedge of Chipaque claystone in the central part of the anticline. This wedge, yet to be proven salt-bearing

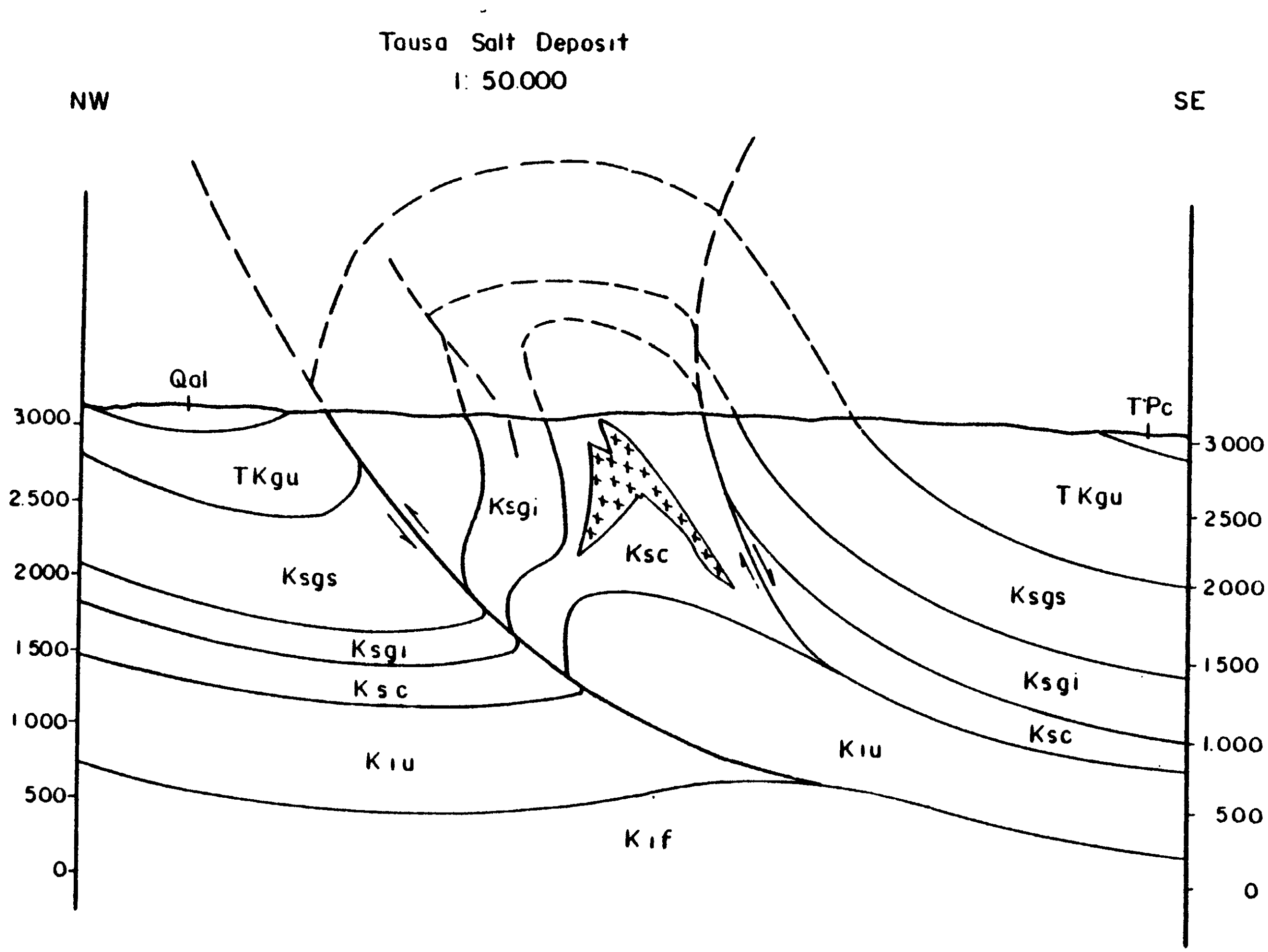


Figure 8. Diagrammatic section of the Tausa anticline.

north of the former salt mine, is capped by weathered salt residue; it is some 1500 m long and as much as 500 m wide. These structural relations are shown on figure 9 and plate 1, area b-4.

Tear faults are present southeast of the former mine portal, as may be seen on plate 1, area b-4.

Salt deposits inferred from surface structure

East of the Sabana de Bogotá generally poor exposures precluded detailed studies of other salt deposits. In the Sabana de Bogotá region the most promising salt prospects are continuations of known salt-bearing areas such as those at Zipaquirá, Sesquilé, and Tausa. About 3 to 4 km northwest of the Zipaquirá mine, in the Pantano Redondo area, (shown erroneously as Laguna Verde on pl. 1), surface mapping suggests the presence of salt at little depth. This is also true immediately north of the Sesquilé mine. Detailed mapping south of the Tausa salt spring indicates that salt may be continuously present toward the southwest over a distance of 9 km. About 20 km northeast of Bogotá, surface mapping indicates the possible presence of salt in the Pericos area. Hubach (1957b, pl. 1) notes a salt "excema" in this area and several of the local streams are reported to be salty at times.

GEOLOGY OF THE EVAPORITES

Surface exposures

Rute - The local mining term rute was introduced into the geologic literature by R. Scheibe (1933, p. 51-59). Rute is insoluble residue of salt-bearing strata remaining after leaching by meteoric waters. The bulk of rute is soft, black, marly, massive clay that contains fragments of black, marly, massive to shaly claystone of various sizes. Pyrite is

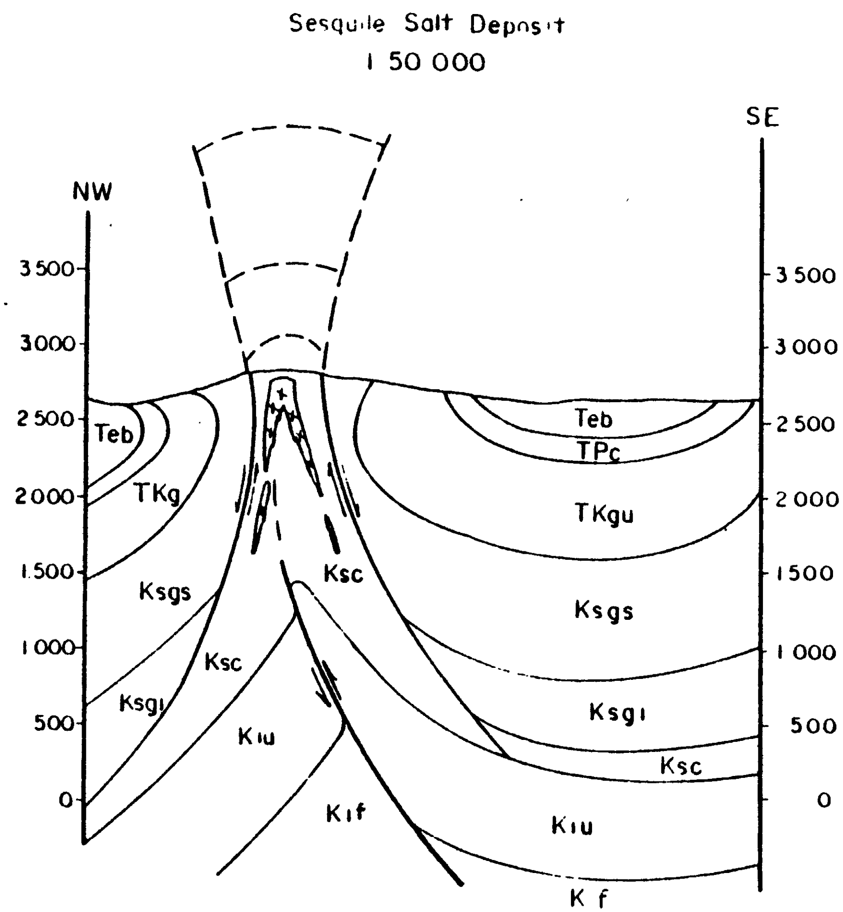


Figure 9. Diagrammatic section through the Sesquilé salt deposit.

common in all rute and is either in the claystone fragments or in disseminated grains. In addition to the insoluble materials derived from salt strata, rute commonly contains very coarse grained limestone in irregularly shaped fragments as much as 15 cm long that formed by secondary processes in the rute. The limestone is various shades of light gray and commonly emits a fetid odor from freshly broken surfaces. Locally these limestone fragments contain patches of native sulfur that coat calcite grains, the coarsest of which range to several millimeters.

Although rute is generally massive, faint outlines of slumped salt bedding can be seen in road cuts over the Zipaquirá mine and in landslide scars at Sesquilé. Thoroughly weathered rute, such as that at Sesquilé, is tan to gray, locally decalcified, and greatly resembles the Guaduas Formation. Millimeter-long quartz euhedra, probably formed by secondary origin throughout the Sesquilé rute, are abundant. In the Sesquilé rute, which underlies a narrow, high valley, limonitic cubes are pseudomorphic after pyrite. Why the Sesquilé rute flooring this valley is more weathered than rute elsewhere is not known. Perhaps overgrazing stripped off the protective grasses and allowed deeper weathering, erosion, and local slumping.

Chemical analyses of rute were made by the Laboratorio Quimico Nacional (table 1).

Table 1. Chemical analyses of rute from Zipaquirá and Nemocón (in percent)

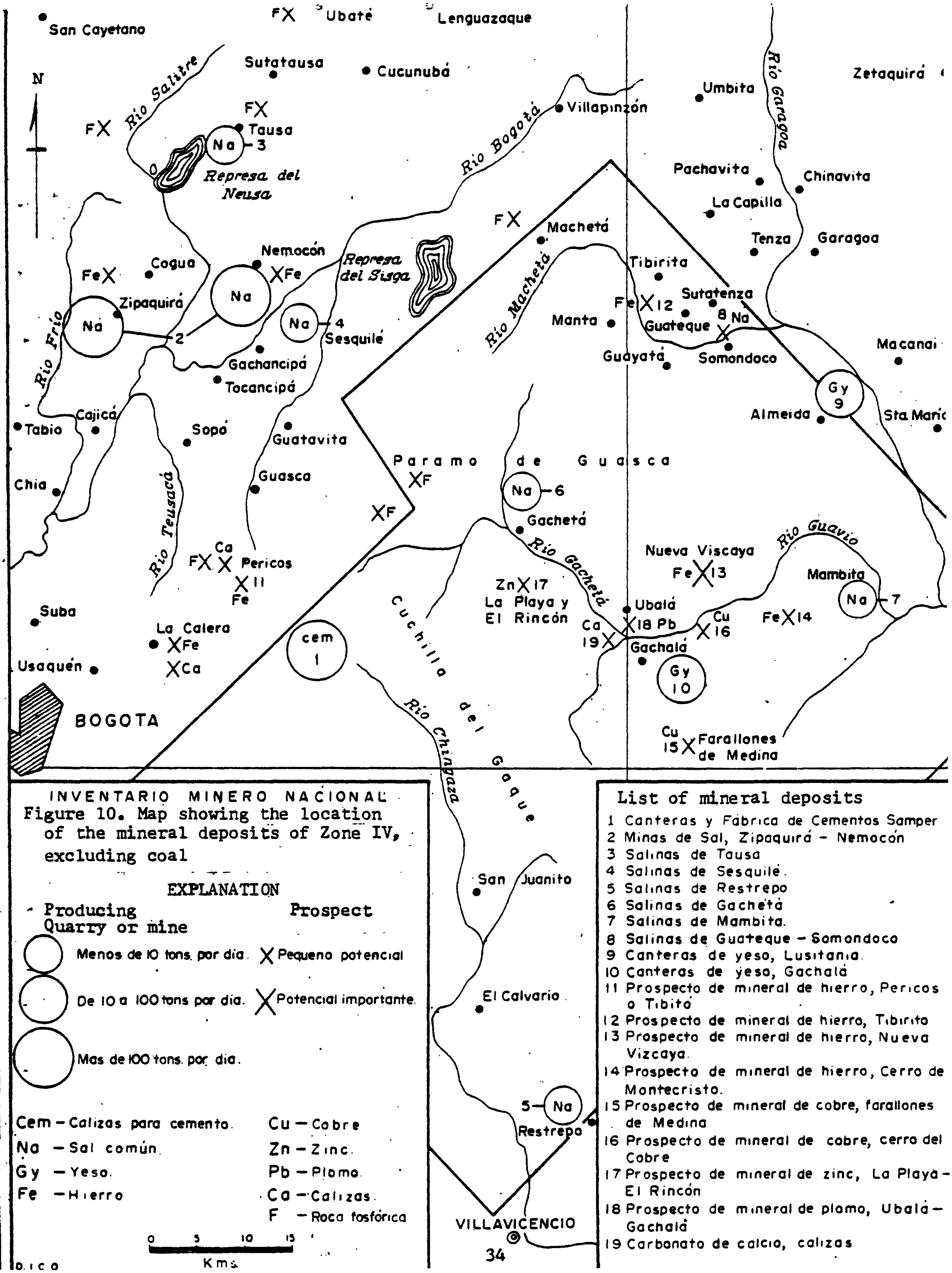
Minerals/compounds	Zipaquira	Nemocón
Halite	17.5	18.4
Pyrite	6.7	5.5
Anhydrite	11.9	3.2
Calcite	18.7	27.8
Magnesite	7.5	5.9
Clay minerals	32.3	23.4
Tri-calcium phosphate	0.4	0.5
Organic material	5.0	2.4
Sphalerite	0.0	0.3
Leucoxene	0.0	0.3
Quartz	0.0	11.5
H_2O plus	0.0	0.9
	100.0	100.1

This same laboratory did an analysis of the dump material from the Upín mine. Unfortunately they did not follow the same analytical procedures used for the Zipaquirá and Nemocón samples. Regardless, the results from the Upín dump sample are the following :

Minerals/compounds	Upín (percent)
Halite	5.84
Fe_2O_3	2.86
SiO_2	45.40
Al_2O_3	17.72
CaO	10.10
MgO	3.80
TiO_2	0.88
Zn	Trace
CO_2 and organic material	2.91
H_2O plus	2.16

The relatively low amount of halite in the dump is probably a reflection of the greater amount of rainfall that the Upín dump receives as compared with those of the Sabana de Bogotá. The greater amount of quartz, shown as SiO_2, is a reflection of the sand which appears to have been washed into the original evaporite lagoon, as mentioned on page 131.

Gypsum deposits - The outcrop of the deposit at Lusitania (fig. 10) is a chaotic mixture of gypsum in meter-thick lenses and broken, irregular, brecciated fragments. The gypsum is intimately associated with massive to shaly, pyritic, black, locally fossiliferous claystone. Accompanying these rocks is black, commonly calcareous muck which is identical to



INVENTARIO MINERO NACIONAL

Figure 10. Map showing the location of the mineral deposits of Zone IV, excluding coal

EXPLANATION

Producing Quarry or mine	Prospect
Menos de 10 tons. por día	Pequeno potencial
De 10 a 100 tons por día.	Potencial importante.
Mas de 100 tons. por dia.	

Cem — Calizas para cemento.	Cu — Cobre
Na — Sal común	Zn — Zinc
Gy — Yeso.	Pb — Plomo
Fe — Hierro	Ca — Calizas.
	F — Roca fosfórica

0 5 10 15 Kms.

List of mineral deposits

1 Canteras y Fábrica de Cementos Samper
2 Minas de Sal, Zipaquirá - Nemocón
3 Salinas de Tausa
4 Salinas de Sesquilé.
5 Salinas de Restrepo
6 Salinas de Gachetá
7 Salinas de Mambita.
8 Salinas de Guateque - Somondoco
9 Canteras de yeso, Lusitania.
10 Canteras de yeso, Gachalá
11 Prospecto de mineral de hierro, Pericos o Tibitó
12 Prospecto de mineral de hierro, Tibirita
13 Prospecto de mineral de hierro, Nueva Vizcaya.
14 Prospecto de mineral de hierro, Cerro de Montecristo.
15 Prospecto de mineral de cobre, farallones de Medina
16 Prospecto de mineral de cobre, cerro del Cobre
17 Prospecto de mineral de zinc, La Playa - El Rincón
18 Prospecto de mineral de plomo, Ubalá - Gachalá
19 Carbonato de calcio, calizas

the rute described above. Locally present, interbedded in the black claystone, are centimeter-thick lenses of fibrous calcite identical to that present in all the bedded salt deposits. Blocks of light grayish-tan, laminar, slightly pyritic limestone are local.

The senior writer did not have the opportunity to visit the Santa María de Batá or Gachalá gypsum deposits, but his Colombian collegues report that they are similar to the one at Lusitania.

Iron-rich sedimentary rocks - Two types of iron-rich sedimentary rocks are assoicated with salt strata. One is locally highly pyritic claystone that forms clasts and large bodies; the other is hematite-impregnated siltstone and fine-grained sandstone.

In the Sabana de Bogotá area the hematitic strata appear to be correlative with the salt deposits and are obviously spatially related to the salt at Nemocón and Tausa. Early Coniacian fossils were collected from these strata at Nemocón and La Caldera near the north end of the possibly salt-bearing wedge at Pantano Redondo several kilometers northwest of the Zipaquirá mine. Turonian fossils were found in the lowest part of the thick, hematitically impregnated sequence in the Pericos area 8 km southwest of Guasca (pl. 1). Above this main iron-bearing zone are thinner, less extensive hematitic strata that lie on strike with lower Coniacian claystone and are near a probable salt-bearing wedge from which rute has been reported by Hubach (1957b, p. 110 and pl. 1). Rute is in fault contact with hematitic strata in the Siberia region, about one km east of La Caldera.

Siderite float (Luis Castillo, written commun., 1967) is common in the forested region about 5 km north of the Salinas de Gachetá and may be derived from sedimentary siderite on strike with claystone at the Salinas.

Carbonaceous strata - The Berriasian-Valanginian salt interval locally contains carbonaceous material. Campbell and Burgl (1965, p. 576) state that plant remains and carbonaceous material are abundant in argillaceous strata of Berriasian age near Villavicencio. In the Río Upín, immediately south of the Upín mine, minor amounts of coaly material are present in the siltstone-claystone strata of the Cáqueza Group. Coal is reported (Justo Correal, oral commun., 1967) near Algodones, some 18 km east of Gachalá and about 7 km south-southwest of Mámbita.

No markedly carbonaceous strata have yet been found in the Barremian-lower Aptian salt sequence. During the senior writer's tenure in Colombia, however, this interval had not been studied in detail, as it lies in the Guavio quadrangle where mapping is still in progress.

In the upper Aptian interval small coal fragments were found in silty claystone, near rute, a short distance south of the Salinas de Gacheta.

At Hacienda San Bernardo, a few kilometers west of Choachí, two coal beds, the larger about a meter thick, lie within the Turonian-lower Coniacian salt interval. The thicker bed was exploited until recently. Several kilometers to the north, more coal crops out in this same general stratigraphic interval.

Mine exposures

Rock salt - Three operating salt mines (Zipaquirá, Nemocón, Upín) are the only localities where bedded rock salt can be seen. The salt is lithologically similar at all three deposits, and especially so in the

Zipaquirá and Nemocón mines which are only 16 km apart. Halite at Zipaquirá and Nemocón ranges in grain size from about 2 to 5 mm; halite in the Upín mine is somewhat finer grained. In all three mines halite ranges in color from light to dark gray, depending upon the amount of carbonaceous argillaceous impurities. Locally lenses and irregular patches are relatively pure aphanitic white salt. Large crystals having faces as much as 15 cm across are found in fractures in the interbedded claystone. Small pyrite crystals are locally present in the halite.

Disseminated clay and small claystone particles are ubiquitous throughout the salt of all three mines and are commonly distributed along the original halite bedding planes. The more argillaceous halite beds alternate with the less argillaceous, lighter colored beds, giving the rock salt a characteristic banded appearance throughout much of the mine workings. At Zipaquirá the darker layers alternate with lighter ones at the rate of 17 to 20 alterations per meter, a figure that probably also holds at Nemocón, although no measurements were made there. The layering at the Upín mine is generally somewhat thinner. Contacts between the light and dark layers are generally gradational. In many places, however, rock salt is not laminated but is massive. At Zipaquirá salt is light to medium gray and contains abundant minute to very small fragments of dark-gray to black claystone. Contacts between banded and nonbanded facies are vague. In many places the banded facies appears to grade laterally into the massive facies over distances of only several meters. Run-of-mine salt contains about 20 percent argillaceous impurities, according to the operators.

Claystone - Massive to shaly, pyritiferous, dark-gray to black, marly, carbonaceous claystone is abundant in all three mines. In general the massive claystone is harder than the shaly. Minor associated rocks include very dark brownish-gray, thinly stratified, fine-grained limestone and, rarely, white kaolinitic claystone. At places in the black claystone are lenses of fibrous calcite several centimeters thick and as much as 15 cm long.

Anhydrite - Massive, weakly indurated, fine-grained anhydrite sand is sparingly present at Zipaquirá. Only one small patch was seen at Nemocón and none was found at Upín. Beds of anhydrite range to a meter in thickness and the largest extends along strike for 70 m. At Zipaquirá most anhydrite is intimately associated with black claystone; both materials are brecciated. The anhydrite-claystone beds are rudely concordant with the enclosing salt strata, although in detail contacts are irregular. Included in the anhydrite-claystone in the southwest part of the main Zipaquirá level are numerous calcite rhombs as much as 5 mm long and quartz euhedra as much as 15 mm long. Orientation of both minerals in the anhydrite is random. Beds and filaments of light- to medium-gray claystone, as much as several millimeters thick, strike irregualrly through the anhydrite.

Locally minor amounts of anhydrite sand are associated directly with halite, and claystone is absent. The anhydrite is less stratiform than the more massive type and relations with the enclosing halite are less obviously concordant. No discrete grains of anhydrite were seen in halite beds, and the low sulfate content of the halite found by chemical analyses shows that little anhydrite is occluded there.

Sandstone - In the Zipaquirá mine Singewald (1949, p. 189) noted the presence of boulders of Guadalupe sandstone in the salt. These were not seen by the writer.

Fragments of brown, brownish-gray and gray, fine- to medium-grained quartz sandstone consitute a zone interbedded in the salt in the central part of the Upín mine. The sandstone fragments are in a matrix of black, sandy clay. Most of the clasts are soft; some are somewhat rounded. All sandstone clasts are impregnated with halite cubes that are slightly coarser than the sand grains in the sandstone.

Composition

Tables 2 and 3 list analyses of samples from the Zipaquirá and Upín mines, respectively.

Table 4 gives results of analyses of residues evaporated from brines collected in the Cordillera Oriental.

Trace elements - The following elements were found in trace amounts in five halite samples from Zipaquirá by six-step spectrography: magnesium, titanium, manganese, barium, cobalt, chromium, copper, germanium, phosphorus, nickel, tin, vanadium, strontium, lithium, rubidium, bromine, iodine, and zinc.

Minor amounts of potassium are present in most of the salt springs in the Cordillera Oriental and in most of the salt samples analyzed. The highest potassium content, 3 percent, was found in a claystone sample from Zipaquirá. Whether this potassium is in water-soluble salt or is bound with the probably illitic clay minerals is not known.

A small emerald was found in the Zipaquirá mine by Mr. Willis Bronkie (oral commun., 1965), the general manager of the Chivor Mines, the only private, large emerald mine. R. Scheibe (1933) reported an emerald found in the Quebrada de Las Salinas in the rute associated with the Nemocón salt deposit.

Table 2. Chemical analyses of five salt samples from the Zipaquirá mine (in percent)

[Br from Omar Raup (X-ray fluor.); no I detected.
Na_2O by flame photo (Mountjoy and Lipp).
SO_4 (not SO_3) on "acid" soluble (Lipp).
Other oxides by atom. abs. (Mountjoy).
Insolubles by Lipp. Acid insol. by 1:10 HCL/Cl
by AgCl gravimetric (Lipp); possibly should be rounded to 3 figures?]

Lab. No.	Field No.	Na_2O	Cl	K_2O	CaO	MgO	SO_4
Dl 20874	Z-1	52,0	59.62	0.02	0.33	0.10	0.04
Dl 20875	Z-2	47.5	54.62	0.39	1.03	0.24	0.44
Dl 20876	Z-3	46.9	53.86	0.32	1.86	0.50	0.05
Dl 20877	Z-4	50.8	58.48	0.18	0.51	0.15	0.46
Dl 20878	Z-5	49.7	57.33	0.17	0.93	0.18	0.16

Lab. No.	Field No.	Water Insol.	Acid. Insol.	Br. (ppm)	SrO (ppm)	Rb_2O (ppm)
Dl 20874	Z-1	0.87	0.46	25	10	12
Dl 20875	Z-2	7.90	6.02	Tr	50	11
Dl 20876	Z-3	9.43	5.52	25	16	11
Dl 20877	Z-4	2.03	1.77	65	10	5
Dl 20878	Z-5	3.90	2.54	20	115	5

Table 3. Chemical analyses of twelve salt samples from the Upin mine.

[Total Fe as Fe_2O_3, MgO, CaO, Na_2O, Sr, Li, Rb and Zn determined by atomic absorption by Wayne Mountjoy and Elsie Rowe.

P_2O_5 determined volumetrically by Roberta Wilkey.

SO_4, Cl determined gravimetrically by H. H. Lipp.

Water insoluble determined by water leach, acid insoluble determined by acid leach by H. H. Lipp.

Organic carbon determined on insoluble residue from 10 percent HCl, 2,000 g sample by I. C. Frost.]

Serial No.	Field No.	Total Fe as Fe_2O_3%	MgO %	CaO %	Na_2O %	K_2O %
D1 29058	R-1	0.34	0.35	1.34	47.4	0.35
D1 29059	R-2	0.25	0.28	0.87	49.8	0.23
D1 29060	R-3	0.13	0.20	0.61	51.2	0.10
D1 29061	R-4	0.31	0.31	1.08	48.7	0.29
D1 29062	R-5	0.26	0.23	0.89	49.1	0.23
D1 29063	R-6	0.46	0.38	1.45	46.2	0.47
D1 29064	R-7	0.39	0.34	0.98	48.0	0.36
D1 29065	R-8	0.26	0.24	0.87	49.3	0.48
D1 29066	R-9	0.42	0.38	1.18	47.1	0.42
D1 29067	R-10	0.09	0.15	0.66	51.9	0.07
D1 29068	R-11	0.14	0.19	0.34	51.2	0.10
D1 29069	R-12	0.46	0.34	1.32	46.8	0.40

Table 3 - continued

Serial No.	Field No.	P_2O_5%	SO_4%	Cl %	Sr ppm	Li ppm	Rb ppm
D1 29058	R-1	0.05	1.33	53.1	82	6.4	14
D1 29059	R-2	0.05	0.74	55.9	51	3.6	10
D1 29060	R-3	0.05	0.51	57.4	30	2.8	5
D1 29061	R-4	0.05	1.00	55.1	53	4.6	12
D1 29062	R-5	0.05	0.76	55.7	35	4.5	13
D1 29063	R-6	0.05	0.50	51.9	42	5.6	17
D1 29064	R-7	0.05	0.51	53.7	41	5.8	16
D1 29065	R-8	0.05	0.34	55.2	34	4.4	13
D1 29066	R-9	0.05	0.67	53.0	50	7.0	17
D1 29067	R-10	0.05	0.63	58.0	22	1.8	4
D1-29068	R-11	0.05	0.19	59.1	6	2.6	5
D1 29069	R-12	0.05	0.23	52.4	38	6.3	19

Serial No.	Field No.	Zn ppm	Organic Carbon %	Water Insol %	Acid Insol %
D1-29058	R-1	8.0	0.22	7.76	7.21
D1-29059	R-2	8.0	0.15	5.68	4.17
D1-29060	R-3	6.4	0.10	2.60	2.19
D1 29061	R-4	6.2	0.17	6.42	5.27
D1 29062	R-5	6.4	0.22	5.86	4.95
D1 29063	R-6	10.3	0.29	11.7	8.36
D1 29064	R-7	9.6	0.20	9.50	7.32
D1 29065	R-8	16.8	0.16	7.28	5.94
D1 29066	R-9	12.7	0.30	4.66	7.27
D1 29067	R-10	4.0	0.10	0.91	1.51
D1 29068	R-11	3.0	0.12	1.11	1.98
D1 29069	R-12	14.4	0.29	5.97	7.95

Table 3 - continued

Serial No.	Field No.	Br ppm	I ppm
D1 29058	R-1	32	0.2
D1 29059	R-2	40	0.2
D1 29060	R-3	34	0.2
D1 29061	R-4	23	0.2
D1 29062	R-5	34	0.2
D1 29063	R-6	22	0.2
D1 29064	R-7	42	0.2
D1 29065	R-8	40	0.2
D1 29066	R-9	18	0.2
D1 29067	R-10	26	0.2
D1 29068	R-11	32	0.2
D1 29069	R-12	39	0.2

Table 4. Analyses of 26 water residues from saline springs in the Cordillera Oriental.

[Br and I determined by X-ray fluorescence by J. S. Wahlberg.

All samples except D1 29060, D1 29067, and D1 29068 showed 0.7 percent K in six-step spectrographic analyses, which represents a slight increase in the amount of potassium present in the Zipaquirá mine.]

Serial No.	Filed No.	K_2O %	Br ppm	I ppm
D1 22197	IMN 15313	0.01	22.	0,20
D1 22198	IMN 15314	0.03	47.	0.22
D1 22199	IMN 15315	0.01	20.	0.12
D1 22200	IMN 15317	0.04	29.	0.22
D1 22201	IMN 15318	0.80 x	-	-
D1 22202	IMN 15321	0,11	650.	100.
D1D22203	IMN 15323	0.09	-	-
D1 22204	IMN 15324	1,17	170.	24.
D1 22205	IMN 15325	1.36	-	-
D1 22206	IMN 15327	0.73	74.	22.
D1 22207	IMN 15328	0.53	64.	1.9
D1 22208	IMN 15330	0.62	-	-
D1 22209	IMN 15332	0.07	60.	0.6
D1 22210	IMN 15333	0.01	54.	0.05

Table 4 - continued

Serial No.	Filed No.	K_2O %	Br ppm	I ppm
D1 22211	IMN 15334	0.13	44.	2.6
D1 22212	IMN 15335	1,50	460.	5.2
D1 22213	IMN 15336	2.2 x	-	-
D1 22214	IMN 15338	0,08	23.	0.45
D1 22215	IMN 15339	3.41	460.	15.
D1 22216	IMN 15340	0.04	40.	1.3
D1 22217	IMN 15341	0.03	41.	0.75
D1 22218	IMN 15344	0.10	29.	0.05
D1 22219	IMN 15345	0.03	26.	0.22
D1 22220	IMN 15347	1.93	650.	9.
D1 22221	IMN 15348	0.22	-	-
D1 22222	IMN 15349	0.18	274.	19.

x = On basis of very small sample. Usual accuracy may not apply.

K_2O determined by atomic absorption by Wayne Mountjoy

Br and I determined by X-ray fluorescence by J. S. Wahlbert.

Sedimentary structure of the deposits

Laminated halite - Lamination is a characteristic feature of most halite exposed in Colombian salt mines and has been attributed to tectonism (Singewald, 1949, p. 189). However, if halite laminae in salt domes that have risen hundreds or thousands of meters is a relic sedimentary structure, as is considered by some workers (Muehlberger, 1968, p. 360), it is unlikely that laminae in the relatively less deformed Colombian halite is solely of tectonic origin. Rather it is concluded here that the laminae of Colombian halite are inherited from sedimentary bedding, a view supported by evidence given in the following paragraphs.

Crossbedding and truncation - Gentle crossbedding and truncation are locally present in the laminated salt facies on the north side of the main level of the Zipaquirá mine. Angles of truncation are generally from 5° to 10°, although some may be greater locally. Zones of gently forset salt strata may be present also. More crossbeds are probably present than were recognized, as detailed examination of much of the halite in the Zipaquirá mine is impossible because of poor illumination and heavy dust cover on the mine walls. Other areas in Zipaquirá as well as the entire Nemocón and Upín mines, are much more structurally deformed than the north side of the main level at Zipaquirá; to distinguish with confidence sedimentary from structural phenomena at those places is not possible.

Claystone clasts and beds - Claystone clasts are abundant in all three salt mines. They range from small flakes less than a millimeter to a few individual clasts about a meter in diameter; the majority are between several millimeters and several centimeters in size. The clasts generally are randomly scattered throughout the halite, as may be seen in figures 11 and 12. Individuals of all sizes are relatively isolated from other clasts. Numerous smaller clasts are aligned along the salt bedding planes in brecciated zones as much as several meters long. However, in virtually all exposures, the halite layers immediately adjacent to the clasts and zones of clasts were emplaced by sedimentary rather than structural processes.

Claystone bodies of mappable size and conformable with the enclosing laminated halite are present in all mines. At Zipaquirá the claystone bodies are as much as 80 m long and from 5 to 20 m thick. Where deformation is relatively slight, as in part of the Zipaquirá main level, several of these large bodies are aligned approximately along what is probably the same general stratigraphic

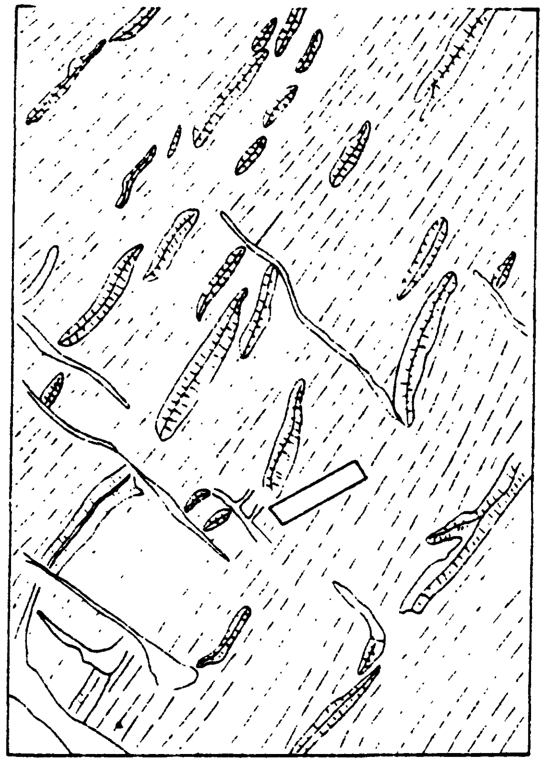


Figure 11– Lenses of fibrous calcite with well developed septa. Lenses lie in the plane of the bedding Clear areas are composed of secondary halite Taken in the church of the Zipaquirá mine from a photograph. Scale is 10 centimeters in length.

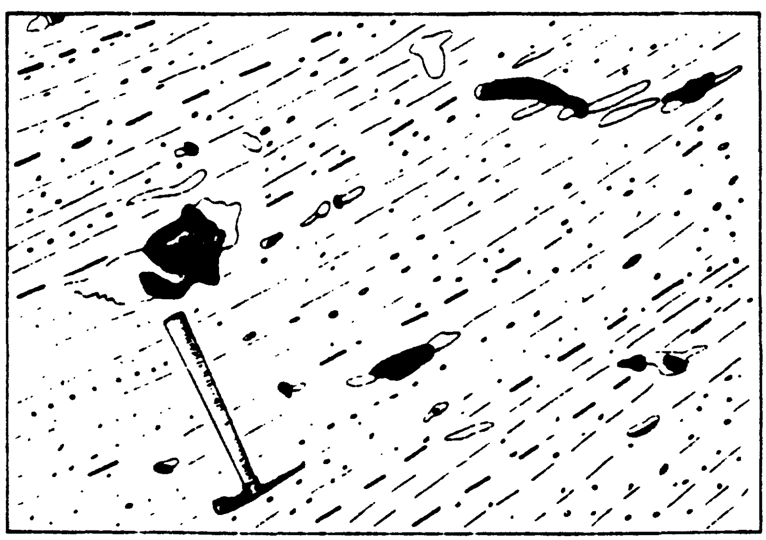


Figure 12 Argillaceous salt containing numerous claystone clasts the larger of which have secondary halite halos, indicated by the clear areas. Bedding is less well developed than in the areas of less clasts. Taken on the church level of the Zipaquirá mine from a photograph

interval and are separated along strike by as little as 40 meters of halite. Along strike these large bodies terminate abruptly at high angles to both their bedding and that of the enclosing halite. Many of the claystone bodies are folded and faulted in the more structurally complex parts of the mines.

Large claystone bodies are not as common in the Upín mine. Only three were mapped. They are much smaller than those at Zipaquirá and Nemocón and only about a meter thick. However, as the Upín mine is small, more such bodies may exist in other parts of the deposit yet unreached by mine workings.

<u>Basal contact of halite in the Zipaquirá mine</u> - The basal halite contact in the Zipaquirá mine is interpreted as the base of the halite sequence for the following reasons:

(1) The halite-claystone contact extends about 600 meters along the northeast limit of the Zipaquirá mine. The length of the contact — about 7.5 times the length of the largest claystone body mapped in the mine — suggests that the underlying claystone is not just another claystone body interbedded in the halite sequence. See plate 6.

(2) The attitude of the contact is conformable not only with the overlying salt strata but also with the underlying rocks exposed on the surface.

(3) The claystone beneath the contact in the mine is lithologically unlike that within the halite throughout the mine. The claystone underlying the contact is plastic and massive; in many

places it is a clay rather than a claystone. Its colors range from locally tan to brownish gray and black. The black facies is pyritic in places and contains brecciated fragments of black claystone similar to that enclosed in halite elsewhere. The clay and claystone below the contact are not marly, whereas virtually all argillaceous rocks in the overlying halite sequence are.

(4) At times fresh water seeps into the mine along the contact. While the present study was in progress, fresh-water seepage had completely undercut a large pillar of salt adjacent to the contact. Seepages occur elsewhere in the mine but they are all briny, resulting from meteoric waters filtering through the salt residue that caps the deposit. Where the basal clay is exposed in the mine workings, it contains zones of hair-like acicular melanterite ($FeSO_4 \cdot 7H_2O$) and halite crystals, some more than a centimeter long and rodlike: others are shorter and curly. These crystals are found elsewhere only where normal halite is dissolved by fresh water.

(5) No salt has been reported northeast of the contact.

Internal structure of halite deposits

Zipaquirá - With local exceptions lamination of the salt shows relatively little range of attitude throughout the north half of the main level (pl.6). The average strike of the halite beds is N. 40° to 50° W., and the generally southwest dips are moderate to gentle, verging on the horizontal in some places. If the reversal of dip in the central part of the mine (pl.6) is synclinal, it probably is part of a large satellitic fold on the northwest flank of the overturned and faulted anticline which contains the Zipaquirá salt deposit. If the reversal is caused by faulting, the fault is probably related to an upthrust salt-bearing wedge of Chipaque claystone. This inferred wedge would lie in the crestal area of the anticline. Of these two possibilities the writer favors faulting (fig. 5). Other interpretations are also possible.

The synclinal axis is the stratigraphic top of the salt sequence. The halite appears to be about 180 meters thick if poorly understood sedimentary and tectonic minor structures are ignored. Such structures include isoclinal flow folds where crestal reversal is not seen, and flowage lensing resulting from tectonic deformation. Local salt flowage is common adjacent to the sharp terminations of the large claystone bodies. Here salt has locally turned in toward the claystone terminations, showing a tendency to wrap itself around them. Flow folds are only locally present at Zipaquirá and other mines. Flow fold axes are generally horizontal.

Nemocón - The Nemocón salt deposit, considerably more complex structurally than Zipaquirá (compare pls. 5 and 7), appears to occupy a small, steep-flanked, south-plunging fold. Exposures are insufficient to determine the nature of this fold owing to the relatively small extent of the mine workings and the structural complexity of the deposit. The writer considers, however, that the fold is probably an anticline, as it lies along the northeast extension of the northeast-plunging axis of the South Nemocón anticline.

Timbering obscured the salt-country rock contact, precluding determination of its nature, and structure complicates the salt stratigraphy. The thickness of the Nemocón salt deposit is therefore much in doubt.

Despite these problems, the Nemocón salt may by only slightly thinner than the section at Zipaquirá.

Upín - The outline of the present mine workings is roughly an equilateral triangle with sides approximately 100 meters long. The east side is north-south. The mine portal is at the south apex. Salt strata in the southwest half of the mine strike from N. 40° to 50° W.; dips are moderately to steeply southwest and are locally vertical in the extreme southwest part of the mine. The structure in the northeast half of the mine is more variable; the salt strata here have a general north strike and dip steeply to the west. (See pls. 3 and 8). Preliminary study suggest that the salt strata at Upín are between 60 and 80 meters thick.

Sesquilé - Entry to the Sesquilé mine is now impossible because of caving. Singewald (1949, p. 191), who visited the mine, states that the salt strata dip to the west.

Depositional environment

Size and location of evaporite pans

Information about the size and location of the evaporite pans is meager, especially those older than Turonian east of the Sabana de Bogotá. All that is known about the numerous salt springs beyond Zone IV (fig. 4) is that they are either in black claystone or alluvium which covers black claystone (Zambrano and Mojica, oral commun., 1966).

Berriasian-Valanginian - As mentioned earlier the gypsum deposits at Lusitania, near Santa María de Batá, and near Gachalá are probably equivalent and correlative with the salt at Upín and Mámbita. Whether these five deposits are part of one large evaporite pan or several smaller ones is not known. If a single large pan existed here, its northeast-southwest dimension would be at least 70 km; its minimum northwest-northeast extent would be about 30 km. The pan may continue southeastward beyong the mountain front, passing below the Llanos. To the northwest the evaporite pan probably passes under younger strata and may extend for an unknown distance.

Upper Barremian-lower Aptian - In Zone IV evidence for salt of this stratigraphic interval is limited to the one salt spring near Somondoco. Therefore at the present writing (1969) nothing is known of the dimensions or location of the evaporite pan within this interval.

Upper Aptian - As evidence of Upper Aptian evaporites is limited to the salt springs near Choachí and north of Gachetá, little can be surmised regarding the dimensions and location of this evaporite pan. As these two springs are about 50 km apart, the salt forming them may have been deposited in a northeast-trending pan about 50 km long. Possibly the evaporite pan was discontinuous and deposition limited to small, local lenses of salt.

Turonian-lower Coniacian - The salt mines and much evidence of salt in the Sabana de Bogotá, plus the numerous salt springs to the north and in the Upper Cretaceous rocks to the southwest suggest that the Turonian-lower Coniacian evaporite facies is widespread and may extend from the Pandi-Girardot area in the southwest to the Málaga-Guasca area in the north. (See fig. 4), or over an area 350 km long and from 50 to 100 km wide. Field evidence in the Sabana de Bogotá and adjacent regions suggests, however, that this large area is not underlain by a single evaporite pan but probably by several. Examination southwest of Bogotá shows a gap in salt spring distribution, as may be seen on figure 4 . North and northwest of the Sabana de Bogotá the Turonian-lower Coniacian beds, known as the La Frontera facies, consist of dark-gray to black, marly, concretionary, locally fossiliferous claystone. To the west similar strata crop out near Albán on the road between Facatativa and Villeta (Champetier de Ribes and others, 1961; Thompson, 1967, p. 10 and 16). To the east are lower Coniacian silty claystone and coal beds in the region between Choachí and Machetá. None of these exposures contains rute or anhydrite, nor are there any indications that these materials were once present and subsequently removed. Therefore the salt facies or pan in the Sabana de Bogotá area is probably about 40 km wide and possibly 100 km long.

Facies relationships within salt intervals

The equivalence of salt, hematitically impregnated siltstone, and fine-grained sandstone, and cealy, silty claystone has been established on fossil evidence. This tripartite facies association is best exposed in the Turonian-lower Coniacian interval in the Sabana de Bogotá. Whether or not this association also exists in the older salt sequences is not known because exposures are poor.

Argillaceous material associated with salt - The abundant argillaceous material associated with the salt deposits was derived by erosion of the claystone that flanked the evaporite pans. The clay forming a dark, argillaceous laminae was washed into the evaporite pans periodically and flocculated by the brines.

The large claystone bodies in the salt are of similar origin but involve a much greater amount of argillaceous material than that in the laminae. Heavily clay laden streams, probably fresh-water, entered the evaporite pans when evaporite deposition temporarily ceased, either due to dilution of the brines by fresh water entry or, more likely, by a temporary retreat of the brines as a result of small-scale regional warping. Local uplift due to the warping exposed more surrounding claystone to erosion, increased stream gradients, widened local watersheds, and resulted in larger, more heavily clay laden streams entering the evaporite pans. The abrupt lateral terminations of these claystone bodies, indicated on the various mine maps, were probably caused when streams dissolved the salt beneath them faster than that flanking them. Several contemporaneous streams or meanders of the same stream across the floor of the evaporite pans may have resulted in the apparent alignments of some of the claystone bodies.

The emplacement of the various sized, generally small claystone clasts is less easily visualized. As mentioned above, they are probably of sedimentary origin. The minute, nonaligned clasts or particles of claystone present throughout the halite of all mines may have been formed by the flocculation of clay swept into the pans. Once flocculated, the particles would then settle slowly to the bottom and become incorporated with the halite crystals accumulating there. The abundance of these small particles suggests that this process continued, essentially uninterrupted, throughout the deposition of the salt. The zones of clasts aligned along the bedding are suggestive of collapse of former claystone beds. Such a collapse implies the gradual removal of the underlying halite, presumably by solution caused by less saturated brines.

As the supporting halite was removed, the overlying claystone bed would settle slowly into the resulting void, fragmenting in the process because of various rates of settling. Minor transport of some of these clasts by current action is implied by the rounded edges on a few of them. The isolated clasts were probably emplaced by currents in the brine pans as there commonly is no evidence of structural deformation in the enclosing halite. A few of these clasts in Zipaquirá and Nemocón are somewhat rounded; sandstone clasts in Upín is definitely rounded.

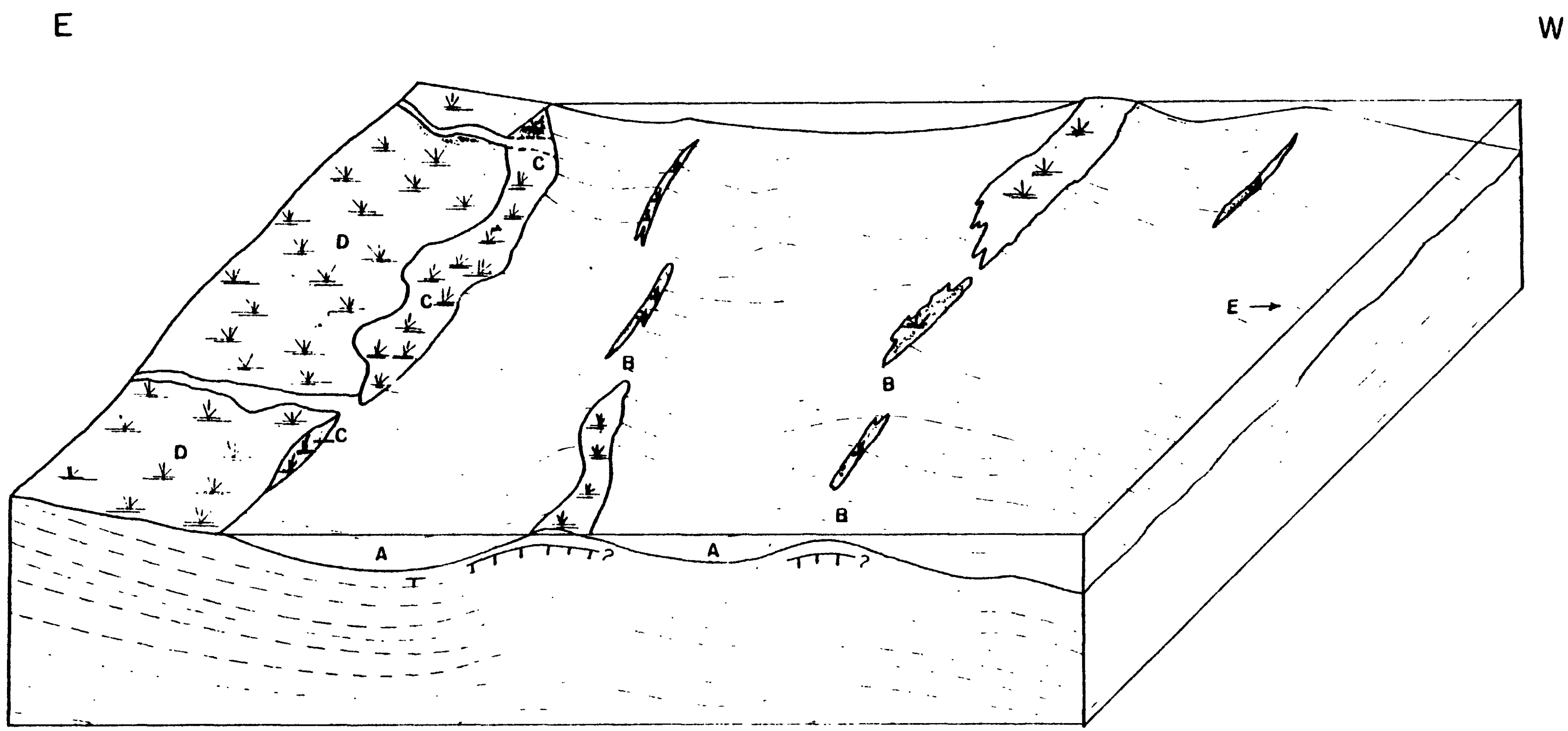
<u>Significance of iron</u> - Hematite, pyrite, and probably siderite are present in strata associated with salt facies. Hematite-impregnated siltstone and fine-grained sandstone are adjacent to the Nemocón deposit, associated with the rute at Tausa, and crop out at the Pericos and Pantano Redondo salt prospects. Pyrite is common throughout much of the Cretaceous strata but is abundant in the black claystone associated with the halite in all salt mines. Siderite float is present in the area of Fómeque outcrop about 5 km northeast along strike from the Salinas de Gachetá.

Hematite is considered to have been deposited in the porous strata of the Chipaque Formation in the topographically higher barrier areas where waters were probably well oxygenated. Pyrite was formed in the topographically low, restricted regions of poor ventilation and reducing conditions which comprised the evaporite pans. Siderite was probably precipitated under conditions intermediate between those which resulted in hematite and pyrite. These facies relationships are illustrated schematically in figure 13 and seemingly conform to the ideas of James (1954, fig. 3) and Woolnough (1937).

Significance of carbonaceous material - Carbonaceous material is present throughout the Cretaceous silty claystone section of the Cordillera Oriental but is most prevalent in the Berriasian-Valanginian (Campbell and Bürgl, 1965, p. 576) and Turonian-lower Coniacian salt sequences. Carbonaceous strata suggest a generally quiet, shallow-water environment. The greater amount of these strata in the two salt facies suggests that shoaly regions of increased plant growth may have acted as barriers to water circulation and aided in the formation of evaporites.

Sulfate deficiency

As noted above, anhydrite is only sparingly present in the three operating salt mines of the Cordillera Oriental, and the comparatively well exposed Turonian-lower Coniacian interval is devoid of gypsum on the outcrop. The three gypsum deposits in the Berriasian-Valanginian interval may have been formed by local refluxing of sea water (King, 1947), a phenomenon which apparently did not occur during the Turonian-early Coniacian. A possible alternative to refluxing, however, involves the leaching of considerable amounts of halite, which resulted in the collapsed, chaotic aspect of these deposits. If this halite were sulfate deficient, a more or less continuous supply of sulfate must have moved up faults into the zone of meteoric leaching and resulted in the concentration of anhydrite that was soon hydrolized to gypsum. As the gypsum deposits are in structurally complex areas adjacent to the Quetame uplift (fig. 2), the tectonic emplacement of halite over short distances might be expected.



A – Evaporite basins, restricted, euxinic conditions. NaCl & FeS_2 plus clay

B – Sills forming margins of evaporite basins. Oxidizing condition. Fe_2O_3 & $FeCO_3$?

Part of sill which is above water. Possible plant growth

C – Coastal, Marginal, marine swamps. Plant growth well developed

D – Landmass forming edge of lagoonal environment. Fresh streams drain into lagoons

E – Direction of open, ventilated marine waters

DIAGRAM OF SUGGESTED SALINE ENVIRONMENT OF DEPOSITION

Figure 13

The lack of sulfate in the Turonian-lower Coniacian deposits is perhaps more normal than is generally considered. Experiments by Usiglio in the last century (Borchert and Muir, 1964, p. 74) show that the ratio between $CaSO_4$ and NaCl is 1:30 after evaporation of sea water. This suggests that the evaporite deposits elsewhere that contain considerable anhydrite are anomalous, rather than that the sulfate-deficient deposits.

In the Colombian deposits the apparently small amount of sulfate dissolved in the brines may have been further diminished by bacterial reduction in the presence of a continuing supply of organic material that was swept in from the sea. This sulfate reduction would produce H_2S and $CaCO_3$. The H_2S would combine with the ferric hydrosols bacterially to form pyrite; the $CaCO_3$ would be deposited with the claystone. This would explain both the abundance of pyrite and the marly nature of virtually all the claystone associated with halite, in contrast to the surrounding claystone of the Caqueza and Chipaque Formations, which are only locally pyritic and generally noncalcareous. Some of the pyrite may have also been formed by bacterial reduction of nonoxidized organic material, which resulted in H_2S to combine with iron in solution to form pyrite (James, 1954, p. 242).

The sulfate that remained unreduced in the brines may have provided the small amount of anhydrite present in the halite sequence.

Oxygen deficiency

In addition to sulfate deficiency, the black organic claystone associated with the halite suggests that the claystone was deposited in an oxygen-poor, euxinic environment. Oxygen deficiency may have resulted as follows: (1) Oxygen has a low solubility in chloride brines (Peterson and Hite, 1969, p. 906). (2) The constant influx of sea water into the poorly ventilated and restricted evaporite pans undoubtedly swept in countless organisms which soon died and were decomposed, further depleting the oxygen supply of the brines. (3) The presumably high temperatures of the brines would also reduce the amount of dissolved oxygen that the brines could contain.

Climate

The only fundamental climatic requirement for the development of an evaporite depositional regime is that evaporation exceed precipitation plus inflow. Although these conditions are better met under arid climatic conditions, evaporite deposition is not necessarily limited to arid climates. The Cordillera Oriental may be a case in point. Had these deposits been developed under arid conditions, this would have been undoubtedly reflected in the regional stratigraphy. Carbonaceous strata would not be correlative with the salt sequence, and red beds would probably be more extensive.

The climatic regime in the region of the present Cordillera Oriental during the Cretaceous period was probably one of hot, relatively dry seasons alternating with hot, rainy seasons, an alteration which is reflected in the laminate of the halite. The dark, argillaceous halite laminae may have resulted from seasonal changes and the larger, mappable claystone bodies possibly resulted from effects of more pronounced climatic changes, in addition to a slight lowering of sea level.

The more pronounced climatic conditions probably involved longer periods of rainfall and minor seasonal fluctuations.

Post-depositional changes

Solution and recrystallization

Massive halite. - In all the mines where laminated halite facies is locally absent, the halite contains randomly disseminated argillaceous material and is massive. Destruction of the halite laminae is probably due to post-depositional recrystallization rather than to syndepositional mixing. Although other evidence suggests that syndepositional currents were probably operative, it is doubtful that they were capable of reconstituting halite strata as much as five meters thick, although they may have locally destroyed laminae in thinner intervals. If syndepositional mixing had obliterated the laminate, massive halite resulting from such action would not grade laterally as abruptly into the laminated facies. Meteoric waters must have entered the salt deposits at various times, especially during the formation of the rute caps, and water continues to enter the mines causing local recrystallization.

Anhydrite sand - The largest body of anhydrite sand in the Zipaquirá mine lies directly under the surface stream that has cut a small channel over the southwest part of the mine. During the rainy season water from this stream seeps into the mine, dissolves the salt, and flows along the claystone bedding and fractures where the leached anhydrite is concentrated. Most other bodies of anhydrite sand are associated with claystone. Only a few claystone bodies, however, are associated with anhydrite.

During the latter part of July 1968 the anhydrite in the southwest part of the Zipaquirá main level collapsed, leaving a jumble of huge salt blocks underground and a small lake on the surface overlying the collapse. As a consequence, all operations in this part of the mine have been suspended. Thus an abundance of anhydrite sand can be considered as indicating an excessive inflow of fresh water into the mine and can create extremely hazardous operating conditions.

In various places anhydrite sand occurs directly with halite and is not noticeably associated with claystone. The halite associated with the anhydrite sand is generally massive, the bedding having been obliterated by solution and recrystallization.

Gypsum at Lusitania, Santa María de Batá, and Gachalá - Rocks associated with these gypsum deposits indicate but do not prove that the deposits may be acculmulations of insoluble residual material associated originally with halite, and concentrated as the halite was leached by meteoric waters. The general collapse aspect of the deposits further supports this contention.

Low bromine content of halite - Five samples of typical run-of-mine halite was collected through the 180-meter thick section in the north part of the main level of the Zipaquirá mine. The average bromine content of these samples is 25 ppm and ranges from "trace" to 65 ppm. No trend in bromine content is apparent from these analyses. Eleven samples of halite were collected randomly in the Upín mine where the stratigraphic succession is not as obvious as in Zipaquirá.

The average Upín bromine content is 31.3 ppm and ranges from 18 to 42 ppm. Studies (as noted by Holser, 1966, p. 253), indicate that the first halite to be deposited normally has a bromine content of 75 parts per million which commonly increases upward in the section.

The low bromine content of various samples further suggests that solution and recrystallization of primary halite has taken place. The absence of hopper crystals (Dellwig, 1955, p. 89), generally considered as proof of primary recrystallization (Holser, 1966, p. 260), would suggest solution and recrystallization of all Colombian rock salt. That "trace" amounts of bromine were found in at least one sample suggests solution and recrystallization by meteoric water rather than by unsaturated brines (Holser, 1966, p. 264).

Halite halos associated with claystone clasts - Throughout all three salt mines are claystone clasts which are partially or locally completely encircled by white, relatively pure halos of very fine-grained to aphanitic secondary halite; the halos are roughly concordant with the enclosing halite laminae everywhere except a small area in the Zipaquirá upper level. Here the halite halo orientation departs a few degrees from the enclosing halite bedding, probably in response to local tectonism. Although all but the smallest clasts may have halos, they are more prominent among the smaller to medium sized clasts. An average-sized clast (diameter about 5 cm) may have a halo or partial halo that extends some 10 cm along the enclosing bedding before pinching out. The halos are widest immediately adjacent to the clasts; their widths generally correspond to the diameters of the clasts. Clasts and associated halos are illustrated in figure 12.

The halos are considered to have been formed by halite recrystallization in pressure shadows that ringed the claystone clasts (E. Irving, oral commun., 1965). The pressure shadows were formed in zones of lesser lithostatic pressure which surrounded the clasts and became more pronounced as halite deposition increased. The clasts, being more competent than halite, prevented the encircling halite from compacting as thoroughly as elsewhere, resulting in rings of lesser lithostatic pressure in which halite recrystallization was favored. Had they been mainly of tectonic origin, the halos would be oriented normal to the prevailing stress direction and not necessarily parallel to the halite bedding.

Although almost halite halos are nontectonic, their origin is similar to that of secondary crystallization of quartz which commonly encircles porphyroblasts in schists and lies in the plane of schistocity (T. Feininger, oral commun., 1969).

Large halite crystals and veins - Clear halite crystals are locally present in fractured areas of the large claystone bodies. Perfect cubic crystals are commonly several centimeters along a face. Larger, elongated crystals may be as much as 15 cm long.

Clear halite veins, several centimeters in width, are commonly in interbedded claystone bodies at verying angles to the bedding. Somewhat thicker veins are present in the prominent anhydrite area in the southwest part of the Zipaquirá main level.

Sulfate reduction

Gas inclusions - In several places in the Zipaquirá main level the dark-gray, argillaceous, generally massive salt contains considerable H_2S.

This gassy facies commonly has a characteristic exfoliated type of jointing on the faces of the mine workings and decrepitates when struck lightly with a hammer, giving a crackling or popping sound. The gassy halite is not confined to any particular stratigraphic interval. No gassy halite has yet been encountered in the smaller Nemocón and Upín mines, although all mines contain argillaceous halite fron which fresh surfaces emit a fetid odor.

The gas contained in the halite implies bacterial decomposition of sulfates or organic material which was trapped in the clay fraction and buried during deposition.

Fibrous calcite lenses - Numerous sharply defined, elliptical lenses of light-colored, thickly fibrous calcite are associated with several large, marly claystone bodies. These lenses, as much as 20 cm long and from 2 to 4 cm wide, are parallel to the bedding of the enclosing claystone. The calcite fibers, however, are not continuous across the lenses but are divided by laminar, marly septa which lie approximately along the main axial plane of the lenses. The calcium carbonate forming these lenses is considered to have been derived by bacterial reduction of sulfates in the presence of organic matter and contains only 0.2 percent Mg (Laboratorio Químico Nacional).

The lenses are commonly associated with thin veins of halite, mentioned above, which pass through the claystone, generally normal to bedding, cutting across alignments of calcite lenses where the individual lenses pinch out, as illustrated in figure 11.

Elemental sulfur - Small amounts of elemental sulfur form patchy coatings in the anhydrite sand, mainly in the southwest side of the Zipaquirá main level. The sulfur has undoubtedly been derived bacterially by sulfate reduction of the anhydrite.

Sphalerite - Two small lenses of sphalerite are interbedded in marly claystone in the anhydrite area of the southwest side of the Zipaquirá main level. The lenses, the larger of which is 4 to 5 cm wide and about 30 cm long, are on opposite sides of a tunnel and in the same stratigraphic interval. The larger lens is separated from the anhydrite by less than a meter of marly claystone. Among the more prominent trace elements present in the sphalerite as determined by six-step spectrographic analysis are 7 percent Fe, 3 percent Ca, slightly more than 1 percent Cd, and 1 percent Si.

Limestone - Small lentils of dark brownish-gray, locally iron stained limestone, several centimeters in width and of varying grain size, occur sporadically with the marly claystone bodies. Similar limestone also forms a few clasts in all mines. The calcium carbonate was probably derived by bacterial reduction of sulfate in the presence of organic matter, a phenomenon which may have resulted also in the marl content of the claystones present in all the mines.

Origin and growth of salt anticlines

As good exposures are present only in the Sabana de Bogotá area, this discussion is limited generally to the Turonian-lower Coniacian strata.

Structural control of depositional sites

Structural lows separated by highs formed the evaporite pans in which the Turonian-lower Coniacian halite was deposited. Although the geographic extent of this sequence was probably large, the structural lows and resulting evaporite pans are of moderate sizes.

Evidence of high and low areas is provided by contrasting facies within the Turonian-lower Coniacian sequence: halite and marly pyritic claystone were deposited in the lows, and hematitic, coarser-grained strata on the highs.

That these low and high areas are of structural origin is also implied by Bürgl (1962, fig. 25), who shows considerable variation in thickness of the Senonian strata which he attributes to sub-Hercynian (i.e., early Laramide or Andean) folding. Bürgl (1962, p. 43) states that this folding is of Santonian and Campanian age. That this structural development could have been initiated during earliest Senonian (i.e. Coniacian) and Turonian time, an interpretation also accepted by Bürgl (oral commun., 1966), is suggested by the writers.

The association of evaporites with the first folding of the major Andean orogeny probably explains the apparent large size of the Turonian-lower Coniacian deposits as compared with the older evaporites. Although deposition of the latter may also be structurally controlled, structural development in pre-Turonian Cretaceous time was not pronounced and did not initiate a major orogeny. Therefore the pre-Turonian salt deposits are correspondingly smaller.

Formation of salt anticlines

The evidence of salt in at least one locality in every anticlinal trend in the Sabana synclinorium of the Bogotá area might suggest that these structures are everywhere true salt anticlines. That salt is not present, however, in the Suesca anticline (See pl. 1, areas c-2 and c-3) is indicated by the Texaca Suesca No. 1 well and suggests that other parts of anticlinal trends may also be salt-free.

In the absence of more drill data the salt accumulations, all limited to anticlines or features associated with anticlines, may have either resulted from local lateral salt migration or are nonmigratory accumulations. The latter may be considered primary and the former secondary salt anticlines.

Primary salt anticlines - The bottom of the salt pan exposed in the Zipaquirá mine demonstrates that there has been little if any lateral movement of salt in this deposit. Further evidence of the nonmigratory nature of the Zipaquirá deposit is the relatively simple structure of the salt in the north part of the main level overlying the bottom of the pan. Probably significant also is the lack of closely associated hematitic strata, the closest of which are about 5 km north-northwest of the mine.

Geologic mapping of the Zipaquirá trend from the hematitic strata south, through the mine area to Betania, a distance of some 12 km, reveals a marked divergence from the regional structural grain, as may be seen from plate 1, areas a-3 and a-4. The trend in this region is concave to the west. The two anticlinal trends to the east are greatly concave to the southeast. The trend immediately west of the Zipaquirá trend is slightly concave to the west. To the southwest, in the Villeta quadrangle (Champetier de Ribes et al, 1961), the Zipaquirá trend again parallels the regional grain and the fold spacing is regular.

The anomalous eastward warp of the Zipaquirá trend south of the mine probably resulted from a greater amount of halite having been deposited in this area than elsewhere. This relatively thick accumulation diminished the competency of the Upper Cretaceous strata here more than in other salt -bearing regions and resulted in the divergence of the Zipaquirá trend through the salt pan in response to Tertiary compression. Results of thrusting and crestal wedging during the final, late Miocene phase of tectonism were similar to those of other salt areas.

The absence of hematitic strata at Sesquilé suggests that this deposit may also be primary and nonmigratory in origin. Further, the tan and light yellowish-gray claystone cropping out at the north end of the crestal wedge here are similar to the lithology forming the bottom of the evaporite pan at Zipaquirá.

Secondary salt anticlines - The postulated facies and structural relationships associated with halite deposits suggest that in some places salt migrated laterally, under the influence of differential loading, from the relatively low, synclinal pans, in to areas of less lithostatic pressure. This migration began as soon as enough strata overlay the salt to cause lateral flowage, and variation in thickness of post-salt strata was sufficient to cause a lithostatic pressure gradient. Flowage probably became more pronounced during the early Tertiary deposition of the Guaduas, Chacho, and Bogotá Formations. These units, essentially continental, range widely in thickness, and are present only in synclinal areas. They were deposited over the growing anticlinal crests, but the deposits were thin, as no remnants of these formations are now present. The salt probably migrated along bedding planes in the Chipaque Formation into the regions of thinner overburden flanking the synclines, as illustrated in figure 14.

Further migration of salt into the axial parts of the anticlines was probably aided by regional tangential compression, which was increasingly manifest in the later Tertiary. That the crestal areas of the anticlines were under less compression than their flanks or actually in tension probably aided the migration of salt into these areas. Such crestal tension is commonly associated with anticlines elsewhere (De Sitter, 1956, p. 201, figs. 141 and 144; Hills, 1963, p. 220-226). The final and most intensive compressional stresses, probably of late Miocene age (Campbell and Bürgl, 1965, p. 585), converted the crestal tensions into compression and initiated the wedges in which the salt moved a short distance upward, as illustrated in figures 5, 7, 8, and 9.

Salt deposits which have probably undergone lateral migration are Nemocón and Tausa, and probably the salt prospects at Pantana Redondo (pl. 1, areas a-3 and a-4, erroneously shown as Laguna Verde) and Pericos (pl. 1, area b-6).

Opposed structures

Dynamically opposed structures are characteristic features of the salt areas of the Sabana de Bogotá. Geologic mapping has demonstrated the following:

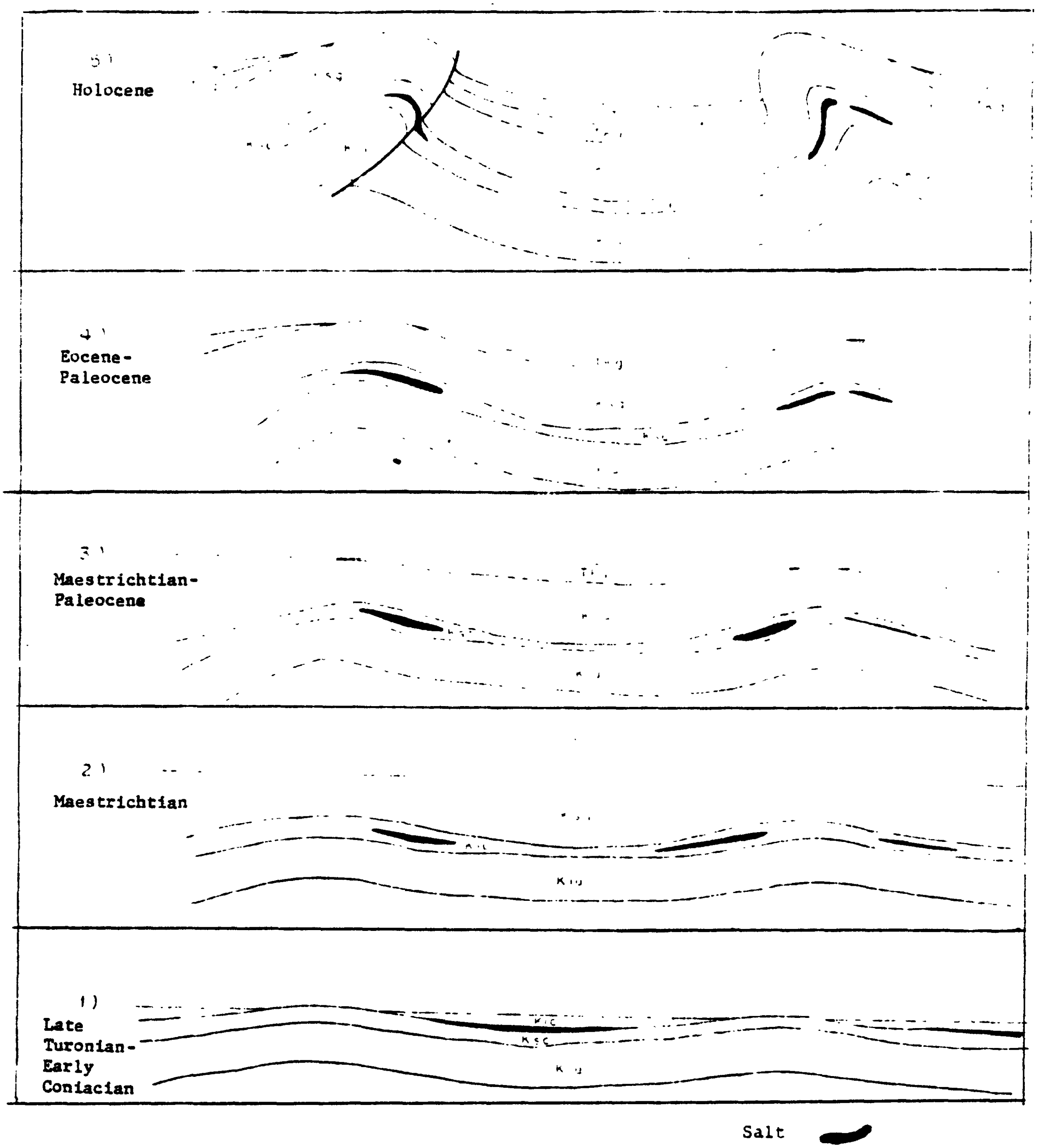


Figure 14. Growth of salt anticlines and resulting opposed structures of the Sabana de Bogota

Anticlinal flanks overturned in one direction may be oppositely overturned along the strike (pl. 1, areas a-2, a-3).

Parallel anticlines may be overturned toward each other, moving slightly over the intervening synclinal valley along dynamically opposed thrusts or high-angle reverse faults (pl. 1, areas a-7, a-8).

Several extensive high-angle reverse fault-systems associated with anticlinal flanks may cut across the anticlinal trends to the opposite flanks where they have opposed dips and displacements (pl. 1, areas a-7, b-7).

Locally the North Nemocón and Sopó-Sesquilé anticlines have oppositely overturned flanks (fan folds). (See fig. 9 and pl. 1, areas b-2, b-3, c-3 and cross section A-A').

These structures, all products of regional compression and undoubtedly affected by gravity, are not to be confused with the numerous, locally large slump overturns that have been developed solely by gravity in and above a prominant siltstone member of the Upper Guadalupe Formation (Julivert, 1963).

These opposed structures developed because of salt in anticlinal flanks, and a possible mode of their formation is illustrated in figure 14.. Salt in one anticlinal flank would lessen the structural competency of that flank in relation to the salt-free flank. Such anticlines would deform more readily along the flank containing the salt, either by overturning toward the less competent flank, or by overturning and subsequent faulting. The anticlines and faults which change dynamically along strike may have done so in response to local salt accumulations in either of the flanks. If salt had migrated laterally from a common syncline into the flanks of the adjacent anticlines and accumulated there, the late Miocene compression would move those folds toward each other as overturned and probably faulted anticlines.

Diapirism versus conformable relationships

Over the years a controversy has existed among geologists as to whether the salt deposits of the Cordillera Oriental are of diapiric or stratigraphic origin. Although all deposits have been considered, the debate has been centered over those in Sabana de Bogotá, as these deposits are the most obvious and accessible.

Many geologists have favored the diapiric origin (Singewald, 1949, p. 189; Bürgl, 1962, p. 20; Campbell and Bürgl, 1965, p. 572, 585 and pl. 1). Benavides (1968, p. 275-278 and fig. 4) cites studies by R. Scheibe (1925), Gerth (1935, 1955), Olsson (1956) and Wokittle (1960) in which these writers consider the mother salt as originally either in part of the Girón or Cáqueza Groups. Those favoring Cáqueza salt considered all deposits higher in the Cretaceous section to be diapirs; those favoring Girón salt, then generally considered of generally early Mesozoic age, thought all salt deposits are diapirs. Bürgl (1962, p. 20) has stressed that the Girón Group, which he considered of Rhaetic-Liassic age, is the only Mesozoic unit in which salt could have been formed, as the Girón is thought to be of arid, continental origin. Later Campbell and Bürgl (1965, p. 572) considered that the salt was deposited from the Liassic marine incursion into the arid, continental Girón depositional basin. Both writers invoked diapirism of the salt into its present position within Cretaceous strata.

Hubach (1957b, p. 110 and stratigraphic column; written commun., 1965) and Ujueta (1969, p. 2317-2320) have considered the salt as interbedded in the various stratigraphic sequences in which it occurs, a conclusion supported by this study.

Evidence favoring diapirism - Data from the present study which could be interpreted as favoring salt diapirism are as follows:

1. The structure of the salt strata in Nemocón and small areas of the Zipaquirá and Upín mines is locally similar to that of salt diapirs (Balk, 1949, map), as numerous steep to vertical dips are present.
2. A poorly preserved pollen grain was recovered from Zipaquirá salt which Dr. John Funkhouser (oral commun., 1965) considers of pre-Cretaceous and possible Permian age.

Evidence favoring conformably bedded salt - The following evidence supports a stratigraphic origin of the salt deposits:

1. The depositional contact between the salt sequence and the bottom of the evaporite pan at Zipaquirá.
2. The relatively large area of salt in the north part of the Zipaquirá main level that is generally gently dipping and conformable with the basal contact of the salt sequence.
3. The conformable relationship between the bottom of the evaporite pan and the underlying Chipaque strata exposed on the surface at Zipaquirá.
4. The overall salt structure in the Zipaquirá and Upín mines does not compare favorably with that of salt diapirs; dips are commonly much less than in diapirs (Balk, 1949, map)

and horizontal strata, never present in diapirs, are present at Zipaquirá.

5. Flow folds in all Colombian deposits have essentially horizontal axes whereas those in diapirs are vertical (Balk, 1949, p. 1791, 1804; Muehlberger, 1968, p. 360). Although many more flow folds than noted undoubtedly exist in the Colombian deposits, these features are not nearly as numerous as observed by Balk (1949, p. 1805) in salt diapirs.
6. Had the Colombian deposits undergone the thousands of meters of vertical movement required for diapiric origin, the large claystone bodies would not have maintained their conformability with the salt and undoubtedly would have been fragmented.
7. All fossils associated with salt deposits or evidence of salt in the Sabana de Bogotá indicate a Turonian to early Coniacian age for the strata underlying and equivalent to the salt deposits. This content association would be unlikely had the salt been emplaced diapirically.
8. Claystone similar to that forming the bottom of the evaporite pan at Zipaquirá is present at the north end of the Sesquilé crestal wedge which is probably salt-bearing.

Conclusions - The local structural similarity of the Nemocón salt to diapirs can be explained by either lateral migration or regional tectonism; probably both were involved. Dips in part of the Nemocón deposit, however, are less than the lowest dips in salt diapirs (Balk, 1949, map). The areas of structurally deformed salt strata in the Zipaquirá and Upín mines probably formed in response to regional tectonism.

Thus the Sabana de Bogotá and probably the older Cretaceous salt deposits are stratiform rather than diapiric.

Reserves of bedded salt deposits in the Cordillera Oriental

Reserve figures for the three operating salt mines in the Cordillera Oriental can only be approximated, as the geometry and lateral extent of these deposits are imperfectly known owing to lack of drill data.

Zipaquirá - The present study indicates that immediately minable reserves of this salt deposit are on the order of 30 million tons of halite over a working depth of 60 meters. Inferred reserves based on geologic interpretation may amount to about 68 million tons of halite over a working depth of 150 meters. Potential reserves, implying a continuation of the salt along the strike to the northwest, may be on the order of 130 million tons of halite. Neither the salt on the upper, or church, level nor that underlying the church on the main level has been included in these calculations.

Nemocón - Immediately minable reserves of Nemocón may be on the order of 3.74 million tons of halite based on a working depth of 30 meters. Lack of data precludes any calculations of either inferred or potential reserves. Geologic mapping in the vicinity of the mine suggests that potential reserves may be two or possibly three times greater than the immediate minable reserves.

Upín - Immediately minable reserves might be on the order of 72,000 tons of halite over a 10-meter working depth, determined from the present highly limited knowledge of this deposit. With more study, this figure would certainly be increased.

Sesquilé - No immediately minable reserves can be given for this deposit as entry into the mine is impossible because of caving. Based on geological interpretation of surface mapping and a working depth of 10 meters, inferred reserves at Sesquilé could be on the order of 7 million tons of halite.

OTHER NONMETALLIC MINERALS

Phosphate rock

Phosphate rock is restricted to small, noncommercial beds which are generally less than one meter thick and commonly limited in lateral extent. No phosphate rock is known in the Guavio quadrangle. Most of the phosphatic strata are in the Lower Guadalupe, a few in the Upper Guadalupe, and several, including the most extensive, in pre-Lower Guadalupe strata. More such deposits will undoubtedly be found when the Cretaceous section is studied in greater detail. The small deposits discussed below were either known prior to the Zone IV mapping project or discovered during the mapping. Phosphate exploration was done by a special group of Ingeominas when it was realized that relatively large deposits might be present in the Cordillera Oriental outside Zone IV.

Pre-Lower Guadalupe deposits - A phosphatic, limy sandstone crops out a few kilometers west of Ubaté in area b-1 of plate 1. This interval is about 3 km in strike length, 20 to 30 cm thick, and locally contains 15 percent P_2O_5 (Pedro Mojica, written commun., 1966). The precise stratigraphic position of this phosphate bed is in doubt but it probably is below the La Frontera marly facies which is generally considered to be of late Turonian age (Champetier de Ribes and others, 1961). The phosphatic section, the largest in Zone IV, may be of Cenomanian age and correlative with the Une Formation which crops out a few km east of Ubaté in area c-1 of plate 1.

Minor phosphatic shows are sporadic in pre-Lower Guadalupe strata elsewhere in Zone IV.

Lower Guadalupe Formation - Several meters of phosphatic, silty, siliceous claystone crop out in a road cut 3 km west-northwest of Machetá in area d-3 of plate 1. The lateral extent of this zone is not known because of structural complications and lack of outcrop.

Another phosphorite lens is present in the Serranía de Pericos (b-6) about 1400 meters west of the prominent, hematitically impregnated sandstone. Here phosphatic material is disseminated through several meters of fine-grained sandstone over a lateral extent of less than 300 meters. This lens is shown on plate 9.

Slightly less than 4 km northeast of Tausa Viejo, at Alto de La Mesa (area b-2), a silty phosphorite bed about 10 to 15 cm thick and several tens of meters along strike crops out near the summit of a small but prominent hill.

Upper Guadalupe Formation - A faulted belt of Upper Guadalupe strata some 10 km north and west of Sueva (area c-6) contains minor amounts of phosphatic material with siliceous siltstone in several places (See pl. 1, c-5, c-6). This phosphatic material, generally no more than a meter thick, could not be traced laterally because of dense brush cover. The most prominent phosphorite bed crops out in a roadmetal quarry along the road to Guasca about 8 km west-northwest of Sueva.

A small, silty phosphatic lentil in the Upper Guadalupe siltstone crops out along the road to the Sanctuario microwave relay station on the high ridge some 11 km west of Neusa in area a-2 of plate 1.

Limestone

Within the Zipaquirá quadrangle two limestone quarries are currently under exploitation. At Palacio (in the eastern part of area b-7) Cementos Samper, Ltda., is quarrying a very dark brownish-gray to dark-brown, massive, coarse-grained, coquinoid limestone lens that is slightly less than 100 meters thick. Extension along strike is not completely known but may approach one kilometer. A good summary of the limestone resources of this area has been prepared by Rocardo de la Espriella (1959, p. 27-60).

The other, smaller operating quarry is in the Serranía de Pericos in the southwest part of (area b-6) of plate 1. See also plate 9. The limestone is massive, dark-gray, locally dark brownish-gray, slightly fetid, coquinoidal, and contains minor argillaceous interbeds. The deposit comprises two beds, the upper of which is about 15 m thick and and is separated from the lower by about 50 cm of dark-gray, silty claystone. The base of the lower bed is not exposed. As may be seen on plates 1 and 9 the limestone has a semi-elliptical outcrop pattern that is about 200 m in major diameter. No extensive studies of these limestone deposits were made during the present investigation as both these properties are privately held and the operators expressed no desire for further study.

Within area a-7 of the Guavio quadrangle and the easternmost part of areas d-7 and d-8 of the Zipaquirá quadrangle, the Ubalá limestone may also be a source of cement for the Ubalá-Gachalá region. This limestone is dark-gray, medium- to coarse-grained, locally sandy, and massive. Studies to date indicate a tentative thickness of about

180 m. As the region is still being mapped, the total lateral extent of the limestone is not known. If feasible, utilization of this limestone as a cement source would greatly reduce construction costs in this relatively isolated region which is some 5 hours by truck from Bogotá.

Minor deposits

Gypsum - The geology and possible origin of the three gypsum deposits was discussed on pages 18 and 33. As these deposits are also under private ownership, detailed studies could not be made. Production from the Gachalá deposit appears to be about 10 tons per day; that from Lusitania is probably somewhat greater. At the present writing nothing is known regarding the production of the Santa María de Batá gypsum deposit. These deposits are mined by dynamiting the brecciated outcrop and washing away the claystone hydraulically with huge hoses.

Sulfur - The one small sulfur deposit known in Zone IV (Harald Laage, oral commun., 1968) was not examined by either the writer or Ingeominas geologists as mapping in the Guavio quadrangle had not advanced into the region of the deposit when the writer left Colombia.

Vincente Suárez-Hoyos (1945, p. 159-166), however, notes that a significant amount of sulfur was present at the Gachalá deposit in Quebrada de Las Minas. This deposit was visited by Ingeominas geologists. No appreciable sulfur is now present there. Suárez-Hoyos mentions that the small sulfur deposit, near San Isidero in area a-8 of the Guavio quadrangle about 5 km southwest of the Gachalá deposit, is associated with black to dark-gray, calcareous, locally pyritic claystone and minor beds of black limestone, all of which are structurally deformed. Suárez-Hoyos states that chemical analyses show only carbonate and sulfate.

San Isidro probably is a relic gypsum/anhydrite deposit and the sulfur at San Isidro and formerly at Gachalá probably resulted from bacterial reduction of $CaSO_4$ in the presence of organic material. That these sulfur deposits are genetically related to gypsum accumulations is indicated by the former presence of sulfur at Gachalá.

<u>Kaolinite</u> - In the Sabana de Bogotá region kaolinite is common in the Lower Guadalupe and also present in the Upper Guadalupe Formation. In both formations kaolinite is locally present interstitially in sandstone and siltstone. In the siltstone kaolinite is occasionally mined where the amount of detrital quartz is not prohibitive and the rock soft enough to be worked by hand tools. The two largest pits in the region, one 2 km northwest of the Zipaquirá salt mine and the other an equal distance southwest of the Nemocón mine, are shown on plate 1. Kaolinite is sporadically exploited and trucked to Bogotá. Both deposits contain about 50 percent kaolinite and 50 percent detrital silt-sized quartz, as determined by x-ray diffraction analyses. The deposit northwest of Zipaquirá is in the Lower Guadalupe Formation and that southwest of Nemocón probably in the Upper Guadalupe. No production figures are known.

Emeralds - Emeralds are mined on a relatively large scale in the Gachalá and Chivor areas in the east and at Muzo in the west. Emeralds have also been found at numerous other places in this part of the Cordillera Oriental. The strata which contain the emeralds of the Chivor and Gachalá areas and the Lusitania emerald prospect on the south bank of the Río Batá are approxiamtely correlative with the Berriasian-Valanginian sequence that contains the oldest known salt deposits. The emeralds reported from Zipaquirá (Oppenheim, 1948, p. 35; Willis Bronkie, oral commun., 1965) and Nemocon (Scheibe, 1933) are obviously much higher stratigraphically and correlate with the Turonian-lower Coniacian salt sequence.

Emeralds in Colombia are everywhere found in carbonaceous, commonly marly, silty claystone that is generally very dark gray to black but may locally be light brownish-gray, as at Chivor. The emeralds are in small clusters in moderately dipping, mineralized fissures that probably are of collapse origin. The principle gangue minerals associated with the emeralds are quartz euhedra, pyrite, albite, and calcite. The gangue minerals and emerald quality differ at various deposits. For more complete descriptions of the emerald deposits the reader is referred to Oppenheim (1948, p. 31 to 38) for the Muzo emerald deposits and Gilles (1966, p. 5 to 16), Mentzel (1966, p. 17 to 19), and Johnson (1966, p. 20 to 31) for the Chivor area.

Because most beryl, including emeralds in deposits elsewhere, is of igneous origin, the emeralds in the Cordillera Oriental have hitherto been assumed to be epigenetic. An ultramafic intrusive near the Muzo emerald deposits has penetrated Albian strata (Bürgl, 1962, p. 54) but not the emerald-bearing, black claystone. With the exception of this ultramafic body, no igneous rocks are present anywhere in the vicinity of any of the other emerald deposits.
A small gabbroic stock is present in Lower Cretaceous strata near Pajarito, about 80 km southeast of Tunja, but no emeralds are known to be associated with it.

METALLIC MINERALS

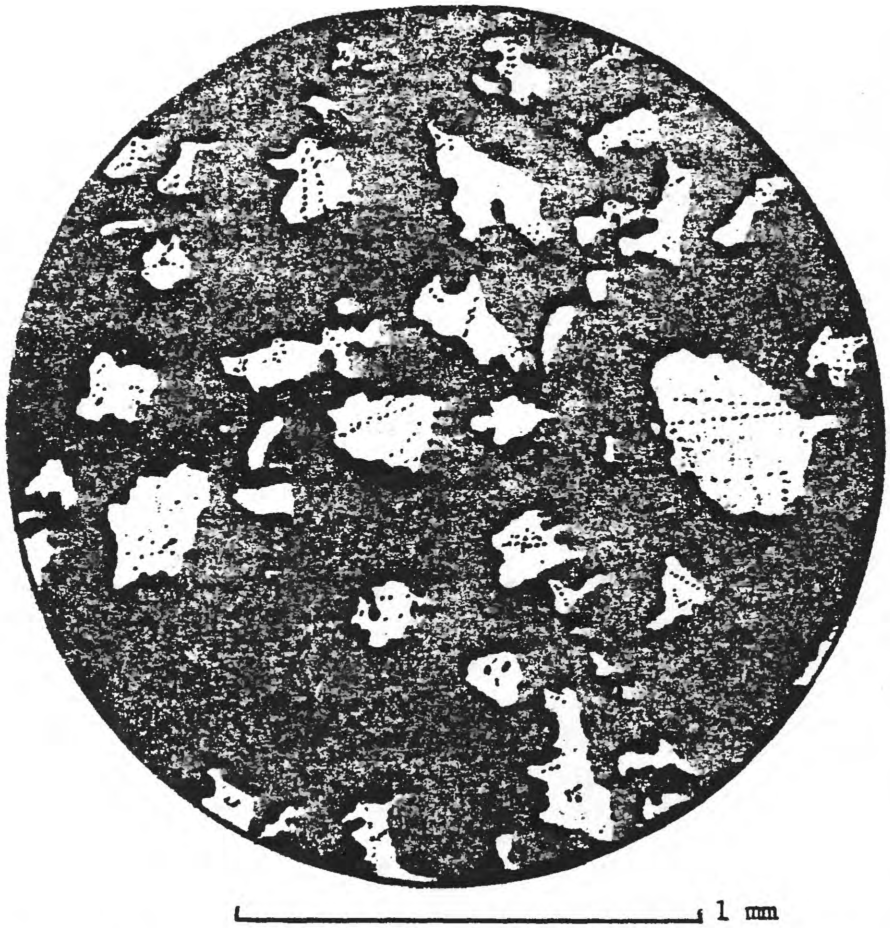
Iron

The Pericos iron deposit - The Pericos iron deposit, also known as Guasca or Tibitó, crops out along the east and northeast slope of the Serranía de Pericos, an arcuate range of hills between the Sopó and Guasca valleys. The iron-bearing zone is shown on plate 5 and on plate 1 in areas b-5 and b-6 from 4 to 8 km southeast of El Salitre, a small settlement in the west part of area b-6.

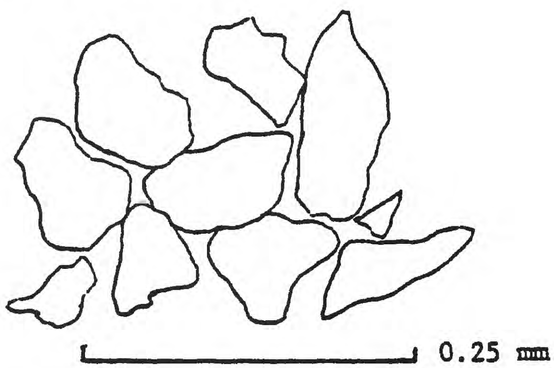
As is illustrated in the cross sections on plate 9 and on plate 1, the Pericos iron zone is on the west flank of the Sopó-Sesquilé anticlinal trend. This flank has moved over the eastern flank of this structure along the Pericos reverse fault.

The zone is composed of hematite impregnated, fine-grained silty, commonly thickly bedded quartz sandstone and siltstone in the lower part of the Chipaque Formation. The maximum thickness of the zone cannot be determined precisely but may range to 80 m. The upper contact is generally poorly exposed and appears to be gradational with the overlying silty claystone. The lower contact along the southern half of the zone is formed by the Pericos reverse fault which cuts out the true base of the zone. Although the northern half of the iron-bearing zone does not crop out, float impregnated with iron minerals is found on an extensive ridge, suggesting that the ridge is formed by the iron-bearing rock which appears to be interbedded in the Chipaque claystone. The Pericos reverse fault passes to the northeast of this ridge and forms the contact between the Chipaque and Upper Guadalupe Formations. The zone extends along strike 6340 m. The north end of the zone is formed by intersection with a splay off the Pericos reverse fault. The south end is either a stratigraphic pinchout or, less likely, was formed by intersection with the Pericos fault. The precise nature of the southern termination of the iron zone is obscu red by lack of outcrop. The downdip extension of the zone is not known and the portrayal of this dimension shown on the four cross sections on plate 9 are speculative. Core-hole information, however, suggests that the zone thins downdip from the outcrop although proof is lacking (Marino Arce, oral commun., 1967).

Geologic mapping indicates that the iron-bearing zone comprises numerous ferruginously impregnated layers, the largest of which is some 10 m thick and has been called the Adelite bed by Alvarado and Sarmiento (1943). The iron-bearing strata are separated by gray- to light-gray, silty, generally thin, lenticular claystone interbeds. The numerous hematitic intervals have been studied by Alvarado and Sarmiento (1943), who described the strata in 26 trenches that expose partial sections within the zone. Attempts to map the numerous hematite beds were largely unsuccessful as facies changes are common and exposures generally poor and laterally discontinuous except in large cuts. On the outcrop the hematitic strata, commonly weathering into dark-red, exfoliated hummocks, appear to be more ferruginous and much harder than the strata penetrated by the core holes drilled downdip from the exposed scarps. The locally high hematite content of strata exposed on the scarp is shown in figure 15, a drawing of a thin section made by John Butler and included in the report of Sarmiento and Alvarado. The locations of the eight core holes drilled downdip from the scarp by the Ministerio de Minas y Petroleos are shown on plate 9.



A. Drawing showing a thin section of sample collected near the iron deposits at Pericos. Blacks areas are iron oxides, and white areas are quartz grains of the original sandstone. The sandstone has been almost completely replaced by iron oxides. Original quartz grains were rounded and angular. Compare with B.



B. Drawing of quartz grains in a thin section of unmineralized sandstone, showing the angularity and subangularity of the original grains.

Figure 15. Thin section of sample from Pericos iron deposit (After J. W. Butler, Jr., written commun).

The four closely spaced, northernmost trenches of significant size cut by Alvarado and Sarmiento and shown on plate 9 were sampled by Antonio David Erazo and the samples analyzed in the Laboratorio Químico Nacional. The analyses (table 5) show an average of 48 percent Fe, and a range from 36.96 to 59.63 percent. Insoluble residue, mainly fine-grained to silty detrital quartz, forms an average of 15.5 percent, and a range from 6.06 to 30.94 percent. Minor amounts of Al, P, Mn, S, Ca, and Mg are also present. A small piece of siderite was reported in one of the cores (Marino Arce, oral commun., 1967). Analyses made by the Instituto de Investigaciones Tecnológicas of three samples of unknown location show an average of 55 percent Fe and a range from 52.02 to 56.72 percent, and an average silica content of 12.5 percent and a range from 8.95 to 15.68 percent. Very minor amounts of Al_2O_3, CaO, MgO, P, S, and Mn are present. No analyses of hematitic strata from the eight cores are available; all are from ourcrop. Surficial enrichment due to weathering may have resulted in higher percentages of Fe than are present downdip.

The iron zone locally contains fossils which Royo y Gómez (in Alvarado and Sarmiento, 1943) considered of Turonian age. Bürgl (oral commun., 1966) has since considered this fauna to be Coniacian. The iron zone is therefore correlative with the Sabana de Bogotá salt facies of the Chipaque Formation. The facies relationships pertaining to the salt interval and possible origin of hematitic deposits in this region have been discussed.

The Pericos iron zone has long been known but exploitation has been sporadic. Minor quantities of iron ore have been mined for use in glass and cement manufacture. The first detailed study of the deposit was made by Benjamin Alvarado and Roberto Sarmiento whose report remains the most comprehensive to date. At the present time the Instituto de Fomento Industrial, a Colombian government agency, is developing the deposit.

A tentative reserve figure for the Pericos iron zone would be on the order of 600,000 tons of hematite. More subsurface data, however, are needed before realistic reserve calculations can be made. The geometry of the deposit needs to be established, the facies changes within the iron zone must be delineated, and chemical analyses of the deposit downdip from the scarp must be made.

Other Sabana de Bogotá iron ore occurrences - Although the Pericos iron deposit is by far the largest in the Sabana de Bogotá, smaller but geologically similar deposits are known in several other localities in this area. None were studied in detail during the present project.

Slightly more than a kilometer southeast of Nemocón, a small ridgelike hill, Cerro Volador, is formed by a hematite-impregnated, fine-grained quartz sandstone bed about 6 m thick and some 400 m in strike extension, as may be seen in area (b-3) of plate 1. The iron-bearing bed strikes N. 65° E., and is overturned to the northwest at 65°. A tunnel bearing N. 50° E. runs along the dip of the bed for about 100 m. Having a 15° divergence from the strike of the bed, however, the tunnel cuts downdip no more than 27 m. Singewald (1949, p. 144-145) states that the deposit contains 54 percent Fe, 8.5 percent SiO_2, and is "moderately high" in P_2O_5 content. Reserves were estimated by Singewald at 50,000 tons.

Immediately southwest of Nemocón is another, thinner, iron-rich, fine-grained quartz sandstone that forms a small elongated hill and has not yet been exploited. Structural studies suggest that this small bed may be at the same horizon as that at Cerro Volador. Both are also of early Coniacian age and are members of the Chipaque Formation. These two ferruginous beds are shown on detailed maps in the files of Ingeominas.

At La Caldera, about 5 km north-northwest of the Zipaquirá salt mine, several hematitic sandstone lenses of limited lateral extent are in area (a-3) of plate 1. Several trenches were dug a number of years ago. Singewald (1949, p. 144-145) notes that the La Caldera iron-bearing beds contain 40 to 55 percent Fe and a "variable amount of SiO_2 and a P_2O_5 content above Bessemer grade." Early Coniacian fossils are present in the adjacent Chipaque claystone. Reserves at La Caldera, according to Singewald, are 50,000 tons of hematite.

In the Serranía de Pericos between the top of the iron zone and the top of the Chipaque Formation are at least three hematite-impregnated sandstone beds that range from 2 to 10 m in thickness, the longest of which has a strike extension of about 2200 m. These strata, not shown in their entirety on plate 9, strike into lower Coniacian strata to the north.

Hematitic sandstone is present in a faulted area, associated with rute and Chipaque claystone, about a kilometer north of La Siberia, in the eastern part of the area (a-7) of plate 1. Cementos Samper Ltda is currently exploiting this iron bed on a small scale for cement manufacture.

Tibirita - The Tibirita is in El Salitre, Municipio de Tibirita, in area (a-4) of the Guavio quadrangle. At least two areas of mineralization are present in the general area.

The southern mineralized area, Munanta, is about 60 m west of the Manta turn-off along the steep eastern side of the Guateque road. Here hematitic strata are interbedded in dark-gray to black, locally marly, shaly, concretionary claystone and siltstone of the Fómeque Formation. The hematite zone is as much as 3 m thick and locally is associated with siderite. Azurite and malachite coatings are common, indicating the presence of minor amounts of chalcopyrite. Melanterite coatings, commonly associated with salt areas, are present locally. Quartz euhedra are common. Small slickensides occur in the claystone. Strike extension has yet to be established but Manjarrés (1966, p. 8) suggests that the Munanta hematite bed may continue some 250 m to the south and be contiguous with another hematite bed in the area. Dr. Marino Arce has estimated that 29,000 tons of hematite may be present in the Munanta area.

The northern mineralized zone, at Cañadas about 600 m north Munanta, contains three hematite beds, according to Manjarrés (1966, p. 6).

The lowest bed, forming a dip slope, is 1.65 m thick and is overlain by another hematite bed about 4 m thick, from which it is separated presumably by claystone. Overlying the second bed is 28 m of claystone. The uppermost hematite bed is about 5 m thick. Manjarrés states that these hematite strata do not extend to the north and their strike extension to the south is only some 60 m. About 120 m southwest of these beds are several large blocks of hematite which may represent a continuation of the three beds mentioned above. Dr. Marino Arce has calculated what must be a minimal reserve figure of 236,000 tons of hematite. His calculations do not take into acount the upper 5-m hematite bed nor the possible 120-m strike extension of these strata to the southwest.

Manjarrés (1969, p. 9) notes that all the hematite is rhombohedral and suggests that it might have been originally siderite that has been oxidized, a conclusion which is supported by the presence of siderite with the hematite at Munanta.

Regional mapping suggests that the Fómeque strata containing the Tibirita hematite beds may be correlative with those at the Salinas de Gachetá. About 15 km southwest along structural strike is the area of siderite float in the Zipaquirá quadrangle which may be related to the halite facies at the Salinas.

Wedow (written commun., 1969) has suggested that lead-zinc sulfide deposits lower in the Fómeque section, to be discussed below, may have originated from brines. Salt or brines may have been present in the Tibirita area. The deposits here are located in an anticline, structures which elsewhere are locally salt-bearing, and the locality is known as El Salitre, a name implying salt. Brines here may have contained the Cu and Fe ions which were precipitated as chalcopyrite. Bacterial reduction, which resulted in the deposition of sphalerite at Zipaquirá, may also have accounted for the chalcopyrite at Munanta. No positive evidence of juvenile enrichment is present here. Quartz occurs not as veins but as small euhedra which may not necessarily be of juvenile origin, as small quartz euhedra are also present in the anhydrite associated with the sphalerite in the Zipaquirá mine.

Nueva Vizcaya - The Nueva Vizcaya deposit is about 9 km northeast of Ubalá in area (d-2) of the Guavio quadrangle. The northern limit of presently known mineralization is several hundred meters southeast of the road camp at Manizales. (See pl. 10 for approximate location).

The hematite zone underlies a locally crinoidal, gray, massive limestone of probable Carboniferous age (Suárez-Hoyos, 1945, p. 176). The thickness of the mineralized zone appears to approach 20 m. The zone has an extension along strike, from Manizales to Las Mercedes to the south, of approximately 4.5 km, according to Geocolombia (1968, p. 5). The iron bed appears to lie in the eastern flank of a syncline in which the western limb has been faulted out.

The important components of the iron bed are present in the following average percentages, according to Geocolombia (1968, vol. 2, p. 58);

		Percent
Fe	-	53.6
Mn	-	4.3
SiO_2	-	5.9
P	-	.08
S	-	.10

Minera Nueva Vizcaya, the current concessionaire, gives the following percentages for important components (written commun., 1969, Andres Parea Gallaga to Miguel Fadul):

		Percent
Fe	-	60.0
Mn	-	3.5
SiO_2	-	<1.0
P	-	.06
S	-	.06

The mineralized zone is dark brown and very dark reddish brown. There is no evidence of igneous activity. The zone forms a very prominant slope that dips 20° to 25° NW. Thin sections indicate that the deposit is the result of oxidation of primary siderite; rhombs are abündant and no particles of quartz silt or sand are noted.

According to Geocolombia (1969, vol. 3, anexo 6) the reserves of hematite are the following:

Total proved	-	741,000 tons
Total probable	-	11,488,000 tons
Total possible	-	12,800,000 tons

Initial geological work was carried out under the direction of Dr. Roberto Wokittle and later by Geocolombia, Ltda. Ingeominas geologists are currently studying the deposit in detail and a drilling program has been initiated.

Cerro de Montecristo - South of the Río Guavio, 10 to 15 km northeast of the Gachalá, in area (b-3) of the Guavio quadrangle, are several outcrops of specular hematite in the general region of Cerro de Montecristo (pl. 10). Chemical analyses indicate that the Fe content may be as high as 68 percent, equivalent to 98 percent Fe_2O_3. Silica and phosphorous are neglible.

The hematite crops out at Tominejas along the Río Naranjito, in the area of Tumbalaya near Algodones, and in the Río Tormenta about one kilometer southeast of Las Mesitas, a small settlement high on the south bank of the Río Guavio. Within this densely forested area of rugged topography there may be more such outcrops as yet unknown.

The largest and most spectacular outcrops of specularite lie along the Río Tormenta in an area of extremely dense jungle and very steep topography. Recent landslides have exposed between 20 and 25 m of Carboniferous quartz sandstone of the Farallones Group that contains lenses of specular hematite which range from a few centimeters to 30 cm in thickness. It is estimated that about 30 percent of the section exposed in the Río Tormenta outcrop is specularite. The outcrop is illustrated in plate 11 which was prepared from a compass-pace traverse made prior to additional exposures by landslides.

Much of this region is under concession to Minera Hansa, Ltda, who have taken out about 15 tons of ore from Tominejas on mule back (Harald Laage, oral commun., 1967).

Copper

Cerro de Cobre - Cerro de Cobre, in the middle of area (a-7) of the Guavio quadrangle, is the only important copper deposit in this region, although small shows of chalcopyrite are present in other places. Cerro de Cobre has not yet been studied in detail by Ingeominas geologists, but a brief report has been written by Vincente Suárez-Hoyos (1945, p. 175-184).

The mine at Cerro de Cobre lies some 7 km northeast of Gachalá. See plate 10. Exploitation is currently sporadic, but at one time 18 adits were being driven, many of which have now caved. This area is also relatively rich in emeralds, the largest ever discovered having been found near Cerro de Cobre.

The stratigraphy of this region is incompletely known. Present here are dark-gray to black, shaly silty claystone of the Cáqueza Group and dense, massive, gray limestone which may be correlative with the Ubalá Limestone of Valanginian age or with members of the Farallones Group mainly of Carboniferous age. Limestone units of both ages may be present. The copper deposit, according to Suárez-Hoyos (1945), is in predominantly calcareous strata which he considers to be of Carboniferous age. Geologic mapping by Ingeominas geologists west of Cerro de Cobre suggests that these copper-bearing strata may be of Cretaceous age and correlative with the locally mineralized Ubalá Limestone to the southwest. Paleontologic proof, however, is lacking.

The geologic structure of Cerro de Cobre is still not clearly understood as detailed mapping is yet to be done. Suárez-Hoyos (1945, p. 176-177) mentions complex structure resulting from folding which he considers to postdate faulting, a sequence of events which is in inverse order to that established in the Zipaquirá quadrangle. Suárez-Hovos. however, considers that the structural development in the Cerro de Cobre area is anticlinal and of Tertiary age, an assignment which is supported by most geologists familar with the Cordillera Oriental.

Suárez-Hoyos (1945, p. 179) states that the Cerro de Cobre deposit is composed of crystalline limestone which has been metasomatically replaced by veins and disseminated chalcopyrite. The gangue material contains large crystals of white calcite and a lesser amount of milky white vein quartz. He considers that during the first period of mineralization calcite and quartz were deposited in cavities of vugs in the limestone and then by chalcopyrite in a second period of mineralization. The final stage of mineralization was chiefly one of quartz veining. Suárez-Hoyos has discussed the irregular distribution of the chalcopyrite and attributes this to varying porosity within the host rock. Stutzer (1924, p. 153) comments on the notable lack of malachite and azurite in the region of mineralization and notes that the mineralized zone is 10 m in thickness.

Twelve samples taken from various localities at Cerro de Cobre show copper content to range from 0 to 3.36 percent and an average value of 1.19 percent (Suárez-Hoyos, 1945, p. 192).

No production figures are given by Suárez-Hoyos. Japanese government geologists (Government of Japan, 1966, p. 41), however, estimate the reserves of chalcopyrite-bearing material to be 1,620,000 tons.

Farallones de Medina - Numerous small outcrops containing chalcopyrite have long been known in the Farallones area southeast of Gachalá in area (a-8) of the Guavio quadrangle, and further south in the Medina quadrangle. Although numerous geologists have crossed this mountain range, which separates Gachalá from the town of Medina to the east, no systematic geologic study has been made because of poor accessibility. The mountains are precipitous, ranging above 4000 m, and the rain forest is very dense. Two trails exist but are locally impassable owing to rains which are especially heavy from March to September. The writer has been into the area as far as Alto de Bojará, but no work could be done because of the dense fog and the heavy rains. The project had to be abandoned after several days.

In 1966 a group of Japanese geologists entered the area and, in addition to examining the chalcopyrite outcrops, obtained valuable paleontologic and stratigraphic data (Government of Japan, 1966). At Las Palmas, about 2.8 km southeast of Gachalá, they (p. 46) report a southwest facing cliff, 20 m in height and 50 m in length, composed of calcareous mudstone and sandstone. Although they do not state so in the text, the accompanying cross section (Government of Japan, 1966, fig. 18) shows these strata included in the Farallones Group. Both the mudstone and sandstone are mineralized along faults by pyrite, chalcopyrite, covellite (covelline in Japanese text) and quartz. The report states that a calcareous sandstone is locally impregnated with chalcopyrite chalcocite, and covellite along a faulted zone about 1.5 m wide. A 70 cm thick zone was sampled and analyses show an average total Cu of 1.45 percent, a figure which includes 0.35 percent of soluble CuO. Similar copper mineralogy is present locally in lenses ranging to 20 cm in length and 6 cm in width.

Two additional outcrops are located near El Salitre, on the northeast side of Alto de Bojará, some 9 km from Gachalá. The Japanese report states that the first outcrop is composed of 1.4 m of argillaceous limestone impregnated with chalcopyrite and malachite. The strike extension of the mineralized zone is 13 m and the Cu content is less than one percent. The second outcrop consists of chalcopyrite and malachite impregnations in a 2-m thick argillaceous limestone interbedded with red mudstone. The strike extension is several meters and the Cu content is below one percent.

Lead

In nine places along the Río Farallones and Río Gachetá, in areas (d-7) of the Zipaquirá quadrangle and (a-7) of the Guavio quadrangle, Suárez-Hoyos (1945, p. 169-172) has located minor shows of galena. In seven deposits the host rock is the locally sandy Ubalá Limestone of Valanginian age. The only readily accessible outcrops are along the Río Gusano at the San Rafael and Cueva Oscura lead prospects in area (a-7) of the Guavio quadrangle. The Ubalá-Gachalá road passes a short distance east of the San Rafael and immediately in front of the Cueva Oscura prospect. See plate 10.

Sulfide minerals have been deposited in fracture zones roughly normal to the bedding. Galena is the prominant sulfide; chalcopyrite and pyrite occur in lesser amounts. According to Suárez-Hoyos (1945, p. 172), an average sample from Cueva Oscura showed 20 percent Pb, an amount greater than he considered the other, smaller prospects to contain. The galena in all outcrops examined by Suárez-Hoyos occurs both in veins several centimeters in width and several meters in length, and disseminated throughout the calcareous host rock. Fractures and porosity have been effective mineralization controls. Although galena is the principle mineral encountered in these outcrops, chalcopyrite, pyrite, possibly bornite, and sphalerite may be present in minor quantities, associated with vein quartz and calcite gangue. At Cueva Oscura small amounts of silver and traces of gold were reported by Suárez-Hoyos (1945, p. 172).

Zinc

Zinc minerals are present at El Rincón, La Playa, and Llano Grande, near the surface in the Río Rucio drainage some 6 km south of Gachetá. These three areas are collectively known as the Junín zinc district, named after a village about 4 km northwest of the deposits. A fourth area of zinc minerals has recently been found by Ingeominas geologists in the Río Mochindote watershed about 14 km northeast of Gachetá in area (d-5) of the Zipaquirá quadrangle (Wedow, oral commun., 1969).

The Junín zinc minerals have been studied in considerable detail by Alvarado (1939-1940) and to a lesser extent by del Río (1943). Del Río was accompanied by D. Singwald who gives a brief account of the Junín area (1949, p. 196-198).

El Rincón - El Rincón, the southern one indicated in area (d-7) of the Zipaquirá quadrangle, is the only mineralized zone that has been exploited over the years. As the adit has since caved and surface exposures are covered, the writer summarized Alvarado's descriptions of the lower and upper cuts.

Alvarado (1939-1940, p. 18) has subdivided the mineralization into four zones in the lower cut. The first, consisting of the vein, contains sphalerite, pyrite, chalcopyrite, and arsenopyrite in a gangue of siderite. Alvarado states that in most places the limit between the siderite gangue and the sphalerite is very poorly delineated, and that the sphalerite commonly metasomatically replaces the siderite. These observations were made in a now collapsed lower cut near the former mine entrance. The zinc vein ranges in width from 40 to 90 cm in the lower cut; it strikes N. 24° E., and dips from 50° to 60° NW.

Alvarado (1939-1940, p. 21) considers the second zone to be transitional between the vein and the host rock, and to extend below the vein, a phenomenon he considers indicative of more fracturing below the footwall than above the hanging wall. Included in the second zone are irregular blocks, stringers, and apophyses of sphalerite, and relatively large amounts of unoriented pyrite and chalcopyrite randomly associated with irregular blocks and fragments of host rock. The host rock is hydrothermally altered and cut by veins of siderite and quartz and generally minor sulfides.

The third zone is a silicified breccia of host rock cemented by sulfides, siderite, quartz, talc, and calcite. Alvarado (1939-1940, p. 22) considers the delineation between the second and third zones to be well defined and of fault origin. No sphalerite was noted in this zone although the local presence of smithsonite and siderite, commonly associated with sphalerite, suggest its possible presence. Slickensides are common on the blocks of host rock.

Alvarado's fourth zone is the host rock, composed of black, shaly claystone of the Fómeque Formation, weathered to gray and yellow with thin beds of limestone which are partly limonitized. He considers fossils found in this zone to be of Albian age, but collections made by Ingeominas geologists indicate an early Aptian age for the Fómeque Formation in this area.

Alvarado (1939-1940, p. 22) states that the vein in the upper cut is much better developed than in the lower cut. Contacts, commonly poorly delineated between some zones in the lower cut, are better developed. He states that the vein may be divided into three parts: two outer sections of some 45 cm in width and a central part some 35 cm in width. Minerals present are sphalerite, chalcopyrite, and pyrite. The zones within the veins area are highly lenticular and vary in mineral content.

Within a year or so after Alvarado's study, a tunnel about 50 m long with several cross cuts was driven along the vein, as reported by del Río (1943, map facing p. 256). The vein outcrop described by Alvarado extends for 24 m on the strike ranging between N. 45° E. and N. 65° E., at a relatively constant dip of 45° NW. The mineralization, mainly sphalerite, continues to the end of the vein where it passes abruptly into siderite which extends about 4 m. Del Río (1943, p. 254) suggests that the vein is cut off by a fault but also mentions that it may pinch out rather than be cut out structurally.

Del Río (1943, p. 255) states that there may be as much as 3,600 tons of sphalerite at El Rincón. He reports the following chemical analyses of the Rincón sphalerite:

SiO_2	-	3.46 percent
Fe_2O_3	-	6.70 do.
Zn	-	59.90 do.
Pb	-	0.00 do.
Au	-	0.21 g.p.t.
Ag	-	1.60 do.

Llanogrande - In this area, approximately 1,400 m southwest of El Rincón, Alvarado (1939-1940, p. 26) noted a limonite-rich zone which he thought was probably derived from the oxidation of siderite. In a deep cut along the trail the expected siderite was found. A 2.50-m hole was dug and the gradation of limonitic material to siderite was noted at slight depth. The siderite vein strikes N. 10° E. and dips 40° to 50° NW. No sphalerite was associated with the siderite, but chalcopyrite and two small pieces of galena were noted. Alvarado suggests that the mineralization here represents the same vein that is present at El Rincón. Ingeominas geologists did not find Alvarado's test hole as it was dug nearly 30 years ago and had been slumped and brushed over.

La Playa (Quebrada Negra) - At the confluence of Quebrada Negra and the Río Rucio is the colluvial accumulation of blocks of sphalerite, siderite, and the accessory minerals present at El Rincón. The mineralogy present at La Playa is, according to Alvarado (1939-1940, p. 25) the same as at El Rincón, a conclusion shared by the writer.

The relatively large size of the float blocks at La Playa suggests that the vein is nearby and that the blocks have not moved any appreciable distance. A trench was dug through the float accumulation a number of years ago in an unsuccessful attempt to locate the vein.

Del Río (1943, p. 256) presents the following chemical analyses of the ore at La Playa:

SiO_2	-	4.28 percent
Fe_2O_3	-	9.70 do.
Zn	-	62.66 do.
Pb	-	0.00 do.
Au	-	0.10 grams per ton
Ag	-	0.70 do.

Although proof is lacking, most geologists familiar with the deposits of the Junín area consider that all three mineralized locations are associated with the same vein or trend of veins. These three locations are aligned and the vein should have a regional strike of about N. 45° E. and a strike extension of about 2,900 m. If the mineralized area in the Mochindote drainage is considered, the mineralized rocks may extend over a distance of 20 km along which there may be other mineralized zones.

Sulfide minerals in areas such as the Junín zinc district and possibly Tibirita may be genetically related to salt-bearing strata interbedded in carbonaceous, black, locally marly claystone.

Alteration halos and significant quartz veins that may contain chalcopyrite are not present in either Junín or at Tibirita. Siderite, probably related to the salt facies as mentioned above, is the principle gangue mineral at Junín. Brecciated claystone is not present along faults, and occurs only in salt deposits, where it is of collapse origin. Both Tibirita and the Junín-Mochindote interval are apparently coeval with salt-bearing strata in the Fómeque Formation. Authigenic sphalerite is present in the Zipaquirá salt deposit.

These data suggest that the Junín zinc and the Tibirita chalcopyrite may have precipitated from brines derived by solution of interstratified salt. This solution would result in collapse breccias which would provide the necessary porosity. Metallic ions such as Zn, Cu, and Fe in the brines would be precipitated as sulfides either by hydrothermal processes resulting from geothermicity or by the action of the bacteria that reduced the sulfate ions in the brines in the presence of organic material associated with the claystone.

RECOMMENDATIONS

Evaporite minerals

Over the years Colombia has viewed her salt deposits with only token concern. No nation can hope to sustain a modern chemical industry without extensive use of salt, one of the "big five" of the primary materials, which include, in addition to salt, sulfur, coal, limestone, and petroleum. No nation without a modern chemical industry can have modern industrialization, as almost every manufactured item that involves chemistry in its fabrication also involves sodium or chlorine. The cheapest source of these two elements is rock salt, a commodity which the Cordillera Oriental appears to possess, possibly, in abundance. In a modern industrial society such as that of the United States, only about 3 percent of the total salt production is allocated for home or table use; the remaining 97 percent goes to the chemical industry. For a detailed summary of the uses of salt, the reader is referred to Kaufman (1960, p. 662-685).

Recommendations for augmenting salt production in Zone IV are presented in the following paragraphs.

Zipaquirá

Underground core hole drilling - The geometry of the salt deposit should be known in order to more effectively plan future underground mining. The downdip extension of the claystone that forms the footwall of the deposit along the northeast side of the mine should be determined by three core holes, the locations of which are shown on plate 6, and are as follows:

Core hole 1. - Santo Corazón area (intersection of the main level entrance with the road leading to the church or upper level).

Core hole 2. -100 m due north from core hole 1 along the road leading to the upper or church level.

Core hole 3. - 180 m due west from core hole 2, at the western end of that east-west gaalery.

Additional core holes are recommended for the structurally more complex area south of Santo Corazón. These core holes should establish, if possible, the depth to the salt-claystone basal contact in this part of the mine. The locations of these three additional core holes are shown on plate 6 and are as follows:

Core hole 4. - 325 m west of and 85 m south of Santo Corazón.

Core hole 5. - 245 m west of and 245 m south of Santo Corazón.

Core hole 6. - 395 m south of and 15 m west of Santo Corazón.

Underground seismic pattern shot - An experimental reflection seismic pattern shot would give valuable information on the configuration of the salt deposit, especially when such information is tied to the core hole data. A suggested location for such a shot point would be 95 m and 305° from the bench mark located at Santo Corazón.

Surface slim hole drilling - The following six slim holes should be drilled to rig capacity in the order in which they are numbered unless geological indications from the first holes suggests that the order and locations should be modified. The locations of these slim holes are shown on plate 12 and are as follows:

Slim hole 1 - Reason: To prove the possible strike extension of the salt.

Location: Barrio Santiago Perez; 110 m 112° from the fork in the road at the southern limit of the barrio.

Slim hole 2 - Reason: To prove the possible strike extension of the salt.

Location: In the vicinity of Casa Blanca; 450 m due south from slim hole 1.

Slim hole 3 - Reason: To prove the possible downdip extension of the salt.

Location: 400 m due south of slim hole 2.

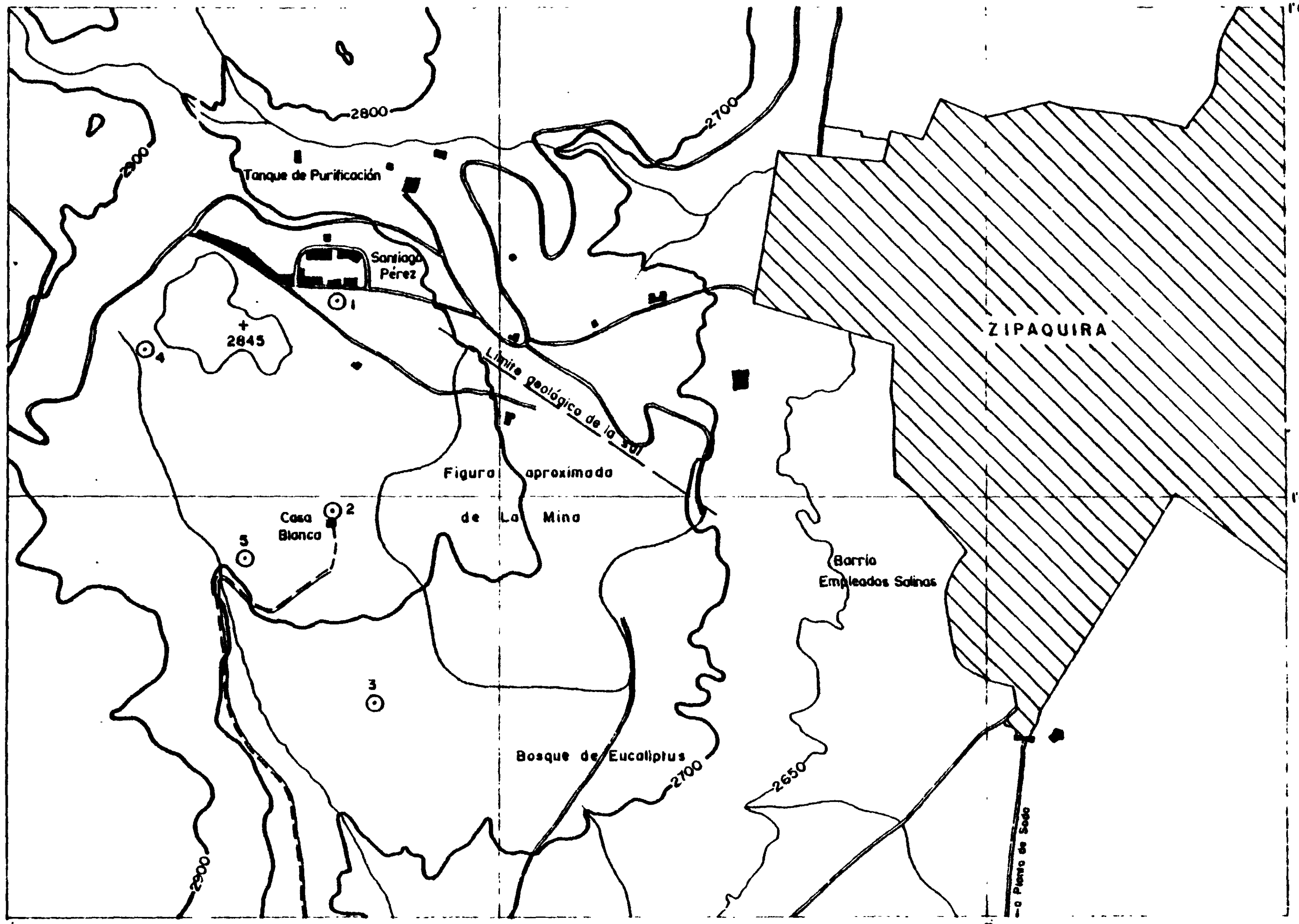


Plate 12. Location of proposed slim holes at Zipaquirá mine

Slim hole 4 - Reason: To prove the possible downdip extension of the salt.

Location: Near the Pacho road; 400 m 255° from slim hole 1.

Slim hole 5 - Reason: To prove the possible downdip extension of the salt.

Location: 200 m 247° from slim hole 2.

Slim hole 6 - Reason: To prove the possible strike extension of the salt if found to be present in significant amounts in slim hole 3.

Location: 260 m 164° from slim hole 3.

Nemocón

Underground core hole drilling - Little is known about the structural configuration of the Nemocón salt deposit. Phantom contouring from the geological map of the mine suggests a south-plunging fold, probably anticlinal. As at Zipaquirá, more information about the geometry of the Nemocón deposit is necessary for the planning of future exploitation. The locations of the underground core holes are shown on plate 5 and are as follows:

Core hole 1 - At the junction of the haulage way at the northeastern corner of the main (upper) level of the mine.

Core hole 2 - 163 m 154° from core hole 1; i.e., at the southeastern end of the gallery in which core hole 1 is located.

Core hole 3 - At the right-angle, "T"-shaped junction of the main tunnels in the Caldas area of the lower level of the mine.

Core hole 4 - At the southernmost end of the southernmost tunnel in the extreme southeastern part of the lower level.

Core hole 5 - At the head of the stairs which lead from the upper to lower level of the mine.

Underground seismic pattern shot - An experimental reflection seismic pattern shot should be contemplated if the seismic shot at Zipaquirá proves useful. The recommended shot point would be on the upper level, at the bottom of the stairs leading to the main entrance of the mine. This location is shown on plate 5.

Surface slim hole drilling - The lateral extension of the Nemocón salt deposit can only be determined by a series of slim holes, the locations of which are shown on plate 13. As at Zipaquirá, these holes should be drilled in the order in which they are numbered unless geological information from the first holes suggests that it would be prudent to alter the order and possibly some of the locations.

Slim hole 1 - Reason: To prove the presence of salt on the possible west flank of the probable fold in the salt deposit.

Location: 230 m 66° from the junction of the Nemocón-Suesca road with the road to Astorga.

Plate 13. Location of proposed slim holes, Nemocón mine

100 0 200 Meters
Contour interval 10 meters

Slim hole 2 - Reason: To prove the possible presence of salt on the west flank of the probable fold if salt is present in slim hole 1.

Location: 215 m due east from the present mine entrance.

Slim hole 3 - Reason: To prove the continued presence of salt in the western flank if salt is present in slim hole 1.

Location: 150 m 222° from the junction of the road to Astorga with the Nemocón-Suesca road.

Slim hole 4 - Reason: To prove the northeastern extension of the salt deposit.

Location: 500 m 76° from the main entrance of the mine.

Slim hole 5 - Reason: To prove the possible eastern extension of the salt deposit.

Location: 650 m 112° from the main entrance of the mine.

Slim hole 6 - Reason: To prove the possible presence of salt in the probable plunge area of the deposit.

Location: 500 m 108° from the junction of the road to Astorga with the Nemocón-Suesca road.

Sesquilé

Surface slim hole drilling - Three slim holes are recommended for evaluation of this formerly productive area. The holes are located with reference to an intersection of roads indicated on plate 14. The base map is used is the CAR 1:10,000 scale quadrangle numbered 209-III-D-2.

Slim hole 1 - Reason: To prove northward continued strike extension of the salt in the old mine workings.

Location: 205 m 114° from the road intersection.

Slim hole 2 - Reason: To prove the northward continued strike extension of the salt if present in slim hole 1.

Location: 520 m 33° from the road intersection.

Slim hole 3 - Reason: To prove the northward continued strike extension of the salt if present in slim hole 2.

Location: 900 m 20° from the road intersection.

Upín

The only data other than geochemical from the Upín mine are presented on plates 3 and 8 . That more studies are very necessary to evaluate this deposit is obvious. Recommendations are as follows:

Underground - (1) If feasible, an exploratory tunnel should be driven northwestward, generally along the strike of the salt, from the central part of the mine to establish the northwestern limit of the salt.
If the operator considers this impractical, regular mining operations should be planned to follow the strike of the salt strata to the northwest from the central and western parts of the mine, and to the north from the northern part of the mine.

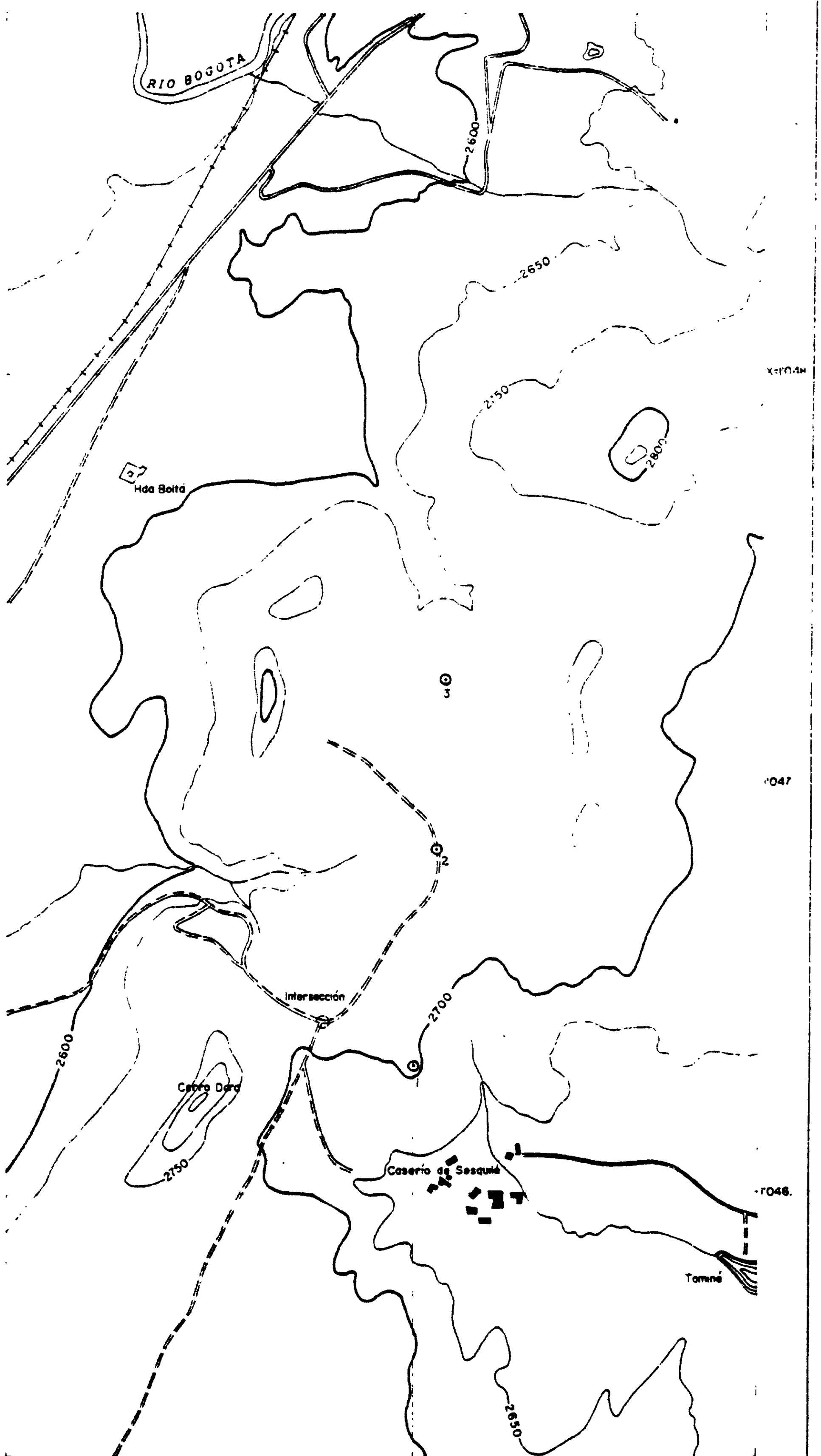


Plate 13. Location of proposed surface slim holes, Sesquilé

0 100 200 300 400 METERS

Base map: C.A.R. 209-III-D-2

(2) Underground core holes at convenient locations well within the mine would provide important data regarding the geometry of the deposit, especially if drilled into the strata underlying the salt.

(3) A seismic pattern shot similar to those proposed for Zipaquirá and Nemocón would provide considerable information regarding the geometry of the deposit. A tentative shot-hole location is shown on plate 8 .

Surface - (1) Geoelectrical prospecting techniques should be tested over known salt deposits in the Sabana de Bogotá area. If the pyrite content of both the rute and the claystone interbedded in the salt is sufficiently concentrated to give anomalies, this method should be tried at Upín. Survey-controlled test traverses should be made along the trails in the heavily forested region immediately northwest of the mine. If results are favorable, further traverses should be made in an effort to delineate the deposit. Care should be taken to avoid any significant amount of terrace gravels which might mask the geoelectrical characteristics of the underlying pyritiferous rute and strata.

(2) Although an extensive slim hole drilling program is probably not feasible owing to brush, topography, and possible terrace gravels, a slim hole or core hole should be drilled in an accessible place along the trail from the mine to one of the areas of rute that outcrops along the Río Upín (See plate 3).

Salt springs

Tausa

Surface slim-hole drilling - Three slim holes are recommended for evaluation of the salt potential of this formerly productive area. The holes are located with reference to Hacienda El Salitre, located on the CAR 1:10,000 scale base map 209-I-D-I. See plate 15.

Slim hole 1 - Reason: To prove the possible extension of salt south of the Tausa Salinas.

Location: 765 m 168° from Hacienda El Salitre.

Slim hole 2 - Reason: To prove the possible strike continuation of the salt south of slim hole 1, if it is present in that hole.

Location: 340 m 117° from Hacienda El Salitre.

Slim hole 3 - Reason: To prove the possible continued south extension of salt if it is present in slim hole 2.

Location: 340 m 102° from Hacienda El Salitre.

Gachetá and Mámbita

Although detailed geologic studies of the Salinas de Gachetá are not possible because of poor exposures, slim holes drilled north and, particularly south of the salinas would probably increase brine production. Rute crops out along the Río Salinero a short distance south of the salinas, suggesting that salt is close to the surface in this area. Present production at the salinas is at a depth of about 18 m.

Because of its isolation, no further development of the Salinas de Mámbita is recommended at the present time. When this salinas was visited by the writer in May 1967, brine was flowing unhindered into an adjacent stream and the local inhabitants were prohibited from exploiting it. Salt in this relatively remote area has to be brought in from Gachetá and the Sabana de Bogotá, some 38 and 85 km, repsectively, to the

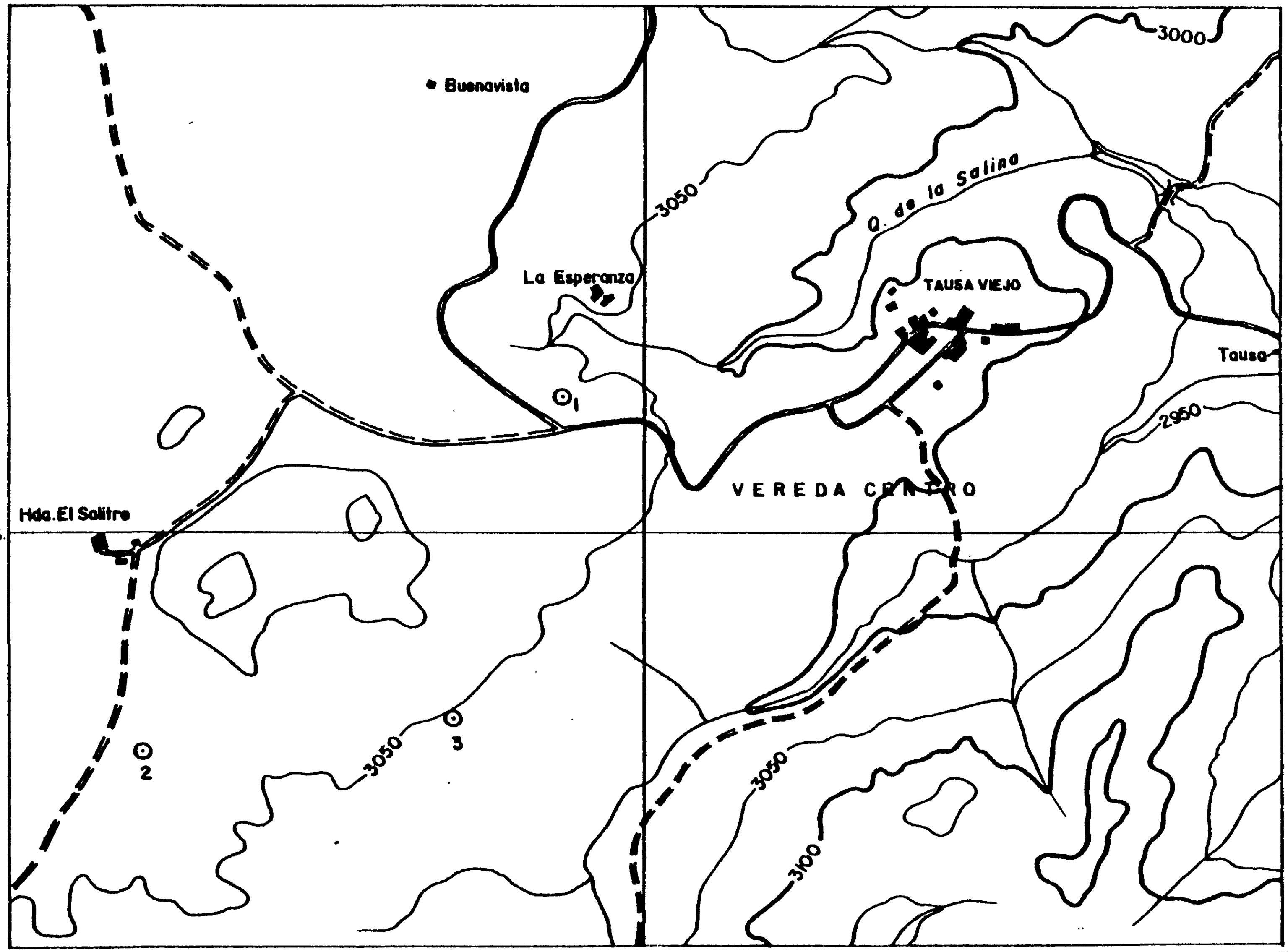


Plate 15. Location of proposed slim holes, Tausa area

Scale 1:10.000

Base map: Overlay C.A.R. 209-I-D-1

west. The last part of this journey is by muleback, which adds appreciably to the cost of salt and other commodities for the local inhabitants. Exploitation of the Salinas de Mámbita for local consimption would be advantageous in this roadless region.

Salt prospects

Pantano Redondo

The Pantano Redondo salt prospect lies some 2 to 6 km northwest of the Zipaquirá salt mine. The prospect is shown in areas (a-3) and (a-4) on plate 1; the lake forming Pantano Redondo in the central part of this high valley is shown erroneously as Laguna Verde on plate 1.

The Pantano Redondo prospect is an upfaulted crestal wedge of dark-gray to black Chipaque claystone in the South Zipaquirá anticline. Here the Chipaque is brought into fault contact with beds as high stratigraphically as the Upper Guadalupe Formation of Campanian to early Maestrichtian age. Geologic mapping shows that the wedge at Pantano Redondo is similar to those interpreted as containing the salt at Tausa and Sesquilé. Although no rute has been found at Pantano Redondo, hematite-impregnated sandstone and siltstone are present at La Caldera associated with faults within the wedge. As mentioned above, hematitic strata are considered as belonging to the salt facies.

The same fauna is present at Pantano Redondo as was recovered from claystone within the rute at the Salinas de Tausa and within claystone adjacent to the Nemocón deposit.

The locations of two test slim holes or core holes are shown on plate 16. The first hole is about 100 m southeast of the southeasternmost part of the lake; the second hole is about 300 m north of the

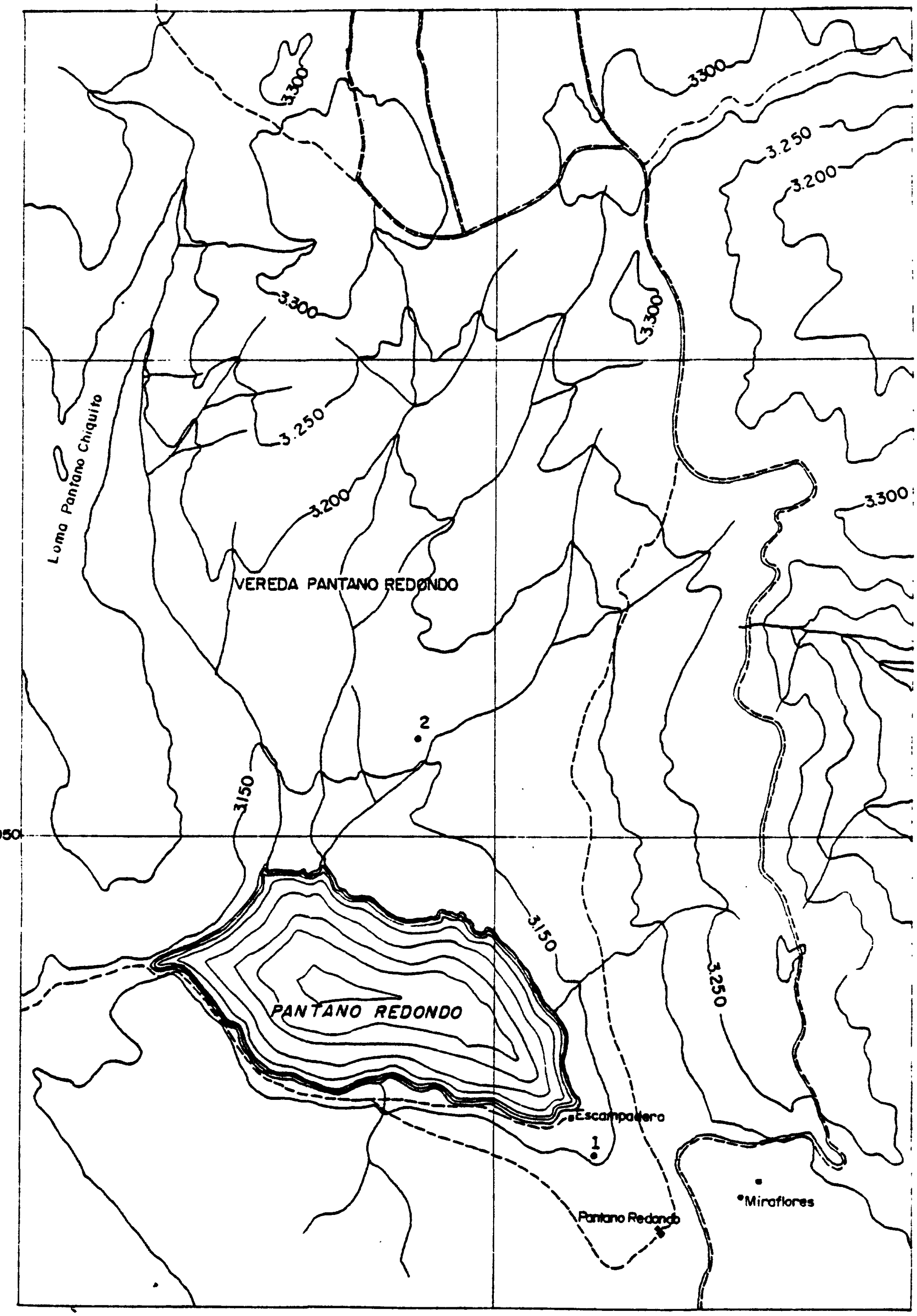


Plate 16. Location of proposed slim holes, Pantano Redondo area

0 100 200 300 400 METERS

CAR Base 209-III-C-2 – 209-III-A-3

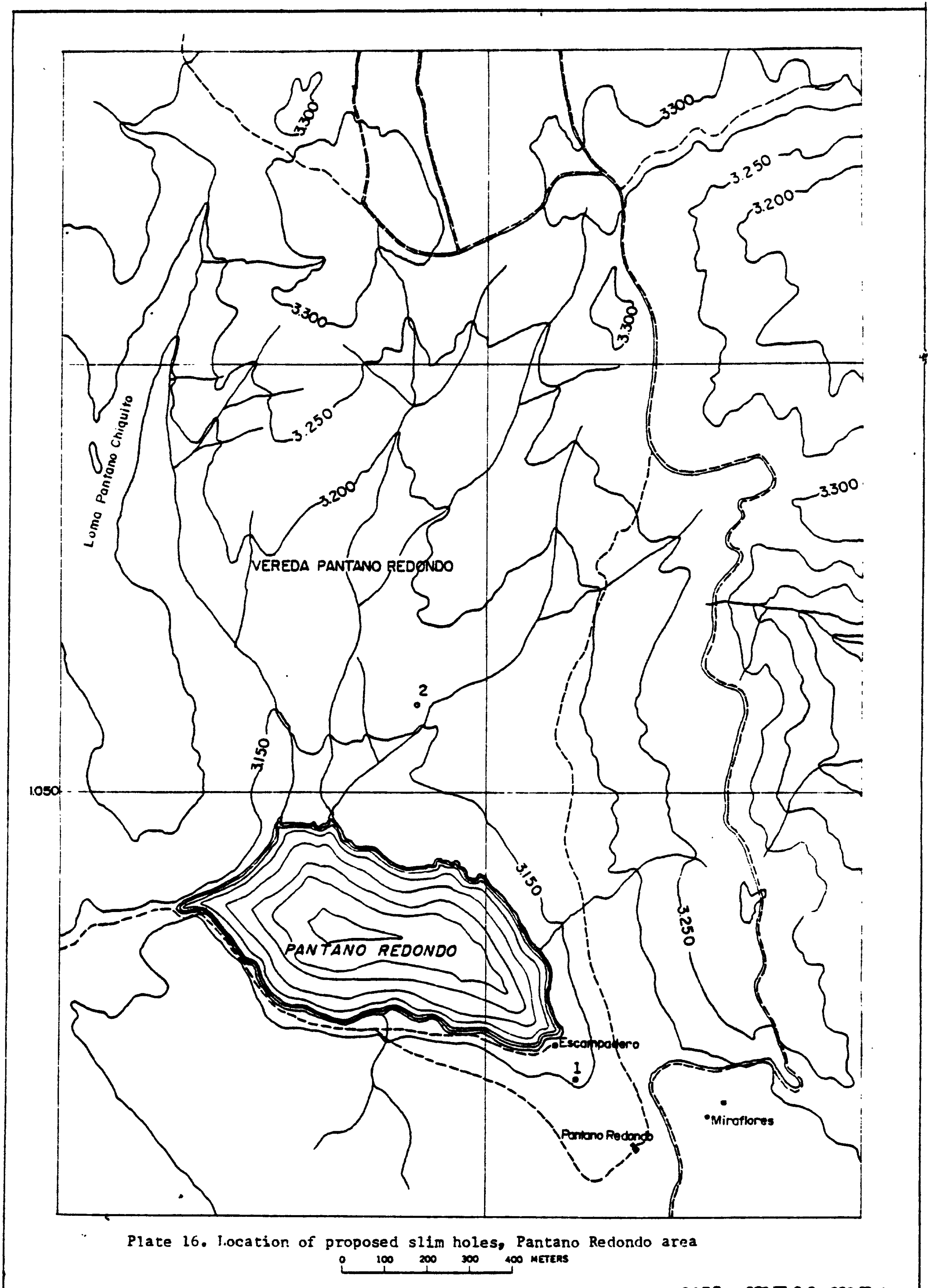


Plate 16. Location of proposed slim holes, Pantano Redondo area

0 100 200 300 400 METERS

CARBase 209-III-C-2-209-II-A-3

irregular north shore of the lake. Upon completion of these two holes, others may be necessary to further outline the deposit, if salt has been shown to exist. Should salt be present in significant amounts, solution mining rather than underground mining methods should be considered, as it would be simpler and cheaper. A brine pipeline could easily be built from Pantano Redondo to the brine tanks at Zipaquirá. No pumps would be necessary as Pantano Redondo is about 500 m higher than the installations at Zipaquirá.

Pericos

Geologic mapping in the Serranía de Pericos suggests that a crestal wedge of Chipaque claystone is present in the Pericos anticline from El Salitre to about 5.5 km to the southeast. This wedge is illustrated in area (b-6) of plate 1. The southereastern half of the wedge is shown on plate 9. Cross sections A-A', B-B', and C-C', shown on plate 9, illustrate the southeastern part of the wedge and the structure of this area. The Pericos wedge places Chipaque claystone in fault contact with both the Lower and Upper Guadalupe Formations. The Chipaque Formation at Pericos is composed of dark-gray to black claystone and also contains the hematite-impregnated beds mentioned above. Hubach (1957b, pl. 1) shows rute in the wedge area, although this material was not found during the present study. The late Turonian-early Coniacian age of the Chipaque in the wedge area is suggested by a meager fauna. The oldest strata in the wedge are the Coniacian limestone of the quarry (pl. 1, area b-6).

Although no drilling locations have been made or noted, the writer suggests that the first test hole should be drilled about midway between the limestone quarry and El Salitre. This location would be in the general area of the rute noted by Hubach. Additional drilling locations could be selected pending analyses of the results of the first hole. The writer considers the Pericos prospect less promising than Pantano Redondo.

Gypsum

Lack of detailed knowledge of the structurally chaotic gypsum outcrops presently being exploited precludes any definite recommendations for further development. Present mining should be continued, following the claystone-gypsum breccia until it is exhausted.

Other nonmetallic minerals

Phosphate rock

No major phosphate rock is known in Zone IV. The most promising deposit, north of the Río Ubatá in area (b-1) of plate 1, is the only phosphate in Zone IV that may warrant further detailed geologic study.

As mentioned above, Zone IV has numerous small deposits of phosphate rock, few of which exceed 15 percent P_2O_5. All of these deposits are shown on plate 1. Although noncommercial because of their small sizes and relatively low P_2O_5 content, these deposits may be suitable for very local, nonbeneficiated use by farmers who live and work in the immediate vicinities. If demonstrated that direct-application procedures are practical, farmers might be persuaded to dig out and grind up these small phosphatic interbeds and apply the material to their fields. Such utilization would require educational supervision until the farmers were convinced that the application of phosphate to their soils would actually increase the agricultural yields.

Limestone

No recommendations are made for further development of the two privately operated limestone quarries at Palacio and Pericos near Bogotá.

The Ubalá Limestone, in areas (a-7) and possibly (a-6) of the Guavio quadrangle is presently being studied by Ingeominas geologists. As this work progresses, chemical analyses should be made and serious consideration be given to developing the limestone for construction and agricultural purposes.

Kaolinite

As industrialization continues, uses of kaolin will increase. Prospecting for these deposits can be done only by systematically examining regions of gentle relief within the outcrop areas of the Lower and Upper Guadalupe Formations. Exploitation of the pits near Zipaquirá and Nemocón should be continued, preferably along strike, until facies changes render the detrital quartz content too high for local use.

Metallic minerals

Iron

Pericos and other Sabana de Bogotá occurrences - The Pericos deposit and other smaller but similar iron ores in the Sabana de Bogotá, although promising on the outcrop, apparently diminish in iron content some tens of meters downdip, as the drilling of core holes at Pericos suggests.

As reserve figures are small and as silica content is slightly over 12 percent, further development of these deposits at the present time does not seem warranted.

Tibirita - This deposit, located in the Guavio quadrangle, should be mapped in detail, sampled, and if warranted, a drilling program should be developed.

Nueva Vizcaya - The area of the iron bed and regions immediately adjacent to it should be mapped geologically in detail. Core-hole drilling should be started as soon as possible to obtain knowledge of the geometry of the iron bed, as a supplement to the mapping. Drilling would be especially useful in areas of poor outcrop where the iron bed is involved in complex structure.

Cerro de Montecristo - All that is shown about this isolated, forested area of steep topography are the locations of the most obvious specular hematite outcrops, and the geology immediately adjacent to them.

The Río Tormenta outcrop, shown on plates 10 and 11, appears on the surface to be the most promising, but nothing is known about its extension along strike. Prior to any development studies, trails would have to be cut through the dense forest along strike from the outcrop as far as practical. Geoelectric methods could be employed to trace the extension of the specular hematite. To warrant core-hole drilling in this isolated, rugged area the geoelectric anomaly would have to be extensive. The Río Tormenta outcrop can be reached only by foot after an hour's climb through densely forested steep slopes which lie above

Las Mesitas. From Las Mesitas animals can be used to reach the limits of the forest. Las Mesitas is some three to four hours by animal from the road to Gachalá.

The outcrop of specular hematite at Tominejas, shown on plate 10, is closer to the Gachalá road than Río Tormenta. To reach Tominejas, however, a two-hour horse- or muleback ride is necessary. To get to the outcrop one must climb down the south bank of the Río Naranjitos, which takes about 15 to 20 minutes. Although several tons of ore have been packed out from the Tominejas outcrop, the deposit does not appear to be as extensive as the apparently thicker Río Tormenta deposit.

In spite of obvious logistic problems, the Cerro Montecristo area should be examined as carefully as conditions permit. Minor amounts of specular hematite have been found in various areas and the region might have significant iron potential.

Copper

Cerro de Cobre - The copper deposit at Cerro de Cobre has yet to be investigated by Ingeominas geologists. The region should be carefully mapped, and many of the old adits should be cleaned out to permit entry and study of the mineralization. Once surface and underground mapping have been completed, further development programs could be contemplated.

Farallones de Medina - Exploration in this area within both the Guavio and Medina quadrangles would be very costly because of the dense forest, poor weather, and precipitous topography. The only copper minerals seen are along the main trail between Gachalá and Medina. The area could have significant copper potential but, in general, it is very isolated topographically, rugged and densely forested.

Initial exploration would have to be limited to the two trails that cross the Farallones, a narrow, rugged highland, to Medina. Areas containing copper shows along these trails would have to be cleared along strike, much in the manner recommended for the Río Tormenta outcrop at the Cerro de Montecristo.

Lead

The Ubalá Limestone, the host rock for galena, should be examined in detail between Ubalá and Gachalá where Suárez-Hoyos (1945, p. 169-172) has found nine small mineralized areas. As the stratigraphy of the lower part of the Cáqueza Group, including the Ubalá Limestone, is not clearly understood, numerous stratigraphic sections should be measured in the Ubalá-Gachalá area. Detailed mapping should also be done to resolve the structural complexities of the region, the effect of the structurally high area at Ubalá on sedimentation, and the lateral extent of facies changes. As soon as feasible, core-hole drilling should be contemplated where these studies indicate mineralization.

Zinc

The adit at El Rincón should be cleaned out and re-entered, if possible, in order to study the mineralization reported by Alvarado (1939-1940). The Junín district, which includes Llanogrande, El Rincón, and La Playa, should be carefully mapped and all attitudes measured. Although slumping is common in the Fómeque Formation, especially in areas of structural complexity, recognition of all but the most obviously slumped beds is often difficult in the field. Structurally controlled attitides that are not slumped can easily be considered slumped if the structural geology of the area is not adequately understood. Structurally significant attitudes may be distinguished from slumped beds by mapping, as structural trends are revealed. In measuring attitudes, however, the geologist should note the degree of accuracy for each. Great care should be given to accurate locations of all field data. Base map control could be the 1:25,000-scale quadrangle sheet for the region, enlarged to 1:10,000 scale if necessary. Aerial photographs should also be studied carefully.

As soon as the area between El Rincón and La Playa is mapped, electromagnetic methods should be used preparatory to selecting drilling locations.

This interval of late Barremian to early Aptian age within the lower Fómeque Formation should be examined southwest of the Junín district, between La Playa and Mochindote, and northeast of Mochindote in the Guavio quadrangle. Special attention should be given areas and stratigraphic intervals that have evidence of salt such as brine springs or rute.

Stream sediments should be sampled for geochemical study in areas likely to contain mineralization.

References cited

Alvarado, Benjamin, 1939-1940, El yacimiento de zinc de "Playas," Municipio de Junín (Cundinamarca): Colombia Bol. Minas y Petroleos, nos. 121 to 144, Anos 1939-1940, p. 7-36.

_________________, and Sarmiento, Roberto, 1943, Informe geológico sobre los yacimientos de hierro y carbón de Guasca: Colombia, Servicio Geol. Nac., p. 1-61.

Balk, Robert, 1949, Structure of Grand Island salt dome, Van Zandt Co., Texas: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 11, p. 1791-1829.

Benavides, Victor, 1968, Saline deposits of South America: in Saline deposits, Geol. Soc. America Spec. Paper 88, p. 249-290.

Borchert, Hermann, and Muir, Robert O., 1964, Salt deposits: Princeton, N. J., D. Van Nostrand Co., 338 p.

Bürgl, Hans, 1962, Historia geológica de Colombia: Colom. Ciénc., Rev. v. 11, no. 43, p. 137-194.

Campbell, Colin J., and Burgl, Hans, 1965, Section through the Eastern Cordillera of Colombia: Geol. Soc. America Bull., v. 76, no. 5, p. 567-590.

Champeteir de Ribes, G., Weecksteen, G., and Quintero, R., 1961, Mapa geologico de la plancha K-10 "Villeta": Colombia Servicio Geol. Nac.

Dellwig, L. F., 1955, Origin of the Salina salt of Michigan: Jour. Sed. Petrology, v. 25, p. 83-110.

Del Río, Alejandro, 1943, Yacimiento de zinc del Municipio de Junín, Cundinamarca: Bogotá, Compilacion De Estudios Geológicos Oficiales, tomo VI, p. 253-256.

De Sitter, L. U., 1956, Structural geology: New York, McGraw-Hill Book Co., 552 p.

Gilles, V. A., 1966, Geology of the Chivor emerald mine, in Buis, Otto, 1966, Guidebook to the geology of the Chivor emerald mine: Bogotá, Colombian Soc. Petroleum Geologists and Geophysicists, p. 5 to 16.

Government of Japan, 1966, Report on the second investigation of ore deposits in Colombia: Report in files of Colombia Inst. Nac. Inv. Geol.-Mineros, 56 p.

Hills, E. Sherbon, 1963, Elements of structural geology: New York, John Wiley and Sons, 483 p.

Holser, William T., 1966, Bromide geochemistry of salt rocks: in Northern Ohio Geol. Soc., p. 248-275.

Hubach, Enrique, 1957b, Estratigrafía de la Sabana de Bogotá y alrededores: Colombia, Boletín Geológico, v. V, no. 2, p. 93-112.

James, Harold L., 1954, Sedimentary facies of iron-formation: Econ. Geology, v. 49, no. 3, p. 236-263.

Johnson, Paul W., 1966, The Chivor emerald mine, in Buis, Otto, 1966, Guidebook to the geology of the Chivor emerald mine: Colombian Soc. Petroleum Geologists and Geophysicists, p. 20-31; Gemmological Assoc. Great Britain, Jour. Gemmology, v. 8, n. 4, October 1961.

Julivert, Manuel, 1963, Los rasgos tectónicos de la región de la Sabana de Bogotá: Bucaramanga, Universidad Industrial de Santander, Bol. Geol., no. 11, p. 5-21.

Kaufman, Dale W., 1960, Sodium chloride: New York, Monograph Series No., 145, Am. Chem. Soc., Reinhold Publishing Corp., 743 p.

Kehrer, Guillermo, 1933, El Carboniano del borde llanero de la Cordillera Oriental: Colombia Bol. Minas y Petroleos, nos. 49-54, p. 105-121.

King, R. H., 1947, Sedimentation in the Permian Castile sea: Am. Assoc. Petroleum Geologists Bull., v. 31, no. 3, p. 470-477.

Manjarrés, Gilberto, 1966, Yacimiento de hierro de Tibirita, Departamento de Cundinmaraca: Colombia Servicio Geol. Nac., Informe 1500, 11 p.

Mentzel, Charles, 1966, Appendix I, Geology of Chivor no. 1 mine, in Buis, Otto, 1966, Guidebook to the geology of the Chivor emerald mine: Colombian Soc. Petroleum Geologists and Geophysicists, p. 17-19.

Muehlberger, William R., 1968, Internal structure and mode of uplift of Texas and Louisiania salt domes: in Saline deposits, Geol. Soc. America Spec. Paper 88, p. 359-364.

Oppenheim, Victor, 1948, The Muzo emerald zone, Colombia: Econ. Geology, v. XLIII, no. 1, January-February 1948, p. 31-38.

Peterson, J. A., and Hite, R. J., 1969, Pennsylvannia evaporite-carbonate cycles and their relation to petroleum occurrence, southern Rocky Mountains: Am. Assoc. Petroleum Geologists Bull., v. 53, no. 4, p. 884-908.

Renzoni, Giancarlo, 1965, Geología del cuadrángulo L-11 "Villavicencio": Colombia Servicio Geol. Nac.

Raasveldt, H. C., and Caevajal, J. M., 1957, Mapa geológico de la plancha K-9 "Armero": Colombia Servicio Geol. Nac.

Scheibe, Robert, 1922, Informe sobre el yacimiento de salt de Nemocón: Colombia Compilacion de Los Estudios Geologicos Oficiales en Colombia, tomo I (1933), p. 51-59.

Scheibe, Robert, 1933, Informe sobre el yacimiento de sal de Nemocón: Bogotá, Compilación de los estudios geológicos oficiales en Colombia, tomo 1, p. 51 to 59.

Singewald, Q. D., 1949, Mineral resources of Colombia (other than petroleum): U. S. Geol. Survey Bull., 964-B, 204 p.

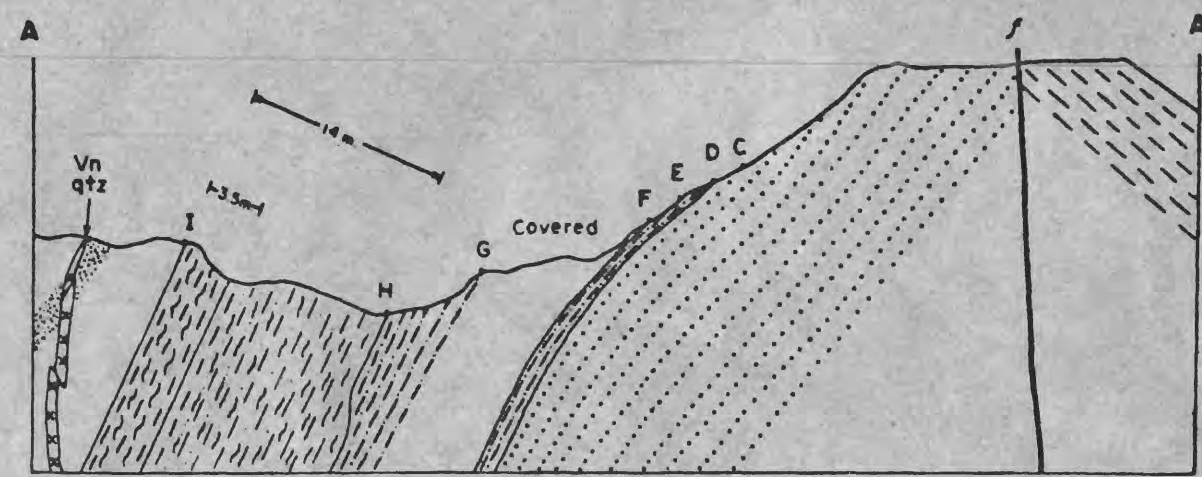
Stutzer, Otto, 1934, Contribución a la geológía de la Cordillera Oriental. Regiones cerca a Bogotá: Colombia Compilacion de Los Estudios Geologicos Oficiales en Colombia, 1917-1933, tomo II, p. 141-182.

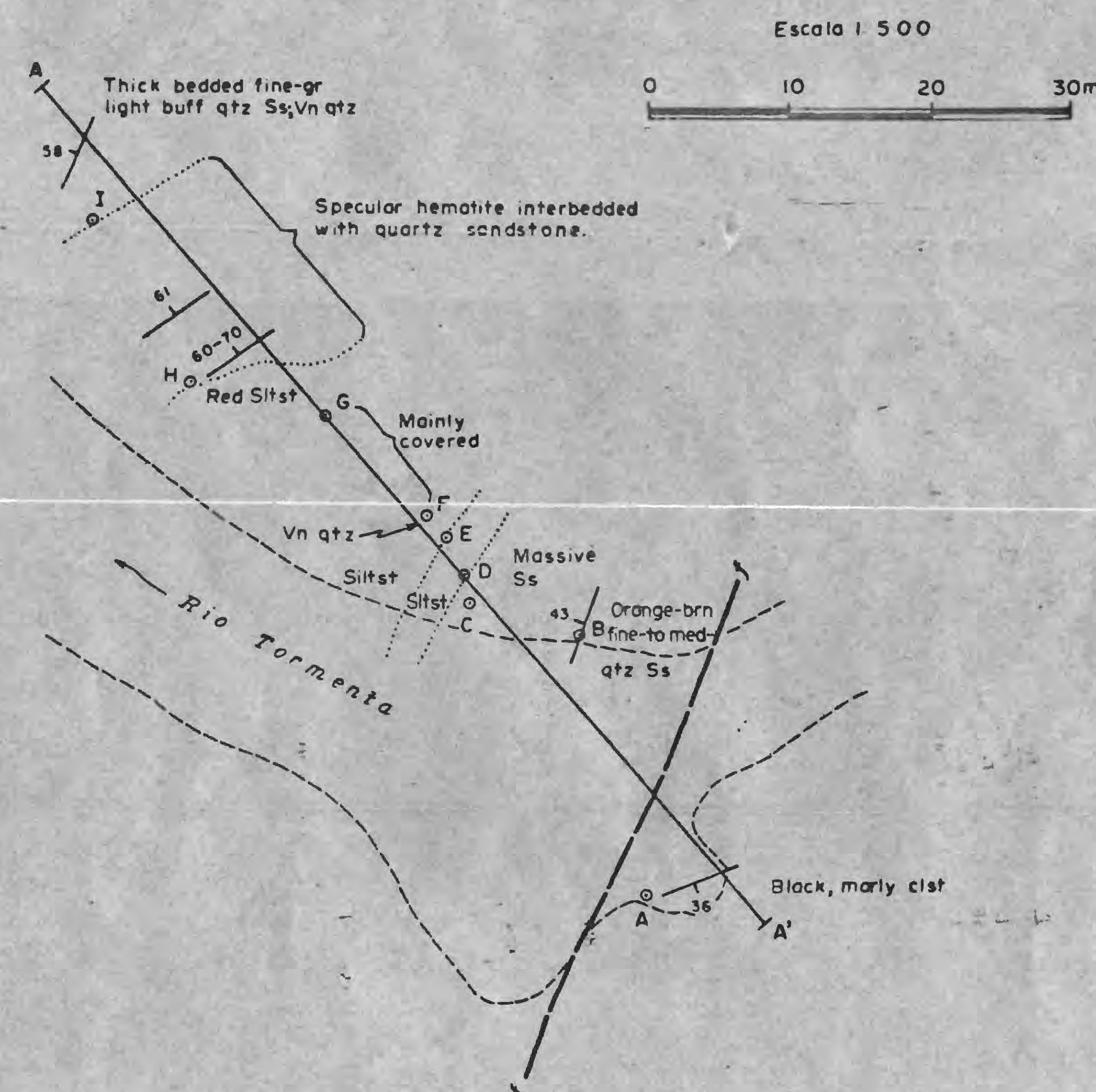
Suárez-Hoyos, Vicente, 1945, Reconocimiento geológico de la región del Guavio, Gachalá (Cundinamarca): Colombia Compilaciones de los Estudios Geológicos Oficiales en Colombia; tomo VI, p. 147-188.

Thompson, Arthur V., 1966, Guide book of a geological section from Bogotá to the Central Cordillera: Colombia Soc. Petroleum Geologists and Geophysicists, 20 p.

Ujueta, Guillermo-L., 1969, Salt in the Eastern Cordillera of Colombia: Geol. Soc. America, v. 80, no. 11, p. 2317-2320.

Woolnough, W. G., 1937, Sedimentation in barred basins and source rocks of oil: Am. Assoc. Petroleum Geologists Bull., v. 21, no. 9, p. 1101-1157.





70-208

Plate 11

SKETCH MAP OF SPECULARITE
OUTCROP IN RIO TORMENTA
CUNDINAMARCA

Elev. 1.860 m

Mayo 1967

 Specularite

D: I. C. O.