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MINERAL RESOURCES OF PARTS OF THE

DEPARTMENTS OF ANTIOQUIA AND CALDAS, ZONE II, COLOMBIA

by

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and

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This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature.

CONTENTS

METALLIC RESOURCES (CON'T.)

ILLUSTRATIONS

PLATES

(In pocket)

FIGURES

TABLES

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ABSTRACT

The mineral resources of an area of 40,000 sq km, principally in the Department of Antioquia, but including small parts of the Departments of Caldas, Córdoba, Risaralda, and Tolima, were investigated during the period 1964-68. The area is designated Zone II by the Colombian Inventario Minero Nacional(IMN). The geology of approximately 45 percent of this area, or 18,000 sq km, has been mapped by IMN.

Zone II has been a gold producer for centuries, and still produces 75 percent of Colombia's gold. Silver is recovered as a byproduct. Ferruginous laterites have been investigated as potential sources of iron ore but are not commercially exploitable. Nickeliferous laterite on serpentinite near Uré in the extreme northwest corner of the Zone is potentially exploitable, although less promising than similar laterites at Cerro Matoso, north of the Zone boundary. Known deposits of mercury, chromium, manganese, and copper are small and have limited economic potential.

Cement raw materials are important among nonmetallic resources, and four companies are engaged in the manufacture of portland cement. The eastern half of Zone II contains large carbonate rock reserves, but poor accessibility is a handicap to greater development at present. Dolomite near Amalfi is quarried for the glass-making and other industries. Clay

saprolite is abundant and widely used in making brick and tiles in small backyard kilns. Kaolin of good quality near La Unión is used by the ceramic industry. Subbituminous coal beds of Tertiary age are an important resource in the western part of the zone and have good potential for greater development. Aggregate materials for construction are varied and abundant. Deposits of sodic feldspar, talc, decorative stone, and silica are exploited on a small scale. Chrysotile asbestos deposits north of Campamento are being developed to supply fiber for Colombia's thriving asbestos-cement industry, which is presently dependent upon imported fiber. Wollastonite and andalusite are potential resources not exploitable now.

INTRODUCTION

Inventario Minero Nacional

The Inventario Minero Nacional(IMN), or National Mineral Inventory, was a four-year cooperative project jointly sponsored and financed by the Republic of Colombia through the Ministry of Mines and Petroleum, and the Agency for International Development, U. S. Department of State. The work of the IMN was done in cooperation with the U. S. Geological Survey; the IMN began in September 1964 and continued until December 1968, at which time a successor organization, the Instituto Nacional de Investigaciones Geológico Mineras (Ingeominas), was created by Presidential decree. Ingeominas incorporates the original IMN, the former Servicio Geológico Nacional, and the Laboratorio Químico Nacional. Most of the information contained herein was obtained during the IMN project, successively under the directorship of the late Dr. Aurelio Lara, and Drs. Dario Suescun G., and Andrés Jimeno V.

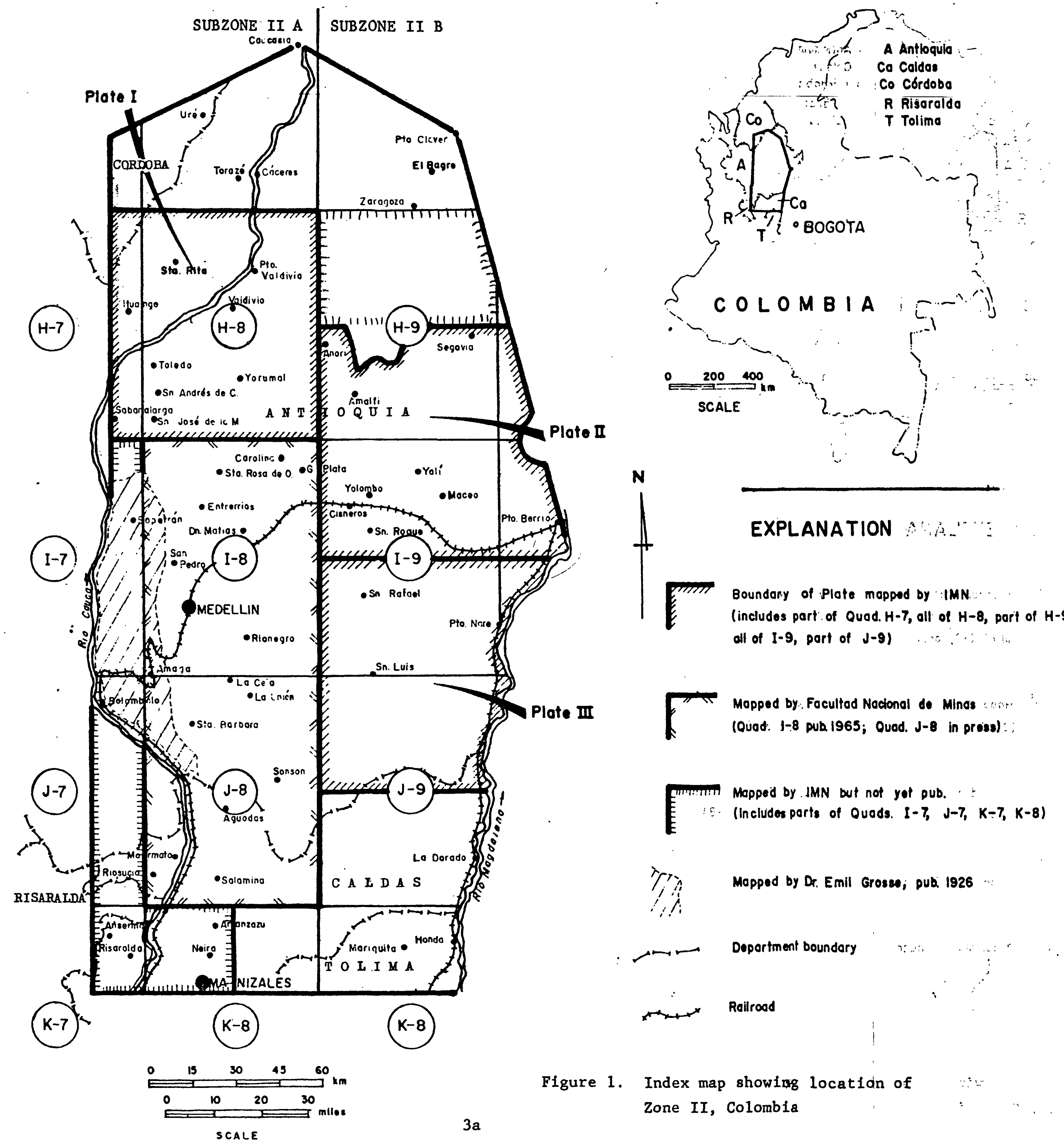

Figure 1. Index map showing location of Zone II, Colombia

The purpose of the IMN was to evaluate the mineral resources (excluding petroleum, coal, emeralds, and alluvial gold) of four selected zones in Colombia, which total about 70,000 sq km. Each zone was assigned one or more geologists from the U. S. Geological Survey(USGS) to serve as technical advisors. The greater part of the field work and geological mapping was done by Colombian geologists who joined IMN from the Servicio Geológico Nacional or from the schools of geology of the Universidad Nacional in Bogotá and Facultad Nacional de Minas in Medellín.

Area of this report

Approximately 45 percent of Zone II, or about 18,000 sq km was mapped at a scale of 1:100,000 by IMN exclusively. The areas of this mapping are shown on figure 1. The areas labelled plates I, II, and III cover about 16,000 sq km. In addition, parts of subzone II-A including a 15 km-wide strip covering 750 sq km adjoining the west edge of quadrangle J-8, and a rectangular area of 1,350 sq km northwest of Manizales in the extreme southwest corner of the zone were mapped by IMN geologists in 1968, but are as yet unpublished. In subzone II-B the greater part of the northern half of quadrangle H-9, comprising an area of 1,720 sq km, was mapped early in 1969 by Colombian geologists led by Jairó Alvarez A.

Other parts of the zone have been mapped by agencies other than IMN or Ingeominas as shown on fig. 1. For example, two quadrangles, I-8 and J-8, each covering 4,800 sq km, have been mapped by Facultad Nacional de Minas. Quadrangle I-8 was published by IMN in 1965, as mapped by Dr. Gerardo Botero A. (1963). An irregular strip of territory roughly 100 km north-south by 12 km east-west, extending from Sopetran on the north to La Pintada on the south, was mapped by Dr. Emil Grosse (1926).

Figure 1 shows the areas mapped by the abovementioned agencies.

Zone II is the largest of the four IMN mineral-resource zones, covering about 40,000 sq km, principally in the Department of Antioquia, although small parts are in the Departments of Caldas, Cordoba, Risaralda, and Tolima (fig. 1). Owing to its large size and the difficulty of transportation within most of it, the zone was divided arbitrarily into two subequal parts. The west part was designated subzone II A and the east part subzone II B, hereafter referred to in this report simply as II A and II B respectively. Each subzone had its own cadre of field geologists and a USGS technical advisor. Lawrence V. Blade was advisor in II A until early 1967, when Robert B. Hall took his place. Tomas Feininger served as advisor in II B throughout the IMN program. Colombian Zone Chiefs were Hernan Vasquez C., Héctor Rico H., and Jairo Alvarez A.

Locations

Locations of places on the three 1:100,000 geological maps, Plates I, II, and III, are given by simple coordinates. The maps are subdivided into small rectangular areas called "planchas," each 10 km north-south by 15 km east-west. The planchas are lettered on the maps in rows from left to right (west to east) a, b, c, d, and e respectively, and numbered from top to bottom (north to south) 1, 2, 3, 4, etc. Thus, the plancha in which the town of Ituango is located would be designated as Plate I, a-4; the town of Maceo is in Plate II, c-7; San Carlos is in Plate III, b-11. (Note that on the IIB side the numbers run consecutively from north to south on Plates II and III, the southernmost row of planchas on Plate II being row 8, followed by the northernmost row of planchas on Plate III numbered 9, and continuing south to row 16 at the bottom of the map).

Plates I, II, and III, together cover about 45 percent of the total area of Zone II, but this report deals with mineral resources in the entire zone. Places not located on the above plates are designated, for exampl as "6 km south of La Ceja." Figure 2 is a resources map showing the locations of the most important mines, quarries, and prospects in the whole zone, and the municipalities referred to in the text of the report are indicated on that map.

Exploration by IMN

The principal effort was put into regional geologic mapping because a knowledge of the geology of a country is an essential first step toward a realization of its resource potential. Concomitant with the regional mapping, IMN carried out special exploration projects to explore known deposits or prospects about which few data were available. The most important of these are listed on table 1. Results are discussed under individual commodity headings.

Considering the rugged terrain and deep cover of soil and colluvium, it is possible that some mineral deposits were overlooked during the mapping program. For example, some virgin gold veins may remain undiscovered because they are too poor in sulfides to form gossans which might have attracted the field geologist's eye. Wholly concealed or "blind" deposits may be found in these areas in the future by geophysical or geochemical exploration techniques. These techniques are more likely to be successful if good geologic maps are available, such as those made by IMN.

TABLE 1

SPECIAL IMN EXPLORATION PROJECTS IN ZONE II, 1964 - 1967

Project Title and Location	Metal or Mineral	Kind of work performed	1964-1967
Buriticá 8 km NE of Buriticá	Cu, Pb, Zn Au, Ag	Large-scale topographic and geologic mapping, diamond-drilling, sampling, assays, appraisal of potential.	July 1964 - Oct. 1966, intermittent
Morro Pelón laterite (Plate I, e-6)	Fe, Ni	Test pitting, sampling, assays.	Dec. 1964- Feb. 1965
Maceo (Plate II, c-7)	Wollastonite	Large-scale topographic and geologic mapping, diamond-drilling, sampling, reserve calculation.	Aug. -Oct. 1966
Yarumal (Plate I, d-6)	Talc	Large-scale topographic and geologic mapping, diamond-drilling, sampling, analyses, reserve calculation, market study, appraisal of large-scale development potential.	Feb. 1966 - Nov. 1967, intermittent
Amalfi (Plate II, a-3)	Dolomite	Large-scale topographic and geologic mapping, sampling, analyses, reserve calculation.	June 1966
Llanos de Cuivá (Plate I, c-8)	Bauxite	Test-pitting, auger drilling, sampling, assays.	June - July 1966
Uré laterite 2 km W of Uré	Ni, Fe	Large-scale topographic and geologic mapping, test-pitting, sampling, analyses, reserve calculation.	Oct. 1966 - Dec. 1967, intermittent.

Zone II resources

Almost every known mineral occurrence of potential economic importance, however slight, inside the boundaries of the zone is mentioned in the sections following. Figure 2 shows the location of most of the known mines, quarries, and prospects with the exception that only gold mines now active and some of the principal abandoned gold mines are shown. It is impractical to attempt to show on fig. 2 the locations of the several hundred abandoned small gold mines and prospects known in Zone II.

The mining industry in Zone II (Antioquia) was founded on the exploitation of gold, and a romantic aura continues to linger about this tradition. Even today, most persons think of mining in Antioquia as synonymous with gold mining. This is a deserved association, for Antioquia has been the main source of gold in Colombia, and is a major gold province that has produced roughly one percent of all the gold recovered in the world since the beginning of man's history. At present, however, mining in Zone II must be viewed more realistically and less romantically. Excluding two large gold mines, Pato Consolidated Gold Dredging Ltd. and Frontino Gold Mines Ltd., both in the northeastern part of the zone, the production of gold and byproduct silver has a value only a small fraction of that of concurrently produced nonmetallic minerals and mineral derivatives.

GENERAL GEOLOGY

Precambrian rocks

Isolated patches of metasedimentary rocks of presumed Precambrian age are found near the eastern margin of the zone (Plate II). These are chiefly feldspar-quartz gneisses with sporadic lenses of amphibolite and calc-silicate marble. No mineral resources of economic interest are known to be associated with these rocks.

Paleozoic rocks

Gray to black shale, siliceous siltstone, arkosic metasandstone, and sparse intercalated limestone cover an area of 45 sq km (Plate III, e-9). These lightly metamorphosed sediments are assigned to the Ordovician on the basis of fossil graptolites.

A complex suite of metasediments of undifferentiated Paleozoic age (Devonian? to Permian?) covers large areas of the zone, especially around the periphery of the Antioquian batholith, which discordantly intrudes them. Feldspathic and aluminous gneisses, quartzites, and quartzose gneisses, amphibolites, and pelitic schists are dominant lithologic types. Marble and associated calcareous rocks are prominent members of the Paleozoic metasedimentary suite in II B, but sparse in II A. The schists and gneisses are collectively designated as the "Valdivia Group" on the II A side, and on the II B side are referred to simply as metamorphic rocks of the Central Cordillera.

Epigenetic auriferous quartz veins are common in Valdivia Group and equivalent graphitic quartz-sericite schists. Regional and contact metamorphism of aluminous pelitic schists formed andalusite porphyroblasts, a potential although presently unexploitable resource. Greenschist is quarried as a decorative building stone near the town of Valdivia (Plate I, c-4), from which the Valdivia Group takes its name.

Syntectonic plutons of late Paleozoic (Permian?) age intrude the Valdivia Group and correlative metasediments, and some gold deposits are believed to have originated from these plutons.

Mesozoic rocks

Pre-Cretaceous(?)

Metabasalts and intrusive metagabbros and serpentinites, collectively assigned an undifferentiated Mesozoic (Late Jurassic?) age, are prominent in II A, but equivalent rocks of the alpine ophiolite suite are sparse on the II B side. The serpentinites are of special economic interest because some of them contain deposits of talc, chrysotile asbestos, and chromite, and deep weathering has formed nickeliferous and ferruginous laterities on others.

A diorite pluton of Jurassic age (160 ± 7 m.y. based on one hornblende K-Ar age determination; R. Marvin, USGS, written commun., 1968) covers about 600 sq km in eastern II B. Gold veins in this unit are exploited by Frontino Gold Mines Ltd. (Plate II, a-4).

Local poorly exposed outcrops of highly fractured felsic volcanic rocks occur as inclusions in the Jurassic diorite near Puerto Berrio (Plate II, e-7).

Clastic marine sediments of the San Pablo Formation associated with spilitic metabasalts are assigned to the undifferentiated Mesozoic (the southeast corner of Plate I (Planchas e-5, 6, 7, and 8)).

Cretaceous

Cretaceous sedimentary and volcanic rocks are prominent in some areas. Black carbonaceous shale, locally fossiliferous, is the dominant lithologic type in the Cretaceous of IIB; interbedded graywacke, siltstone, sandstone, and conglomerate are interbedded with shale in IIA (La Soledad Formation, Plate I, e-5 and 6), and are locally prominent in IIB also. Minor limestone and marl, and andesitic or dacitic metatuff beds, are intercalated locally with shales. The Cretaceous sedimentary rocks ar of relatively minor economic significance. White quartz-pebble conglomerate beds near Amalfi (Plate II, a-3) are a potential source of ganister for silica brick, and bloatable black shale nearby constitutes a potential source of lightweight aggregate.

Metabasalt and mafic pyroclastic rocks of predominantly tholeiitic composition form a prominent north-trending belt near the western boundary of the zone. This belt is assigned to the Cretaceous on the basis of Foraminifera identified in intercalated lenses of radiolarian chert (Botero A., oral and written communs., 1968). Manganiferous lenses occur near Santa Bárbara, 50 km by road south of Medellín, associated with cherts intercalated in metabasalt of presumed Cretaceous age. Minor showings of copper minerals occur in metabasalt near Anserma, Department of Caldas, in the southwest corner of the zone. No other minerals of economic significance have been recognized in the Cretaceous metabasalt suite.

The Antioquian batholith covers some 8,000 sq km and is assigned a Late Cretaceous age on the basis of K-Ar analyses on biotite (Botero A., 1963, p. 81). It is dominantly tonalite composed of plagioclase (An_{40}-An_{55}), quartz, biotite, and hornblende. The batholith is of considerable economic significance because it is the host for many auriferous quartz veins, and the source of hydrothermal mineralizing solutions that formed gold-quartz veins in schists of the Valdivia Group which were intruded by the batholith. Weathering of the batholith has produced saprolite clay, widely used to make brick and tile. Kaolinite for high-quality ceramic products is taken from a cupola of the batholith at La Unión. Quartz veins formed by hydrothermal solutions residual from the freezing of the batholith are a source of industrial silica, and pegmatite from the same magma is exploited for ceramic feldspar south of La Ceja. Thermal metamorphism of quartzose calcite marble along the batholith contact near Maceo (Plate II, c-7) formed deposits of wollastonite, a calcium silicate of potential economic importance.

Other silicic plutons similar in composition but presumably slightly older than the batholith have been mapped, but are of lesser importance both spatially and as a source of economic minerals.

Tertiary

An irregular but continuous belt of Tertiary nonmarine clastic sediments occurs along the eastern boundary of the zone, parallel to the Río Magdalena. Tertiary sedimentary and volcanic rocks are prominent in the southwest part of the zone from Sopetrán southward to Anserma, especially on the west side of the Río Cauca. Subbituminous coal beds are an important resource in IIA, presently exploited near Amagá and Riosucio.

Isolated patches of alluvium perched well above the present base level of erosion, and presumed to be of late Tertiary (Pliocene?) age, have been hydraulicked for placer gold, especially near Amalfi (Plate II, a-3).

Tertiary diorite and andesite porphyry plutons intrude Cretaceous and older Tertiary rocks in the southwest corner of the zone. One of these at Marmato, Department of Caldas, is host for auriferous quartz veins, and the source of hydrothermal solutions that formed similar veins in roof-pendants of Paleozoic schist. Minor base-metal sulfides are associated with the precious metals.

At Aranzazu and Aguadas, also in the Department of Caldas, native mercury and cinnabar occur in fissures in Paleozoic graphitic quartz-mica schist host. The mercury minerals are believed to have been deposited by hydrothermal solutions emanating from nearby Tertiary andesite intrusions.

Quaternary

Quaternary alluvium occurs in virtually all stream valleys but only the most prominent deposits have been mapped. In most cases it is difficult to distinguish between Pleistocene and Holocene material; the degree of compaction or cementation is an unreliable age criterion. Most alluvium is poorly consolidated or unconsolidated and nearly all of it is gold-bearing, although minable placer deposits are very limited. Pato Consolidated Gold Dredging Ltd., which may be the largest gold dredging operation active in the world today, exploits Quaternary alluvium in the valley of the Río Nechí near El Bagre in the extreme northeast corner of the zone. Probably 55 percent of all gold produced in Zone II is taken from placers. Alluvium near population centers is an important source of sand and gravel for construction.

Structural geology

Zone II is part of a complex synclinorium intruded concordantly by syntectonic catazonal or mesazonal tonalite plutons, and later discordantly by the epizonal post-tectonic Antioquian batholith. They synclinorium originated during the Paleozoic concomittant with the accumulation of clastic and mafic pyroclastic sediments, the Valdivia Group, in a great north-trending eugeosynclinal trough. Extensive calcareous beds were deposited in II B but not in II A. This great prism of geosynclinal sediments, possibly as much as 13 km in total thickness, was intensely folded and metamorphosed to the greenschist facies, locally to the amphibolite facies, possibly during Late Permian or Early Triassic time, by regional tectonic forces acting normal to the axis of the trough. Syntectonic tonalite intrusions are believed to have been emplaced at this time also. This tectogenesis was followed in the Mesozoic by outpourings of basaltic lava, intrusion of gabbro and serpentinite along faults and fractures, and deposition of marine clastic sediments or flysch. A second tectogenesis near the end of the Cretaceous was culminated by intrusion of the post-tectonic Antioquian batholith.

During the Tertiary, land lifted above sea level was eroded extensively, resulting in the deposition in adjoining basins of molasse sediments, both terrestrial and littoral marine, accompanied by beds of volcanic ejecta and the formation of coal seams. These younger sediments were tilted from their original horizontal attitude by Late Tertiary orogenic forces, but were not appreciably metamorphosed. Pliocene to Holocene epeirogenic uplift and the accompanying erosion have sculptured the land into its present form.

Major wrench faults, such as the Romeral in IIA and the Otú and Palestina in IIB, are among the most striking geologic structures recognized in Zone II, but their relation to the tectogenic forces that caused folding and metamorphism is not clear. Some of these wrench faults are traceable along strike for several hundreds of kilometers, and have lateral displacements measurable in tens of kilometers, although only the Palestina fault with a measured right-lateral displacement of 28 km is well documented (Feininger, 1970). Movements on these faults have transported segments of the earth's crust for considerable distances. Some movements apparently commenced in the Mesozoic, and may have continued intermittently through the Tertiary; however, none of the Zone II faults are known to be currently active. No mineral deposits of economic importance are known to be directly related to these large wrench faults.

Gold and Silver

Historical background

Gold and silver deposits were not especially studied by IMN and most of our information comes from the literature or from personal communication with mine operators. The mining of gold and silver has been traditional in this region for the past 400 years, and although its relative importance to both the local and the national economies has declined sharply in modern times, it still makes a significant contribution. Gold and by-product silver continue to be paramount among metallic resources in Zone II. The aborigines were extracting gold from veins and alluvium before arrival of the Conquistadores, although they probably worked only lodes with visible free gold and the placers that contained nuggets and coarse gold. The desire to find the great quantities of gold and silver that were supposed to exist in the New World was one of the principal driving forces behind the expeditions and conquests of the Spaniards, beginning at the close of the 15th century and continuing for 300 years. Although historical accounts of the fabulous riches taken from individual mines or mining districts probably are exaggerated, there can be little doubt that the value of the gold and silver produced in Colombia from the time of the Conquests up to the present amounts to well over a billion US dollars reckoned at US $35 per troy ounce for gold and US $2 per troy ounce for silver. Most of this came from Antioquia. There are few gold mines or mining districts known today in Zone II that were not known to the old Antioqueños several hundred years ago. Vicente Restrepo's famous memoir, "Estudio sobre las minas de oro y plata de Colombia" (1937) includes glowing descriptions, extracted mostly from colonial reports and chronicles, of the numerous "rich" mines in this region. Undoubtedly there were some true bonanzas equal to these extravagant descriptions, but the average gold tenor of most of the veins worked in those times probably was not notably higher than the tenor of ore samples taken more recently at these same mines, which cannot be worked economically today.

The 19th century saw changes and improvements in mining techniques. Notable among these was the stamp-mill, the first primitive model of which was brought into Antioquia in 1828 by an Englishman, Tyrell Moore (Restrepo, 1937, p. 52). This relatively simple machine, which reached its zenith in the gold mines of California U.S.A. after the Gold Rush, gradually came to replace the hand-crushing and primitive "arrastres" that had been used in Colombia for centuries. Since the early 20th century the stamp-mill has become obsolete in other parts of the world, but it is still in common use in Antioquia where it is called "molina californiano", (California mill), and a homemade adaptation of it called "molino antioqueño" (Antioquian mill).

The cyanidation process developed in the years after 1891 (Forbes and Smart, 1921, p. 6), eventually came to be adopted at some of the mines in Colombia, and resulted in recovery of a considerable part of the gold and silver that previously had been lost in tailing.

Placer mining techniques also were improved over the primitive hand panning and sluicing that had been in use without change since ancient times. In 1883, the first mining dredge in Colombia was constructed on the Río Nechí by a French company. This venture failed eventually, but it was the fore-runner of a fleet of highly successful dredges that have been operating in Colombia since 1913, financed mostly by English, American, and Canadian capital. Later, hydraulic mining was introduced with the socalled "giants" or "monitors" which shoot powerful jets of water against banks of alluvium, washing it into a riffled channel; sand and gravel pass over the riffles while denser mineral particles, including gold, are caught between them. This method is adaptable to alluvial deposits too small or in terrane too broken to accommodate a dredge and is still used in some places in Antioquia.

Gold mining in Zone II persisted through the latter half of the 19th century and into the 20th, but its relative importance to the national economy gradually declined. Labor-saving techniques with relatively high productive capacity like those mentioned above were installed at a few mines, mostly by foreign-financed enterprises, but the majority continued to be individually small, operated in a comparatively primitive manner. When the price of gold was raised in 1934 from US $20.67 per troy ounce to $35.00, a new epidemic of gold fever swept Antioquia, accompanied by a great flurry of activity and speculation with the participation of hundreds of small syndicates and individual investors, the great majority of whom had little training and experience in geology or mining engineering. Old prospects that had been abandoned for many years were reopened and new concessions applied for, more often than not over uneconomic veinlets or barren quartz veins. Stamp-mills, mostly "molinos antioqueños" were commonly erected at sites prior to any evaluation of the size of the ore-body or its tenor, and in some cases, prior to even confirming the existence of ore. Most of these prospects and "mines" were closed by 1940 and have not been worked since.

It is popularly supposed that gold mining in Antioquia (and elsewhere) has declined because the deposits are exhausted. Certainly the richer and more easily worked deposits have been depleted. On the other hand, there can be no doubt that there is at least as much gold left in the ground as has been removed previously, and it is not being exploited because its present market value is not equal to the cost of extraction. This condition would be changed dramatically if the world-wide price of gold were to be substantially increased.

Relation of silver to gold

There are no true silver mines in the zone, that is, mines in which silver is the main or most valuable product; instead, silver is a byproduct of gold mining. These two metals coexist as natural alloys such as electrum or are occluded in sulfides. The ores of Zone II contain higher values in gold than in silver because of the much higher price for gold, although the actual weight of silver contained in a given ore may be greater than that of gold. Furthermore, an assay of raw ore will usually show a higher proportion of silver than the crude bullion produced from that ore. This seeming paradox is explained by the fact that a higher proportion of silver than of gold is occluded in sulfides and lost in tailing. But it is rarely practical or economical to recover base metal sulfides at the scale of operations and with the methods used at the small mines being worked in the zone today (Frontino Gold Mines Ltd. is an exception). Cyanidation of stamp-mill tailing does reduce silver losses. No statistics are available, but the total loss in tailing of silver in sulfides, especially galena, from the Conquests to the beginning of the present century, must have been very great, measurable in tens of millions of dollars.

Placer gold usually has a higher gold-to-silver ratio than the crude bullion produced at the lode mines. Some of the silver alloyed with free gold in veins is leached out and lost during weathering, erosion, transportation, and final deposition in alluvium, because of the relatively higher solubility of silver in natural waters. The relatively small percentage of silver alloyed with recovered placer gold is not subject to the same degree of loss as silver contained in the ores at small lode mines, because only native metal is taken at the placer mines, whereas the crude cyanidation of stamp mill tailing does not effectively recover silver occluded in sulfides, especially in galena.

Lode mines

No attempt is made here to include all the mines in Zone II. Those discussed include active and abandoned mines that are believed to be representative. Figure 2 shows the location of the active lode mines known to IMN, and some of the more important abandoned mines. Placer deposits also are shown. It is impractical to show all of the several hundred known small mines and prospects on fig. 2, but these are recorded in the archives of the Ministry of Mines and Petroleum in Bogotá and at the Servicio Minero in Medellín.

Frontino Gold Mines Ltd. This is by far the most important lode gold mining operation in Colombia. It is located at the town of Segovia (Plate II, d-1), 220 km by road northeast of Medellín. Total payroll comprises 800 men of which 350 work underground. Administrative and technical staff includes about 40 persons. The company, now a subsidiary of International Mining Corporation of New York City, inherits its name from Compañía de Frontino y Bolivia, an English company organized in 1852 (Restrepo, 1937, p. 58). Two unconnected underground workings are developed, El Silencio at the western outskirts of Segovia, and Cogote, 2.5 km east of El Silencio. Only the El Silencio, by far the larger of the two, is discussed here. The vein strikes N.20° E., dips 30° E., and has a known down-dip extension of 1,300 m and strike extension of 2,000 m. The north end of the vein consists of two branches which converge to form a single vein south of the main inclined shaft. Vein widths range from a few centimeters to 3 meters, but the average width is slightly less than half a meter. The host rock is a medium-grained quartz diorite, cut by intermediate (dacite?) porphyry dikes roughly a meter thick which lie along the footwall and less commonly along the hanging wall of the vein. The dikes are pre-ore, and it seems probable that they were controlled by major fractures or faults, which, together with the dikes, also controlled the course of hydrothermal mineralizing solutions that later formed the veins. Fissure filling rather than replacement appears to have been the dominant mineralizing process, and alteration of walls is negligible. Gangue is massive milky quartz and minor calcite. Vugs of clear quartz crystals occur locally. Ore minerals, in addition to very fine grained free gold, include pyrite, sphalerite, pyrrhotite, galena, and very sparse scheelite and chalcopyrite.

The mine has been exploited for more than a century, but reserves are believed adequate to support operations for several years to come. Access from the surface is by a three-compartment inclined shaft that follows the dip for several hundred meters; it passes into the quartz diorite hanging wall where the dip steepens. Elevation at the portal is about 610 m (mine datum 724.2 m) and the bottom is about 134 m below sea level. Levels have been developed at 30-m intervals measured down the dip, equal to 15 m true vertical intervals. Stopes are excavated overhand from one level to the next level above, enough pillars being left to insure ground support. The mine has 39 working levels, and the aggregate length of underground galleries is measurable in tens of kilometers. Approximately 1,800 m of new drift and 1,400 m of raise were driven in 1967. Some dilution with wall rock is inevitable, owing to the thinness of the vein, and hand-sorting is practiced underground. Waste is used to fill old stopes. Ore is hoisted to the surface via the inclined shaft, in 2-ton capacity cars. The mine is comparatively dry, but 5,700 liters per minute of electric-driven centrifugal pump capacity is available when needed. Ground support has not been a serious problem, although occasional small rockbursts have been reported. Frontino is one of the few mines in Colombia that regularly uses diamond drilling as an exploration tool to keep ore reserves ahead of consumption. About 17 holes, mostly underground, aggregating 427 m, were drilled in 1967.

A single mill, the "María Dama", adjacent to El Silencio mine is fed by ore from both El Silencio and Cogote, by far the greater part coming from El Silencio. Total ore milled in 1967 was 164,000 metric tons out of 179,000 tons mined. Average tenor of ore being milled in 1968 from both El Silencio and Cogote is as follows (M.A.Burke, written commun., 1968) :

Au	13.27 g per metric ton
Ag	24.63 g per metric ton
Pb	.50 percent
Zn	.80 percent
Pyrite	8.60 percent

Ore is treated at a rate of 550 metric tons per day in a modern cyanidation plant with auxiliary differential flotation circuits which remove sulfides for separate treatment. Until a few years ago, all sulfides were cyanided, then discarded in tailing. Now, however, separate concentrates, about 500 tons per year each of galena and of sphalerite, are extracted and exported via the port of Buenaventura to the American Smelting and Refining Co. smelter at Selby, California (galena), and to an Imperial smelting process smelter in Japan (sphalerite). The value of the lead and zinc helps to defray extraction and shipping costs, but it is the added recovery of the contained gold and silver that makes this differential flotation step more economical than the previous system of simple cyanidation of a bulk sulfide concentrate.

Most of the gold and silver in the ore is recovered from the cyanidation of pyrite and of sand tailing from Wilfley tables. Sludges from the Merrill-Crowe precipitation unit are melted down to a bullion of about 500 fineness (that is 50 percent each of gold and of silver) which is shipped by air to Medellín for parting of the gold and silver and sale of refined gold to the Banco de la República.

Production for 1967 is shown below (in grams) :

Gold		2,193,287
Silver in crude bullion	2,330,200	
Silver in galena concentrate	2,532,513	
Total	4,862,713	2,193,287

<u>Minas Nacionales de Marmato and private mines at Echandía</u>. These mines are famous in Colombia's history, and have been worked almost continuously since the middle of the 16th century (Restrepo, 1937, p. 87), and supposedly were worked by aborigines before arrival of the Conquistadores. The greater part of the productive area is held by a government agency called Minas Nacionales de Marmato under the direct administration of the Ministry of Mines and Petroleum. The northern end of the area, designated as the Echandía workings, is under concession to private interests in Medellín. Marmato and Echandía are discussed together because they constitute a geologic entity. Among lode gold mines in Zone II, operations at Marmato are a distant second in importance after Frontino Gold Mines Ltd.

The mines are located in Quadrangle J-8 outside of the area mapped by IMN, immediately north of the town of Marmato, in rugged terrane west of the Río Cauca, at an altitude of about 1,400 m. The Echandía veins are 500 m north of the Marmato mines. Access is via 15 km of narrow road east-northeasterly from the municipality of Supía, Department of Caldas, and 150 km by highway south of Medellín.

At least 10 subparallel main veins striking predominantly east with vertical or steep south dips have been exploited in the Marmato district. There are numerous smaller subparallel veinlets and branches.

The host rock at the Marmato mines is a Miocene (?) medium-grained gray diorite porphyry stock about 6 km north-south by 3 km east-west intruded in graphitic quartz-sericite schist correlative with the Paleozoic Valdivia Group. W.G. Fetzer (1939) made a detailed study of the Marmato operations on behalf of the Colombian government before the Second World War; he describes the Marmato host rock as a bluish-gray diorite or quartz diorite porphyry composed of plagioclase, hornblende, and sparse biotite, with or without accessory quartz. He suggested that at least part of the quartz might be secondary, related to vein formation (Fetzer, 1939, p. 7,241). The veins consist chiefly of quartz with local sparse calcite; pyrite is by far the dominant sulfide, accompanied by marmatite (so named in 1829 by the French scientist, Jean Boussingault, after the district of Marmato (Dana, 1892, p. 59)), and very sparse glena, arsenopyrite, pyrrhotite, and chalcopyrite.

Veins that do not contain sulfides generally have a very low gold and silver tenor. Widths of the veins range between a few centimeters and several meters; the average is estimated at close to half a meter. The veins are believed to have been formed by hydrothermal metalliferous solutions, residual from crystallization of the diorite porphyry, that entered tension fractures near the top of the freshly frozen porphyry and in the schist roof pendant at Echandía. Tenor is variable; recovery averages about 8 g of gold per metric ton, and slightly less than 8 g of silver, according to the mine manager (J. Márquez, oral commun, 1968). True tenor is higher, especially of silver, since metallurgical losses are high in the primitive mills. Silver tenor is appreciably higher than gold at Echandía, which was described as a silver mine in the early 19th century (Restrepo, 1937, p. 89,95). The host rock of the Echandía veins is a 400 m-long roof pendant of quartz-sericite schist. The distinctly higher silver to gold ratio of these veins suggests that the schist wall rock at Echandía reacted with ascending hydrothermal mineralizing fluids to precipitate silver more readily than did the diorite wall rock of the Marmato veins. The tenor of Marmato ore in 1939 may be calculated indirectly from data given by Fetzer, (1939) although, unfortunately, he does not give an average tenor for mill heads. He mentions loss of precious metals as averaging 5.06 pesos per metric ton of ore milled (1939, p. 7,253), and, with the Colombian peso on 1:1 par with the US dollar at that time, and assuming 65 percent metallurgical recovery, the tenor of mill heads expressed in equivalent gold content may be calculated at 15 g per metric ton. This suggests that the tenor in 1939 was not much different than that reported in 1968, because equivalent gold tenor of 1968 ore, assuming metallurgical recovery of 60 percent, may be calculated at 14 g per metric ton.

The mode of exploitation differs little from that used over the past 400 years. The hillside above Marmato is riddled with hundreds of adits ranging from a few meters to hundreds of meters long, and numerous branches and stopes. At present, about 40 adits ("socavones") are being worked one shift per day by 100 miners, some of whom are boys. These workers are not employees of the company but renters or leasors ("tributers") who work underground for a share of the free-milling gold recovered from the ore that they carry to the company's mills. Blasthole drilling is by hand. Broken ore is trammed to the surface in small wooden mine cars on wooden rails, in wheelbarrows, or carried in sacks on the backs of the miners. Transport from the mine portal to the stamp-mill may be via a small aerial cableway or by mule. Daily production of hand-sorted ore rarely exceeds 2.5 tons per "socavon", and commonly is less than one ton. The miners receive 88 percent of the free-milling gold recovered in the company's mill (J. Márques, oral commun., 1968). The miner's compensation depends upon the grade of ore that he can produce, and he probably does not earn more than 15 pesos (about US $0.90) per day.

The milling is almost as primitive as the mining. The company operates three small stamp-mills; two of these have two batteries of five 850-lb stamps each, the third has one 5-stamp battery of 500-lb stamps. Total tonnage milled is about 25 or 30 tons during a normal 24-hour operating day. Lump ore is reduced to sand-sized particles in the stamp mills. Amalgamation is not practiced because of the high cost of mercury. Sand from the stamps is passed over Wifley-type shaking tables which make a bulk gravity concentrate composed roughly of 65 percent total sulfides of which at least 95 percent is pyrite, a few percent of marmatite, and sparse amounts of galena, arsenopyrite, pyrrhotite, and chalcopyrite. Twenty tons of feed yield 1 ton of table concentrate. Tailing from the table is discarded and some precious metal loss occurs at this stage, but the amount is unknown because there is no assay control. The pyrite concentrate is hand-mulled in wooden launder troughs through which a gentle stream of water is passed. After some minutes of mulling, the crude concentrate of heavier particles including gold is panned to recover the free gold. Approximately 60 percent of all the gold recovered is taken in this way. It is of interest to note that this same hand concentration method was described by Jean Boussingault in 1826 (Restrepo, 1937, p. 246-247), and probably had been in use long before.

The pyrite tailing is shoveled into small concrete vats through which is percolated 0.2 percent solution of sodium cyanide for periods of as much as 20 days, the dissolved gold and silver being precipitated in coffin-shaped wooden boxes filled with zinc shavings. Once or twice a month the zinc-box sludges are melted to crude bullion in a graphite crucible. The bullion is shipped to Medellín for parting of silver from the gold. About 40 percent of the recovered gold is taken by batch cyanidation. All mills run three 8-hour shifts per day, employing a total of 65 workers of whom about one quarter are women. The Echandía operation is identical to that of Minas Nacionales de Marmato, but smaller in scale, with one 8-ton-per-day stamp mill.

Production from the Marmato district for 1967 was reported by the Asociación Colombiana de Mineros as follows :

Au	71,312	g
Ag	60,823	g

About 80 percent of the above came from Minas Nacionales de Marmato, the rest from the private Echandía workings.

Present operations are marginal at best, and it is said that operating deficits are covered by government subsidy. Reserves are unknown because neither exploration nor planning of extraction ahead of actual stoping are practiced under the tributer mining system. Operations are strictly day-to-day, hand-to-mouth. Marmato will never be of much importance unless the entire system of exploitation can be modernized and put on a much larger scale. Before this could be done, it would be essential to make a very thorough investigation of remaining ore reserves to determine what capital investment is justified. Not only the veins but the enclosing wall rocks should be considered, with the possibility of mining the whole mountainside in an open-pit operation, analogous to the methods employed at porphyry copper deposits. Wokittel (1960, p. 88) suggested this idea, and the present authors agree that it deserves consideration. However, this type of operation requires a very large investment and cannot be undertaken without making a thorough study beforehand. Such a study can be made best by a large private mining company with long experience, a technically competent staff, all facilities, and, most critical of all, risk capital. Much money would have to be spent before anyone would know whether or not Marmato has the potential to become transformed into a profitable large-scale mine. A rise in the price of gold would probably be necessary to stimulate this kind of investigation.

La Bramadora mine. This ranks third in importance in Zone II after Marmato, but is only a short step ahead of other small lode mines operating in the zone. The mine and stamp mill are located near the east edge of plancha e-7, Plate I, on the west bank of the Río Porce alongside the road 20 km south of Anorí. An estimated 65 men work at La Bramadora, 50 in the mines, 15 at the mill. The concession is held by a syndicate of Medellín businessmen. A series of subparallel north-striking nearly vertical quartz veins and stockworks in fractures and along faults occur concordant to foliation in graphitic thin-bedded quartzose metasiltstones of the Valdivia Group. At least six veins or vein stockworks are exploited, ranging from a few centimeters to 1.5 m, averaging roughly half a meter. Fine-grained pyrite, accompanied by sparse sphalerite, pyrrhotite, arsenopyrite, galena and chalcopyrite, occurs disseminated in a milky quartz gangue. Reliable assay data are lacking, but average gold and silver tenor of hand sorted ore is probably less than 15 grams per ton each, and copper, lead, and zinc less than 1 percent each. The veins are considered to have been deposited from hydrothermal fluids residual from crystallization of the nearby Antioquian batholith.

The mine comprises a dozen or more horizontal adits driven by hand into the hillside. Ore is hand sorted underground and at the adit portal, and is transported to the stamp mill by wheelbarrows or in burlap bags carried on the miner's backs. Ratio of ore to waste is estimated at roughly 1 to 1. The miners are leasors or tributers who have been given permission to exploit the veins in exchange for a share of the gold recovered, similar to the system employed at Marmato. Each gallery is the private domain of a small team of miners whose income is dependent upon the tonnage and grade of ore they produce. The ore-treatment plant includes one 5-stamp battery of 500-lb stamps, a small ball mill, two Wilfley-type vibrating tables and several concrete-lined vats for batch cyanide leaching. Capacity is about 15 tons per 24-hr day, but this is rarely achieved. The Wilfley tables collect 10 tons per month of mixed sulfide concentrate, chiefly pyrite, which is exported to the American Smelting and Refining Co. at Selby, California. The base metals probably pay little more than transport costs, but the additional gold and silver recovered at the smelter justifies the recovery and shipment of the sulfide concentrates.

Berlín mine. No discussion of lode gold mines in Zone II would be complete without mention of the old Berlín mine, 25 km airline northwest of Yarumal, in plancha b-5, Plate I. The mine formerly was accessible by 54 km of tractor road constructed by the company at a cost of US $100,000 from the Yarumal-Valdivia highway, but this has long since become impassable to vehicles. The site can be reached today only by muletrail. The original mine was abandoned in 1946 when ore reserves were exhausted.

Unlike most of the gold deposits in the zone which have been well known since the early 19th century, or even before, the Berlin deposit was not discovered until 1929 (Singewald, 1950, p. 131). During its relatively brief period of exploitation it rivaled Frontino's mine at Segovia as a major gold producer. An excellent summary of the mine as it existed in 1942 is given by Wilson and Darnell (1942). The concession was acquired by the N.A. Timmins Corp., headed by the famous Canadian mining entrepreneur, Noah Timmins, and operations were conducted under the name Timmins-Ochalí Mining Company. The old workings are inaccessible and most of the following data concerning the original mine are extracted from Wilson and Darnell (1942), and from Singewald (1950, p. 131-132).

The auriferous quartz vein had a strike almost due north, with steep east dip, and was located along the contact between quartz-sericite schist on the west or footwall side and chloritic greenschist on the east or hanging wall side. The host schists are of the Valdivia Group. Width of the main vein was reported to range from a few centimeters to 24 meters, averaging close to a meter. A felsite dike, possibly post-ore, of unspecified thickness, also was reported to have followed the vein along the hanging wall (Wilson and Darnell, 1942). Faulting along the contact provided the channel for hydrothermal mineralizing solutions of presumed magmatic origin. The nearest igneous rock is Paleozoic metatonalite, 250 m east of the vein, but it is not clear whether this metatonalite or the more distant late Cretaceous Antioquian batholith 13 km south of the mine, was the source of the mineralizing fluids. The Antioquian batholith is known to be a major source of gold-bearing quartz veins, but is separated from the mine by the Romeral fault, a major wrench fault. The Paleozoic metatonalite is auriferous also, although less productive than the batholith. Gold-quartz veins in the metatonalite a few kilometers west and northwest of Briceño (Plate I, c-5) have been exploited sporadically in the past, but evidently are too low grade to sustain operations. Alluvium on the metatonalite is locally auriferous. The present writers favor the Paleozoic metatonalite as the probable source of the Berlin vein.

Average mill-heads tenor for 1940 was reported to be 0.408 ounce per short ton (14.0 g per metric ton). Cut-off grade was reported to be 0.22 ounce per short ton (7.5 g per metric ton). Silver tenor was not specified, but bullion fineness of 710 Au and 270 Ag was reported, suggesting a recoverable silver tenor of about 5.3 g per metric ton; true tenor undoubtedly was a little higher. The richest parts of the vein contained abundant schist inclusions around which sulfides and gold tended to be concentrated. Pyrite was the dominant sulfide, accompanied by minor galena and sphalerite, sparse pyrrhotite and arsenopyrite, and only traces of chalcopyrite. Base-metal tenor was not specified but presumably was too low to permit economic recovery. Horizontal adits were driven into the steep hillside, and 13 levels had been developed by 1942, of which three in hanging wall schist were used as main haulageways. The vein was developed along a horizontal distance of 1,200 m and vertical distance of 480 m. An internal inclined shaft with 1.5 ton skips served lower levels. The stope-and-fill mining system was employed. Mining was mechanized with compressed air-driven rock drills and mechanical ore loaders; ore was transported to the surface by trains of one-ton ore cars drawn on steel rails by electric trammers. Power for all operations was supplied by the company's own Pelton wheel generators having total capacity of 950 kilowatts (Wilson and Darnell, 1942). The mill was modern for its time, treating 340 metric tons per day, achieving 96 percent gold recovery; fine grinding in ball mills was followed by all-slimes cyanidation and precipitation in a Merrill-Crowe unit. When operations were at their peak in 1940, a total of 116,600 metric tons of ore was milled, producing 1,602,000 grams of gold. During the period 1933 to 1946, a grand total of 880,231 metric tons of ore was milled, yielding 12,847,852 grams of gold which at US $1,125 per gram, had a gross value of US $ 14,453,833.50. Average net tenor was 14.6 grams per metric ton. An ore extraction factor of 99 percent was attained (H. vom Staufen, written commun., 1969). The Berlín mine was a model operation in its day, and testimony to the courage and efficiency of its developers. More than 800 persons were employed at the height of operations.

For the past several years mining has been resumed on a small scale, the concession having been acquired by private interest in Medellín. Ore is taken from short adits driven on narrow quartz veins below the original mine and mill. In 1968 two stamp mills were operating at a combined capacity of about 10 tons per day; tailing is cyanide-leached in small concrete vats. About 30 persons are employed. Judging from external appearnaces, the present operations are scarcely better than marginal. According to one of the former managers at the old Berlín, there is little chance of discovering another large vein immediately adjacent to the original, but the surrounding terrain may contain important ore bodies, and probably would deserve further exploration if the price of gold were to be raised substantially above US $35 per ounce (H. vom Staufen, mining consultant, oral commun., 1968).

El Limón mine. This small lode mine is located 6 km south of Zaragoza on the west side of the road to Segovia, in rolling terrane at an altitude of 150 m. The following data were supplied by Mr. Hubert vom Staufen, Medellín mining consultant and present owner of the mine. The vein is said to have been discovered in 1938 by a prospector named Nepo Mira, who erected a three-stamp mill and commenced exploitation on a small scale. Mira sold the mine in 1940 to Otto Feckler, a German physician, who worked the oxidized zone during the Second World War, but was obliged to shut down in 1946 because of financial and operational difficulties. Messrs. George R. Leland and Hubert vom Staufen examined the mine in 1947 on behalf of the N.A. Timmins Corporation. This company had just closed the Berlin mine northwest of Yarumal because of exhaustion of the Berlín vein after a decade of highly successful operation, and was looking for new ventures. El Limón was too small to be of interest to the Timmins company, but Leland and vom Staufen bought the mine, improved the mill, and continued work as a partnership until obliged to shut down in 1953 for lack of development capital, combined with the problem of resisting marauding bandits who had moved into the territory during the political unrest prevailing at that time. In 1958 they leased the mine to Cia. Minero Chocó Pacífico S.A., a subsidiary of South American Gold and Platinum Co. of New York. This company, whose main interest is in dredging for gold and platinum in the Department of the Chocó, further explored the El Limón vein by underground galleries and 5 diamond drillholes, and by 1961 the proven ore reserve was calculated at 25,000 metric tons with an average gold tenor of 39 grams per ton and a roughly equal tenor of silver. However, in 1962, the parent company (now called International Mining Corporation) decided to concentrate its efforts on the Frontino Gold Mines Ltd. properties at Segovia, which had just been acquired from English interests, and gave up the lease on El Limón. Squatters moved into the mine during the interim shutdown period, and vom Staufen, now the sole owner, was forced into litigation from 1964 until 1966 to recover his property. Development was resumed and a small pilot mill constructed in 1966 (H.vom Staufen, written commun., 1969).

The quartz vein strikes N.5°E., dips 40o west, in quartz-feldspar-mica gneiss of Paleozoic age. The vein is offset in many places by crosscutting normal faults of a few meters displacement. Gold and silver are associated with disseminated sulfides, dominantly pyrite, that constitute up to 12 percent of the vein matter. About one-half percent each of galena and sphalerite also are reported. Vein width is fairly uniform, averaging about 40 cm, with developed strike-length in ore of 300 m and proven down-dip extension of 200 m. The orebody has not been fully delimited (H.vom Staufen, oral commun., 1969).

Present mine equipment includes a 125-cubic foot per minute portable compressor (a 330-cubic foot per minute stationary diesel compressor is soon to be installed), several pneumatic rockdrills, a compressed-air-driven ore loader, three 1-ton mine cars, rails, pipe, and auxiliary equipment. The mill has a capacity of 1 ton per hour and consists of a small jaw crusher, hammer mill, and Wilfley table. Gold in table concentrates is recovered by amalgamation in barrels. Tailing from the amalgamation barrels is being stored for further treatment by cyanidation in a small plant now under construction in Medellín (H.vom Staufen, written commun., 1969).

During the past 20 years development has been sporadic, but the proven reserve and geologic possibilities for additional reserves now justify the installation of a small permanent mill. During the first seven months of 1968 about 40,000 grams of gold (and an approximately equal amount of silver) were produced by simple amalgamation from roughly 1,000 tons of ore extracted by hand drilling and carried to the mill on the miner's backs, (H.vom Staufen, written commun., 1969). If present plans for increased mechanization and production are carried out during 1969 and 1970, El Limón could move up to second place, admittedly a very distant second place, after Frontino Gold Mines Ltd., among all the active lode gold mines in Zone II.

Small lode mines in Zone II. In the past more than 400 small lode mines have been worked in the zone at one time or another, and some of them have been known since the 16th century, although none have survived as long as Marmato. More than a hundred small mines were reported active in 1937 (Singewald, 1950, p. 133). Today the number has shrunk to scarcely more than a dozen, and these are on such precarious footing that the slightest adversity could close any one of them. A typical small mine is worked by a team of campesinos, who are miners only when not engaged in agricultural work. The "mine" consists of a series of shallow adits driven by hand into the hillside in decomposed bedrock, most commonly the Antioquian batholith, to intersect one or more narrow quartz veins, which then are drifted on with pick and shovel, rarely with drills and explosives, until fresh rock is encountered. This usually is cause for abandonment of the adit because the veins seldom are rich enough to pay for the additional cost of explosives and of drilling blastholes. A new adit is then driven nearby, so that after a time the hillside comes to resemble a block of Swiss cheese. Reserves are unknown because operations are strictly on a day-to-day basis, but probably do not exceed a few thousand tons of vein at any individual deposit. The miners work on the tributer system, receiving a share of the recovered free-milling gold in lieu of wages. The concession holder, typically a businessman or syndicate of businessmen living in Medellín or other urban center, rarely visits the mine, and has scant knowledge of the techniques and problems of the mining industry. The owner provides a stamp mill, typically a water-wheel-driven wooden "molino antioqueño", and one or two concrete vats for cyanidation.

Operations are overseen by the owner's hired supervisor. The gold recovered by cyanidation is the property of the owner; only the gold liberated in the stamp mill and won by panning is shared with the miners. Total production from one of these operations seldom exceeds 1,500 grams of gold per month, and not rarely is only a few hundred grams. The miner's compensation is hardly better than the income earned by his nonmining neighbors, except on those rare occasions when he may strike a rich pocket. The lure of striking a rich lode keeps the miner at his arduous and dangerous job. So long as men are willing to work under these circumstances, small tributer mines will continue to operate indefinitely, but their contribution to the national economy is almost negligible.

Placer mines

Only one major placer mine is currently active in the zone. Other placer operations are mostly small, although a few are of moderate importance. Probably more than 55 percent of all gold produced in Zone II is from placers. The placer deposits in the zone may be classified as follows :

1) Extensive wide and deep alluvial fill in the lower reaches of major streams: potential gold-bearing material measurable in hundreds of millions of cubic meters, best exploited by large dredges. Example : the Río Nechí downstream from El Bagre in the northeastern corner of Zone II.

2) Alluvium in floodplains and terraces of large streams potential gold-bearing material commonly measurable in tens of millions of cubic meters; potentially exploitable by dragline ("doodle-bug"), hydraulicking, or by small dredges. Example : Río Supía south of the town of Supía in the Department of Caldas.

3) Pre-Holocene alluvium perched well above the base-level of modern drainage; potentially gold-bearing material commonly measurable in millions of cubic meters; exploitable by hydraulicking. Example : La Viborita mine near Amalfi in Plate II, a-3.

4) Thin local patches of Holocene alluvium in the beds of small streams, or in narrow terraces along their banks, potentially exploitable material in any individual deposit seldom exceeds a few hundred thousand cubic meters; exploitable locally by small-scale hydraulicking, but commonly worked by individuals or small groups with pans ("bateas") and rudimentary sluices. Example : Río Anorí and its tributaries some 20 km north-northeast of the town of Anorí.

Pato Consolidated Gold Dredging Ltd. Pato Consolidated Gold Dredging Ltd. operates a fleet of 5 electric-powered continuous bucket-type dredges, digging to depths of 24 to 28 m below water level along the Río Nechí, downstream from the town of El Bagre in northeastern Antioquia. This is probably the largest gold-dredging operation active in the world today. The area is in the extreme northeast corner of Zone II, and beyond the area mapped by IMN. The summary presented here is based on a visit to the site in September 1967.

The nearest road to El Bagre is at Zaragoza 13 km to the southwest and 285 km by road northeast of Medellín. However, there is scheduled daily DC-4 air service between Medellín and El Bagre. The company also maintains its own twin-engine aircraft. Elevation is less than 50 m above sea level, and the climate is hot and humid throughout the year, although rainfall is markedly less during December to March than during the other months.

Zaragoza has been famous as a producer of placer gold since the 16th century. Dredging was successfully established in this district in 1913, and the present company inherits its name from an earlier English company called Pato Gold Mines Ltd. (Singewald, 1950, p. 124), named after the tiny village of Pato, 17 km southwest of El Bagre. In 1934 the company became a subsidiary of Placer Development Ltd. of Vancouver, British Columbia, and the number of dredges eventually was increased to 7, then reduced to its present level. After 1961, the company became a subsidiary of International Mining Corporation, formerly South American Gold and Platinum Company, with headquarters in New York City, which also operated dredges in the Departments of Chocó and Nariño through other subsidiaries.

Besides the 5 active dredges, each of 13½-cubic-foot bucket capacity, Pato Consolidated also has three small dredges standing idle, one of 8½-cubic foot, the others of 2½- and 6-cubic foot capacity buckets respectively. Two of the idle dredges are to be transferred to Cía. Minera de Nariño S.A. in the Department of Nariño, the third to Cía. Minera Chocó - Pacífico S.A. in the Department of Chocó, during 1969 (E. Moseley-Williams, general manager, Pato Consolidated Gold Dredging Ltd., written commun., 1969). The Río Nechí channel and flood plain from Dos Bocas (junction of the Rios Porce and Nechí) northward to the present dredging sites has been dredged during the past half century. The Río Porce, above Dos Bocas to its confluence with the Río Mata, a distance of 21 km, was dredged between 1949 and 1961 with outstanding success with a 2½-cubic-foot dredge (E. Moseley-Williams, general manager, Pato Cons. Gold Dredging Ltd., oral commun., 1967). Broad alluvial flats near the riverside villages of Puerto Claver and Cuturú, 14 and 20 km respectively, downstream (northward) from El Bagre are presently being dredged, and are only partly within Zone II. The dredges are serviced by small powerboats from El Bagre camp, the site of employees' living quarters, school, recreational facilities, commissary, warehouses, and large fully-equipped and staffed repair shops. Power for the dredges, camp, and surrounding communities is generated at the company's hydroelectric stations, one located 3 km north of Dos Bocas, the second and much larger at Providencia, 32 km upstream from Dos Bocas on the Río Anorí. Seventy one kilometers of transmission line were constructed by the company to distribute current. Power is carried to the dredges by long heavy-duty cables mounted on temporary pole-lines which are shifted with the dredges when necessary.

The dredges are operated continuously except for maintenance and repairs. Nearly 500 persons are directly employed, and several thousand others derive their support indirectly from the company's operations.

The five active dredges are fitted with buckets of 13½-cubic-foot capacity and each dredge has a nominal digging capacity of 500,000 cubic yards (382,000 cu m) per month, but under normal operating conditions excavates slightly more than 400,000 cubic yards (306,000 cu m) per month, or more than 2,000,000 cubic yards (1,529,000 cu m) per month for all five dredges combined. Digging depths of 80 to 91 feet (24 to 28 m) below water level are readily attained. Digging conditions generally are favorable except where clay overburden exceeds a thickness of about 18 m. These thick deposits make a serious operational problem because the sticky and plastic clay clogs buckets, hoppers, and trommels; furthermore, clay balls passing over the riffle tables tend to adhere to and pick up gold particles which are thus lost in tailing. Some of the richer gold-bearing gravel layers are overlain by thick layers of clay and cannot be dredged economically until some means of overcoming this problem can be devised (E. Moseley-Williams, oral commun., 1967). Samples of the clay were subjected to differential thermal analysis at the laboratory of Centrales de Servicios Corona S.A. in Medellín in an attempt to identify mineral components. DTA curves suggest that a kandite clay (metahallàysite ?) predominates, with appreciable limonite contaminant.

Cobbles and boulders of igneous rock resembling the Antioquian batholith are common in the alluvium, although the nearest known outcrops of this rock are 95 km upstream on the Río Nechí and 100 km upstream on the Río Porce. Of possible interest to mineral collectors are abundant petrified wood and fresh andalusite clasts. Heavy minerals and so-called black sands apparently are too sparse to have byproduct potential. Quantitative data on the average heavy mineral tenor of dredged ground are not available, but it may be as much as one percent by weight. Composition of black sand from Zaragoza, Antioquia, is quoted by Overstreet (1967, p. 292) from a 1906 paper by D.T. Day and R.H. Richards as follows:

Mineral	lb/short ton
Ilmenite	1,484
Zircon	302
Quartz	192
Chromite	14
Magnetite	8
Monazite	trace
Total	2,000

The low concentration of magnetite in the above figures is not in accord with observation of black sand concentrates taken on the dredges today, in which magnetite is the dominant heavy mineral. Perhaps the quoted analysis is of a concentrate from which the greater part of the magnetite had already been removed with a magnet, but we cannot verify this.

A semi-quantitative spectrographic analysis of one grab sample of heavy sand concentrate donated by the company was made by the U.S. Geological Survey (F.J. Flanagan, written commun., February 29, 1968). Some of the more interesting elements reported are as follows :

Element	Concentration (ppm)	Element	Concentration (ppm)
Barium	70	Nickel	70
Cerium	3000	Niobium	30
Chromium	1000	Praseodymium	300
Cobalt	20	Samarium	1000
Copper	500	Silver	15
Europium	10	Strontium	7
Gold	100	Tin	150
Iron	"major"	Titanium	"major"
Lanthanum	1000	Vanadium	200
Lead	50	Ytterbium	20
Molybdenum	5	Yttrium	300
Neodymium	1500	Zirconium	70,000

The above figures should be considered as within an order of magnitude, at best. Some inconsistencies in the above spectrographic analysis, probably ascribable to limitations of the method, are noteworthy. Zirconium, presumably in zircon, is reported to constitute 7 percent of the concentrate, yet hafnium was not read in the spectrogram. This may have been an oversight. Deer, Howie, and Zussman (1962, v. 1, p. 61) say, "Zircon always contains a certain amount of hafnium: the HfO_2/ZrO_2 ratio varies but is normally about 0.01." Platinum and its usual companion elements were not detected, but small amounts of chromium, nickel, and cobalt, elements associated with ultramafic intrusive rocks, were detected. Chalcophile elements such as copper and lead are relatively sparse, and zinc was not detected. The number and quantities of rare earth elements reported is surprising. Their source is probably sphene, zircon, and allanite, all common minor accessories in Zone II rocks. The high Ti reported indicates that ordinary magnetite in the sand is accompanied by titaniferous magnetite or ilmenite as well as sphene. The above results suggest that heavy minerals of high commercial value are not present in sufficient concentration to be economically recovered.

Total 1967 production of Pato Consolidated is reported as follows:

Gold	2,762,624 g
Silver	295,094 g

The gold and silver were recovered from 26,606,000 cubic yards (20,342,000 cu m) of alluvium, indicating an average recoverable tenor of 0.1149 g of 903 fine gold per cubic yard (0.1503 g/cu m), which at US $35 per troy ounce for gold and US $2 per troy ounce for silver has a gross value of US $0.1173 per cubic yard (US $0.1534 per cu m). Using current exchange rate of approximately 17.25 Colombian pesos to US $1, the value may be expressed as 2.02 pesos per cubic yard (2.65 pesos per cu m).

Precise data on reserves are not available but doubtless many millions of cubic meters of dredgeable ground of tenor approximately equal to that currently being worked remain to be exploited.

La Viborita mine. The La Viborita mine ranks a very distant second after Pato among placer mines in Zone II. The deposit is 2.5 km north-northwest of the town of Amalfi (Plate II, a-3) at an altitude of about 1,450 m, and 1,000 m above the Río Porce, which flows northeasterly in a steep V-shaped canyon 3 km to the northwest of the deposit. An access road serving nearby dolomite and calcite marble quarries passes within 1,500 m of the mine, but there is no road directly to it. The nearest principal stream is Quebrada La Vibora, which passes to the east of the placer area and joins the Río Porce 6 km north of the mine. The Quebrada La Viborita, which gives the mine its name, flows northward 3 km from the placer area to join the Río Porce 2 km upstream from the mouth of the Quebrada La Vibora.

The deposit was worked by an American-financed company from 1911 until the concession was acquired in 1930 by Viborita Gold Mines Ltd., an English concern (Singewald, 1950, p. 125). During the latter company's tenure a tunnel about 1 km long was driven through a low ridge to drain the placer area into the Quebrada La Viborita, and the operations became established on essentially the same basis that prevails today. In 1947 (?) the property was acquired by Señor Manuel Celedon, who operated on a reduced scale owing to closure of the debris tunnel. Amalfi Development Co. purchased Celedon's right in 1963, cleaned the tunnel, and resumed full-scale operations until June 1966, when ownership was transferred to Inversiones y Mineras Ltda. In April 1968 the latter company contracted to sell the mine under an installment-payment plan to Señor Guillermo Mora, a prominent Medellín businessman and gold mine operator (Warren Ziebell, former superintendent at La Viborita, written commun., 1969).

The deposit is 2,000 m east-west by 800 m north-south and is as much as 50 m thick. It consists of alluvial gravel overlain by lacustrine clay that fills a basin formed possibly by an ancient landslide that dammed an east-flowing stream ancestral to the Quebrada La Vibora. Age of the deposit is not precisely known, but it predates regional uplift and is now perched a thousand meters above the present local base level. A sample of wood from the clay (sample W-2138) was analyzed by the radiocarbon laboratories of the U.S. Geological Survey, Washington, D.C. and yielded a radiocarbon age "older than 42,000 years", beyond the limits of this dating technique, and the writers assign it tentatively to the late Pliocene or Pleistocene.

The highest values are in gravel immediately above bedrock, which is chiefly sericite schist. The gravel is poorly sorted and ranges from fine to very coarse grained; boulders are as much as 80 cm in diameter. The gravel is compact but not cemented, and disaggregates readily under the powerful jets of water from the monitors. Many rock types are represented, but vein-quartz, quartzite, and white quartz pebble conglomerate are especially prominent. Rodlike clasts, 2 to 4 cm long, of sericitized andalusite derived from porphyroblasts in adjacent schist are abundant. The gravel is overlain at most places by layers up to 25 m thick of stiffly plastic clay essentially barren of gold. Much of this is dark bluish gray or dark green, probably due to ferrous iron pigment. Samples of this clay were subjected to differential thermal analysis at the laboratory of Centrales de Servicio Corona S.A. in Medellín. The curves are characteristic of the kandite group and show a weak but distinct endothermic peak at 130°C, suggesting metahalloysite. A subsidiary weak endothermic peak at 310°C is due to an impurity, possibly gibbsite or goethite. The clay has the plasticity of a good ball clay, but contains too much iron to be useful as a high-grade ceramic or refractory raw material.

IMN has only scant firsthand information on the composition of La Viborita black sands, but riffle concentrates examined under low magnification contained magnetite, some of it probably titaniferous, accompanied by ilmenite, zircon, and sparse garnet, pyrite, arsenopyrite, and sphene. Cassiterite was reported as an important component in La Viborita black sands (J.M. Restrepo Domenech, mining engineer, oral commun., 1968); however, our examination does not confirm this; if present, cassiterite is very sparse. Other mineral grains have been reported, including chalcopyrite, columbite-tantalite, beryl, corundum, and wolframite (Walter Ziebell, mining geologist, oral commun., 1967), but we are unable to confirm this.

The hydraulic mining system is employed; several batteries of 2 to 4 monitors or "giants" shoot powerful jets of water against the bank washing the gravel into heavy wooden sluices, each 1.3 m wide and 25 m long, fitted with round block riffles in removable sections. Water is delivered to the monitors via 2 km of 30-in. sheet-steel pipe from a reservoir on Quebrada La Vibora, under a hydraulic head of approximately 100 m. Approximately 90,000 cubic meters of alluvium are monitored during an average month. Normally three shifts per day are worked, employing 55 persons at an average wage of about 20 pesos (US $1.16) per day. Once about every 8 weeks the sluices are cleaned and gold separated from other heavy-mineral components by panning. Gold dust is sent to Medellín for refining and sale to Banco de la República.

Reserve estimates are not available to IMN, but the deposit, judged from visual inspection, contains several tens of millions of cubic meters not yet exploited; much of the richer ground may have been hydraulicked during the past half-century. Tenor recovered during 1967 averaged about 0.13 g of gold per cubic meter (Walter Ziebell, oral commun., 1968). The clay overburden is essentially barren, hence the tenor of the gravel must be on the order of 0.25 or 0.35 g per cubic meter. Recovery is estimated at roughly 70 percent (Warren Ziebell, written commun., 1969).

Production of gold and silver for the municipality of Amalfi during 1967 is given by the Asociación Colombiana de Mineros as follows :

Gold	104,710	g
Silver	15,587	g

By far the greater part of this came from La Viborita. From the above figures, the average fineness is 871 gold, 129 silver.

Other Tertiary (?) alluvial bodies near Amalfi are probably gold-bearing also.

Supía placer district. Once an important gold-producing area in southwestern Zone II, this district today is exploited only sporadically by primitive hand methods. It deserves separate mention because of its history and future potential. The Supía district is 135 km by highway south of Medellín, in northwestern Department of Caldas and the northeastern corner of the Department of Risaralda. Dredging by the Supía Gold Dredging Co. in the Río Supía immediately south of the town of Supía has been described briefly by Singewald (1950, p. 135); most of the following information is extracted from his report. The dredgeable part of the valley is 200 to 300 m wide, about 8 km long, with bedrock depth of 5 to 6 m. Reserve was reported to have been 12 million cubic yards (9.2 million cu m), with values of 40 cents US currency per cubic yard, at the start of operations in 1940. This is equivalent to 0.35 g of gold per cubic yard (0.46 g/cu m), at US $35 per troy ounce. One 8-cubic foot electric-driven bucket-ladder dredge mined about 90,000 cubic yards (69,000 cu m) per month, a low output for a dredge of its size. The alluvium contained numerous large boulders, some up to 3 m in diameter, making hard digging, and causing the dredge to vibrate violently. This is said to have caused a serious loss of gold from the riffle tables. Gold production was reported at about 340,000 g for 1942 and 205,000 g for 1944. Figures for other years are not available. The dredge is said to have been dismantled in 1950 after working for 10 years, presumably because the reserve of dredgeable ground had been exhausted.

Although IMN has not studied potential placer deposits west and south of Supía, almost all of the alluvium in this region is known to be gold-bearing. Some of the more extensive and favorably located gravel banks are potentially exploitable by hydraulicking or by dragline dredging. Some of the principal streams, tributaries of the Río Cauca, that appear to be especially promising are : Río Risaralda, Ríos Sucio and Quinchía, Río del Oro, Río Tareas, and Quebrada La Honda. Terraces bordering the Río Cauca also are auriferous. These sites are pointed out as potential targets for investigation. However, a price for gold substantially above US $35 per ounce troy probably will be needed to stimulate exploration of these alluvial deposits.

Anorí placer district. The difficultly accessible Anorí area is famous for placer gold, although it produces much less today than in former times. The district, which lies outside the area mapped by IMN has the form of a rectangle 40 km north-south by 30 km east-west, with the town of Anorí (Plate II, a-1) at the southwest corner.

Hydraulicking was done by Minera El Hatillo S.A. at Madreseca near the junction of the Quebrada El Hatillo with the Río Anorí, some 20 km north-northeast of Anorí, from 1942 until 1950, when work was suspended because of problems of public order and breaks in the pipeline that carried water to the monitors (P. Marín, IMN geologist, written commun., 1968). Production statistics and data on tenor or reserves are not available.

Mining is done with 3 monitors near the junction of Quebradas La Tinta and San Bartolo 40 km due north of Anorí; production is at a rate of 1,300 g per month and 20 workers are employed (A. Andrade, IMN geologist, written commun., 1968).

Small groups of miners construct log jetties at favorable places along the Río Tenche, 35 to 40 km airline northeast of Anorí, causing sand and gravel to collect behind them. Gold is taken by panning. Although individual operations are very small, aggregate production may be as much as 9,000 g per month of 870 fine gold during the dry season (late December through March). At other times the water is too deep and the current too strong to allow hand mining (P. Marín, written commun., 1968).

Puerto Antioquia placer prospect. An area on the west side of the Río Cauca encompassing about 35 sq km, including and surrounding the triangle formed by the towns of Cáceres, Tarazá, and Puerto Antioquia in northern Antioquia, 215 km by road north of Medellín, is covered by coarse gravelly alluvium deposited by the Río Cauca and two of its tributaries, the Ríos Rayo and Tarazá. E. Moseley-Williams (oral commun., 1967), has said that a large U.S. mining company explored this area by drilling shortly before the Second World War, proving a "large" reserve containing gold values of about 21 cents (U.S. currency) per cubic yard, equivalent to 0.187 g of gold per cubic yard (0.244 g/cu m). He also stated that another large mining company had drilled near Cáceres in 1966-67. IMN has no firsthand information on the above-reported drilling projects. In 1966-67 an attempt was made by Señor Guillermo Mora of Medellín to hydraulic a part of the broad alluvial flat 1 km southeast of Puerto Antioquia. This operation was abandoned as unprofitable in early 1968, and pipes and monitors have been moved 10 km southeast to the east side of the Río Cauca on an alluvial flat formed by the Quebrada Purí about 5 km east of El Doce on the Valdivia-Puerto Antioquia highway (A. Andrade, IMN geologist, oral commun., 1968).

The Cáceres-Taraza—Puerto Antioquia triangle represents a potentially important placer district, possibly exploitable by dredge or by dragline with floating washing plant, that may merit further attention under favorable economic conditions.

Other placer districts. The Porcecito district on the Río Grande above its junction with the Río Porce, 30 km east-southeast of Santa Rosa de Osos, was mined by hydraulicking, and also by a 3-cubic-foot bucket-ladder dredge operated by Minas de Oro de Porcecito, a Colombian-Belgian company, from 1930 to 1946 (Singewald, 1950, p. 129). The monitors and the dredge were dismantled when the reserve had been exhausted, but sporadic hand mining has continued to the present.

Hydraulicking flourished along the Río Nus near Providencia (Plate II, b-7) before and during the Second World War, but closed down soon afterward. One mine called the Gallinazo was worked with a dragline and floating washing plant (Singewald, 1950, p. 128). Data are lacking on production, tenor, and profitability of these operations. The Río Nare and its tributaries also were exploited in former times, but work today is negligible. Certain reaches of the Nare, especially in Plate III, c-9, southwest of Caracolí, are filled with huge boulders from the Antioquian batholith, some as much as 10 m in diameter, and the river disappears beneath them (Singewald, 1950, p. 126). These nests of boulders, called "organales", act as giant riffles trapping coarse particles of gold, and have been mined in former times by men wriggling through passages between the boulders and panning the gravel beneath. These deposits are small but rich, and cannot be mined by any other method. Similar "organales" in the Río Nechí north of Angostura (Plate I, d-7) are described by Botero (1963, p. 34).

Origin of the gold

Placer gold in Zone II has been concentrated by eluvial and alluvial processes following the weathering and erosion of auriferous veins that occur in a wide range of rock types. The origin of the veins is less evident. They are presumed to have been precipitated from hydrothermal solutions residual from the crystallization of magma. The fluids moved upward along faults or fractures in the frozen upper part of the plutonic rock itself, or in adjacent rocks. Precipitation was effected by change of temperature or pH of the fluids resulting from contact with wallrock, or perhaps in some cases by mixing with other fluids migrating along the same channels.

Gold veins in Zone II are invariably composed chiefly of quartz, pyrite, and gold. Helgeson and Garrels (1968) discuss the intimate association of these three minerals from a thermodynamic viewpoint and demonstrate that exploitable veins can be formed by acidic hydrothermal solutions containing only 1 to 50 parts per billion of gold, extremely low concentrations, at temperatures between 175° and 300°C. Plutonic rocks in Zone II, that range from diorite to adamellite in composition and from Paleozoic to Tertiary in age, all are gold-bearing, as demonstrated by gold-quartz veins in fractures or faults in the plutons themselves, or in adjacent older rocks invaded by them. These rocks constitute a metallogenetic province in which gold is the principal economic metal, just as the Witwatersrand in South Africa, the Ontario Canadá, gold camps, the California (U.S.A.) Mother Lode country, and parts of the Colorado Rockies are gold provinces. (This statement is not intended to imply that these localities are necessarily similar in other respects to Zone II, or to each other). The causes of these anomalous concentrations of gold in localized parts of the earth's crust is a basic question of geology with fundamental economic importance.

Some interesting speculations regarding the genesis of the world's tin deposits that have been made by Schuiling (1967) might also be applicable to gold in Antioquia. He postulates that geochemical "culminations" or primordial concentrations of tin were formed in the mantle early in the earth's history. Tin deposits, both exploitable and noncommercial, and of all ages, seem to lie in belts that follow orogenic trends which pass unbroken from one continent to another on a reconstruction of the circum-Atlantic continents before postulated continental drifting took place (Schuiling, 1967, p. 546-547). He further suggests that "events", particularly magmatic intrusions related to orogenies within the belts, are necessary to form exploitable concentrations. The primordial tin concentrations in the mantle are merely noncommercial geochemical anomalies, and economic deposits are made only by mobilization and concentration of tin in magma that rises to intrude accessible parts of the crust. Substituting gold for tin, this is an attractive mechanism to apply to Zone II, and might explain why intrusions of various compositions and ages in the zone are auriferous.

Gold and silver refineries in Medellin

Three gold and silver refineries are located in Medellín. Largest and oldest of these is Fundiciones y Ensayes de J. Gutiérrez Ltda., which has been in business since the late 19th century. The others are Fundición Esteban Alvarez y Cía. and Fundición de Jesús Escobar A. y Cía. All are similar in mode of operation. Gold dust, amalgam, "sponge" gold from retorting of amalgam, and crude bullion delivered from the mines, all containing some silver, are melted in graphite crucibles. Chlorine gas is bubbled through the molten metal and combines with the silver to form silver chloride, which rises as a slag, leaving molten gold beneath. The gold, of 996 to 999 fineness, is poured into ingots weighing about 16 kg each and delivered to the Banco de la República. The chloride residue is immersed in sulfuric acid with iron sheets. The iron replaces silver and forms ferric chloride. The liberated silver sludge is fluxed in a graphite crucible and poured into small bars, 996 to 997 fine Ag, for sale on the open market through the Asociación Colombiana de Mineros. Loss of gold during the refining process is said to be only 0.1 to 0.2 percent, but silver loss is much higher, 5 to 15 percent (S. Gutiérrez, oral commun., 1968).

Gold and silver production in Zone II

Most of the gold and silver produced in Colombia in 1967 came from Zone II, and most of that (about 98 percent) from IIB, as shown in the following table :

Table 2

Gold and silver (in grams) from all sources in Zone II, 1967 1/

Municipality	Gold	Silver
Amalfi	104,710	15,487
Anorí	24,900	3,509
Cáceres	10,492	1,372
Carolina	3,722	849
Marmato 2/	71,312	60,823
Remedios	12,323	7,693
Santa Rosa	8.059	3,652
Segovia	2,493,248	2,485,489
Yarumal	21,596	7,806
Zaragoza	3,112,049	351,995
All others	126,821	105,918
Totals		
Zone II	5,989,232	3,044,593
Colombia	8,011,904	3,423,268

1/ From Asociación Colombiana de Mineros, Apdo. Aéreo 874, Medellín. Figures do not include gold and silver in sulfide concentrates exported for metallurgical treatment.

2/ In Department of Caldas.

The contribution from Zone II was 74.8 percent of all the gold and 88.8 percent of all the silver produced in Colombia in 1967. The statistics do not distinguish between lodes and placers, but we estimate that at least 55 percent of the gold, and roughly 12 percent of the silver came from placers. The very large production from the municipalities of Segovia and Zaragoza is attributable to the high output of Frontino Gold Mines Ltd. and Pato Consolidated Gold Dredging Ltd., respectively.

The future of gold mining in Zone II

The international official price of gold was fixed at US $35 per troy ounce in 1934. In the meantime, prices of almost everything else have risen considerably above 1934 levels, and gold mines everywhere have been caught in a squeeze between the fixed price of their product and the continuously rising costs of labor and materials. Gold production has declined appreciably in Zone II, as it has elsewhere in the world, during the past two decades. Obviously, a substantial increase in the official international price of gold would stimulate exploration and production in all gold mining areas, and could cause an impressive gold mining revival in Zone II. Without a price rise, operators will find it increasingly difficult to maintain even present output.

Iron

Commercially exploitable deposits of iron ore are unknown in Zone II, although previous workers have investigated laterites in IIA as potential iron sources. The laterites on the east side of Medellín have been studied by Cock (1938) and also by Restrepo A. (1959) ; no further work on them was done by IMN. The Morro Pelón laterite 7 km northeast of Campamento, Antioquia, was studied by IMN, but no formal report was prepared. Results are summarized later in this report. Neither occurrence has present economic importance.

Medellín laterite

Ferruginous laterite derived from underlying serpentinite crops out on a west-facing mountainside overlooking the Aburrá Valley northeast of the city of Medellín. Thickness of the richest part of the laterite mantle ranges between 1 and 5 m and averages nearly 3 m over an oval shaped area of approximately 450 hectares (Restrepo A., 1959, p. 20). Reserve according to Restrepo is 12.5 million cubic meters. However, investigations by Empresa Siderúrgica S. A. proved less than 4 million metric tons with an average iron tenor of about 28 percent in a mantle only 1 m thick (J. Vollmost, Empresa Siderúrgica technical director, oral commun., 1969). Typically, the mantle grades upward from decomposed serpentinite into yellow, then reddish-brown, and finally dark red, earthy laterite (locally called "terrosa"), capped by up to half a meter of very dark red to nearly black dense hard laterite ("laterita dura"). The hard cap may contain 50 percent or more of iron but is too thin and localized to constitute a workable deposit by itself. The underlying earthy laterite commonly has an oolitic texture and contains 15 percent or more of moisture; the iron tenor ranges between 13 and 38 percent, averaging roughly 25 percent. Calculated on a dry basis, the average iron tenor is about 30 percent according to Restrepo A. (1959). Silica and alumina average more than 20 percent each in Restrepo's samples, very high for iron ore, and would make metallurgical treatment difficult and costly. Restrepo (1959) reports several analyses for other elements in the laterite as follows :

Substance	Range (percent)
TiO_2	0.07 - 0.48
Mn	.49 - 1.14
Cr	.07 - 1.62
Ni	.20 - .83
P	.006 - .34
S	.001 - .09

It is of interest to note that the Empresa Siderúrgica S.A. iron and steel plant was founded in Medellín with the intention of using the local laterite as its main raw material, and a mining concession for this purpose was taken 1 km southeast of the suburb of Bello. However, only token amounts of iron were produced from laterite, and the plant since its beginning in 1938 has had to use scrap iron as its main raw material.

New techniques for reducing iron directly from laterite ores have been developed since 1938 when Dr. Julian Cock A. first proposed to use Medellín laterite. Although these new processes might make Cock's plan a little more feasible than it proved to be in his day, the possibility of using Medellín laterite as iron ore continues to be remote, not only for technical reasons, but because much of the laterite area has been covered with houses during the vigorous urban growth of the past 30 years, a formidable obstacle to mining now, even if the ore were high-grade and proved reserves much greater.

Morro Pelón

The Morro Pelón laterite body has been known since 1939 (Alvarado, and others, 1939) and is 7 km by trail northeast of Campamento, a town 145 km by road north of Medellín. It has the form of an elongated oval 2.7 km north-south by 1 km east-west overlapping the boundary between planchas e-5 and e-6, Plate I, the greater part lying in e-6. The deposit occupies the crest of a broad north-striking ridge with its summit at an altitude of about 1,440 m, sloping gently northward 3 km to the Río Nechí at an altitude of 700 m.

Eleven test pits made by IMN in late 1964 and early 1965 indicate a reserve of nearly 4 million metric tons in a mantle covering an area of 60 hectares to an average depth of about 3 m. The vertical profile is similar to that of the Medellín laterite with a hard cap of iron oxides 10 to 40 cm thick, overlying brown earthy laterite 1 to 5 m thick, grading downward into dark green or black decomposed serpentinite.

Based on 74 analyses, iron tenor ranges between 23 and 56 percent, nickel tenor between 0.23 and 1.21 percent, with an average of 27.6 Fe and 0.69 Ni, respectively. Although Morro Pelón was considered to be an iron prospect before the IMN study, it might now be better classified as a nickel prospect; however, the possibility of economic exploitation for either metal, or for both together, seems very remote because of the small reserves and low tenor.

Age of the laterites

Both Medellín and Morro Pelón laterites are remnants of formerly more extensive mantles. Formation of iron-rich laterite is favored by the slow secular weathering and decomposition of mafic and ultramafic rocks in relatively flat low-lying terrane in a humid tropical climate with alternating wet and dry seasons (Harder, 1952; Sherman, 1952; Parks and MacDiarmid, 1964, p. 414-415). The present climate may not be greatly different than it was prior to the latest regional uplift, but the topography certainly is different. The Morro Pelón laterite lying on a north-striking ridge, with its highest part 1,440 m above sea level and its lower end at an altitude of 700 m, with erosion actively reducing the size of the deposit, is clear evidence that lateritization preceeded the latest regional uplift, which was gradual over hundreds of thousands of years, and may still be taking place. It must have begun in late Pliocene or early Quaternary; the Morro Pelón laterite is tentatively assigned a Late Tertiary age on the geologic map (Plate I). The pre-uplift genesis of the laterite at Medellín is less evident than at Morro Pelón, but it seems reasonable to suppose that lateritization was active under similar conditions at the same time over a large region, and that the several laterite bodies in IIA are more or less contemporaneous.

Medellín's iron and steel industry

Exploitable deposits of iron ore are lacking in the zone but there is, nevertheless, a flourishing iron and steel industry in Medellín, which makes an important contribution to the Colombian economy. Therefore, it is appropriate that this industry be mentioned briefly in the section on economic geology, although geology, as such, does not enter into the discussion. There are a dozen or so iron and steel foundries in Medellín, ranging in size from Empresa Siderúrgica S.A., one of the major industrial plants in Colombia, to small shops making a few hundred tons per year of castings and miscellaneous foundry products.

Empresa Siderúrgica S.A. produces 24,000 metric tons per year mostly of finished steel products, with a small amount of gray iron castings. The company operates 6 electric furnaces ranging in capacity from one-half ton to 8 metric tons, and a single cupola furnace taking a charge of 30 tons. Reinforcing bars are the main product, but a variety of other goods are made including galvanized pipe and fittings, angle-iron, gear assemblies, wheels for railroad cars, ball-mill and crusher spare parts, grinding balls, sugar-processing machinery, and automotive and machine spare parts. The company plans to expand production to 60,000 tons per year by 1970, mainly of reinforcing bars. During 1968 an electrolytic tin-plate plant was inaugurated with capacity to produce 50,000 metric tons per year of finished container tin-plate from rolled stock imported from Japan. The company is capable of producing a variety of chrome, nickel, and molybdenum steel alloys and austenitic manganese steel, and has a quality-control laboratory with the most modern metallurgical analytical and testing apparatus. A serious limitation of the operation is its total dependence on scrap iron and steel although the company was founded with the intention of using Medellín laterite as the principal raw material. About 18,000 tons of scrap were imported in 1968, mostly from the United States, supplemented by 8,000 tons of domestic scrap (J. Vollmost, technical director, oral commun., 1969).

Smaller foundries in Medellín also depend upon scrap. Three of Medellín's foundries are subsidiaries of large textile companies and two are concerned mainly with the manufacture of textile machinery and spare parts.

Nickel

Nickeliferous laterites have been recognized in the Department of Cordoba for at least a decade. The most important known occurrence is at Cerro Matoso, 30 km southwest of Montelibano, just north of Zone II. A concession to exploit the relatively rich and extensive deposits at Cerro Matoso has been applied for by Hanna-Chevron Co., a joint venture of Hanna Mining Co. and Chevron Petroleum Corp., but the project has been long delayed by legal complications and protracted negotiations between the company and the Government of Colombia.

Cerro Matoso lies north of the Zone II boundary, but lesser laterite deposits south of Cerro Matoso near the town of Uré, Department of Córdoba, at the extreme northwest corner of the zone, were considered deserving of special IMN study. Accordingly, a team of two geologists and a topographer were assigned late in 1966 to make topographic and geologic maps and test pits, and to take samples to delimit the laterite bodies and estimate reserves. During the investigation a total of 36 test pits was excavated ranging in depth between 3 and 13 m and having an aggregate depth of 230 m. Field work was carried out between October 1966 and December 1967; analytical work and preparation of the final report continued through 1968. Personnel deserving of special mention in connection with the Uré project include IMN geologists Hernán Vásquez, Hernán Restrepo A., Eduardo Alvarez, and Darío Velásquez H., topographer Luis G. Castañeda, assistant Valeriano Builes, and Ecuadorian trainee-geologist Jorge Checa. Analyses were made by IMN chemist Jorge Vásquez, aided by personnel and facilities of the Servicio Minero laboratory in Medellín.

A total of 578 samples were analyzed for Ni and Fe, and a lesser number of determinations were made of SiO_2, Al_2O_3, MgO, Mn, P, S, Cr, and Co.

Most of the following information was supplied by Darío Velásquez H.

Uré laterite bodies

Four distinct bodies have been delimited in a north-striking belt 1.5 km west of the town of Uré (fig. 3), designated from north to south as La Viera, Las Acacias, Alto del Oso, and San Juan respectively.

The reserve estimate table accompanying the map on fig. 3 clearly shows that La Viera is by far the most important of the four. Las Acacias is a part of the La Viera body, separated from the latter by a narrow band of serpentinite from which the laterite mantle has been removed by erosion. The Alto del Oso body is a poor second to La Viera, and San Juan is of little significance.

Geologic setting

The nickeliferous laterite is the product of weathering of serpentinized ultramafic rock which at Uré is associated with metabasalt and metagabbro (fig. 3). This assemblage of rocks is considered to be characteristic of the so-called alpine ophiolite suite (Thayer, 1967, p. 222). Relative age of the rocks at Uré are not clear but they may be penecontemporaneous, a characteristic of alpine ophiolitic rocks, especially gabbro-serpentinite assemblages (Thayer, 1967, p. 223). Relations at Uré are obscured by the deep cover of soil, saprolite, and laterite.

Serpentinized peridotite, the mother rock of the nickeliferous laterite as shown on figs. 3 and 4, is dark grayish green, composed of antigorite and lizardite with remnants of olivine and augite (diallage). Enstatite was tentatively identified in some specimens according to Velásquez (oral commun., 1969). Rock composed of olivine, diallage, and orthopyroxene is called lherzolite (Wyllie, 1967, p. 2); however, the existence of orthopyroxene is not proven, and the broader name peridotite is preferred for the original ultramafic prior to serpentinization. About 0.2 percent of Ni is present, presumably in substitution for Mg in the crystal lattice of the component minerals, especially olivine. Mason (1952, p. 116) says : "The nickel ion has the same radius (0.78 Å) and the same charge as magnesium, and therefore should be camouflaged in magnesium minerals. However, the ratio Ni:Mg is highest in early-formed crystals (especially olivine) and shows a steady decline in the later-formed rocks and minerals." Ultramafic rocks usually contain 0.15 percent or more of nickel (Goles, 1967, p. 358), contrasted with 0.01 percent in "average" igneous rocks (Hawkes and Webb, 1962, p. 370).

The serpentinite is highly fractured, and slickensided surfaces are abundant.

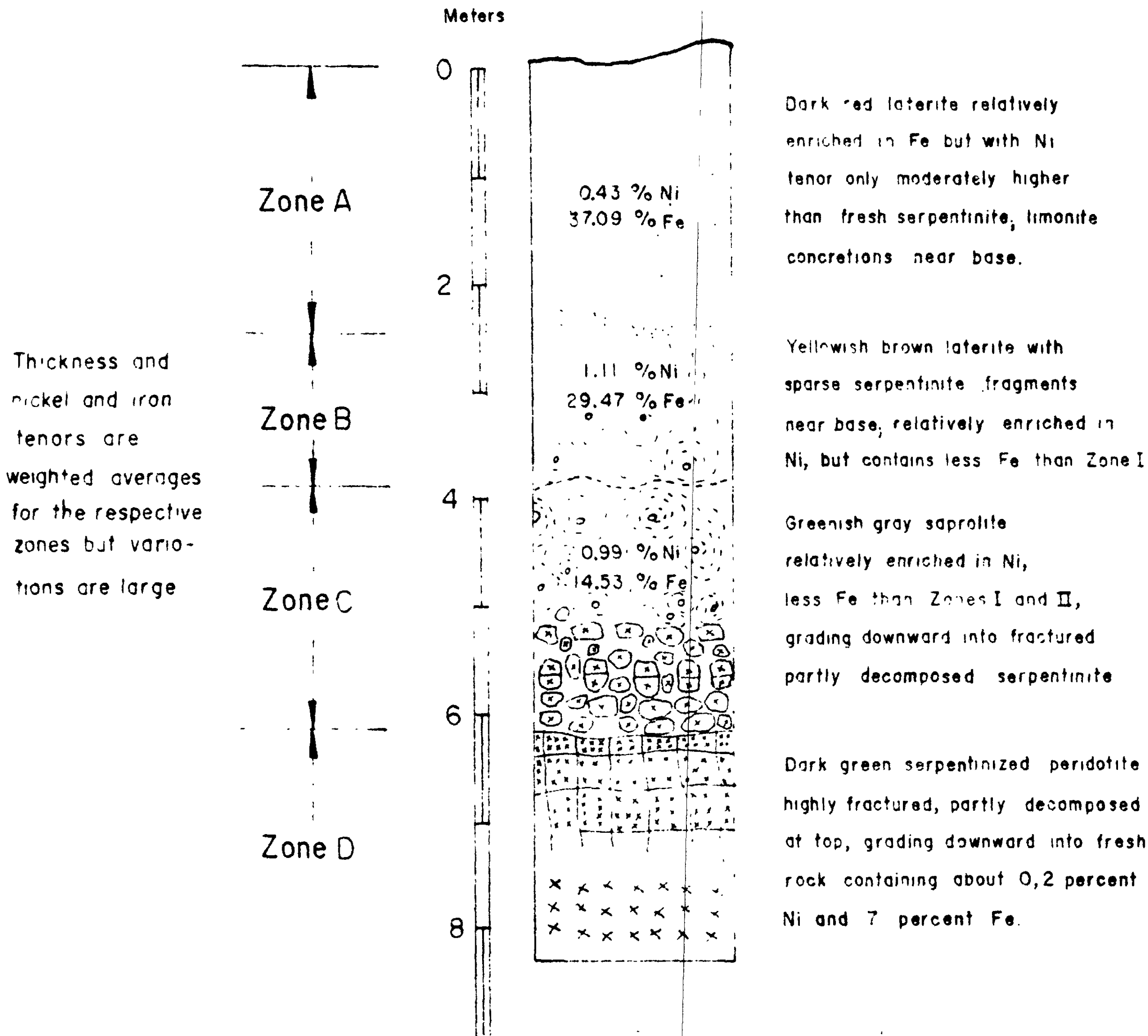

FIGURE 4. Characteristic profile of nickeliferous laterite at Uré

(after Velásquez, 1969, unpub. data.)

Laterite profile

Lateritization of the serpentinite developed a characteristic profile from the surface down to fresh rock. Three layers or zones designated A, B, and C respectively, are easily recognized in the laterite; serpentinite bedrock is arbitrarily designated as zone D (fig. 4). Distinction of these zones is important, both to an understanding of the lateritization process, and also to planning an efficient method of exploitation, because each zone has a different nickel and iron tenor.

Zone A, the uppermost, is typically dark red, reddish brown to brown earthy laterite becoming lighter colored toward the base. It ranges in thickness from 1 to 5 m, averages 2.5 m, and is more dense and compact than subjacent Zone B. Limonite concretions a few centimeters in diameter are common, especially near the base. Judged by color, hematite probably is the dominant iron oxide near the top, and hydrated iron oxide is more prominent near the bottom of the zone. Nickel tenor (average 0.43 percent), is higher than in fresh serpentinite, but lower than in zones B and C below.

Zone A grades abruptly downward into zone B, which is orange or yellowish brown and more porous than zone A. Zone B is the thinnest of the zones, ranging from one-half to 3.8 m, and averaging about 1.4 m. Average iron tenor is distinctly lower than Zone A, but nickel tenor is the highest of the three zones, ranging between 0.5 and 1.4 percent with an average of 1.11 percent Ni (dry basis).

Zone C is the least homogeneous of the three laterite zones. Color is variegated grayish green, olive, or yellowish brown and thickness ranges from one-half to 7 m, and averages 2.3 m. It consists mostly of highly decomposed greenish-gray serpentinite fragments dispersed in a variegated clayey saprolite matrix. The proportion of rock fragments increases downward, and the lower boundary with relatively fresh serpentinite is fairly sharp. Iron tenor is much lower than in the two zones above; however, the average nickel tenor is 0.99 percent, only slightly lower than in zone B.

Should the Uré deposits be exploited sometime in the future, the differing tenors of nickel and iron in the three zones would have to be considered by the engineer obliged to provide a uniform feed to the metallurgical processing plant. Reserves are shown on fig. 3, according to zone. In view of the relatively low average nickel tenor of zone A, it might be more economical to strip it as waste, although this would sharply reduce available reserves.

Origin

The Uré laterite mantle was formed by deep secular weathering of serpentinite in a humid tropical climate with alternating wet and dry seasons. However, the precise nature of the chemical reactions and resultant products is uncertain. Velásquez, (unpub. data, 1969), gives a brief review of two alternate hypotheses that purport to explain in general terms the nickel-enriching mechanism.

According to one theory, the enrichment of nickel is attributed to downward percolating meteoric water that becomes slightly alkaline through dissolution of magnesia in serpentinite; the alkaline state, according to laboratory experiments, favors the exchange of Ni ++ for Mg ++ in the lower parts of the laterite mantle.

A second theory suggests that originally neutral rainwater becomes acidic as it dissolves atmospheric carbon dioxide and humid acids in the soil. The acidic phreatic water leaches magnesia, silica, and some nickel from the upper zone leaving an earthy residuum enriched in iron and aluminum oxides. Although some residual nickel enrichment occurs here, a large part of the nickel is carried downward in the acidic solution and precipitated, possibly in colloidal form, where the acidity of the solution is partly neutralized in the magnesian-rich lower part of the laterite mantle. The nickel enrichment process therefore is not solely residual, but partly supergene as well.

The acidic solution theory seems to account better for the higher concentration of iron in zone A, and of nickel in zones B and C of the Uré laterite.

The nickel-bearing minerals or substances in the laterite are not known. Garnierite, or clay minerals such as nepouite or nickeliferous sepiolite (Caillére and Hénin, 1957, p. 221; 236) may be present, but these are best identified by X-ray and differential thermal analysis, studies not undertaken by IMN. Amorphous or colloidal material sequestering nickel atoms also may be present. Further research is needed. Identification of the nickel host-minerals might well be critical to the metallurgist seeking the most efficient means of nickel extraction.

Age of lateritization

The period of lateritization is not known precisely. Probably it predates the latest epeirogenic uplift of the Central Cordillera and is more or less contemporaneous with the lateritization of serpentinite at Morro Pelón discussed previously under the heading "Iron."

Other elements

Determinations for substances other than Ni and Fe are summarized below :

Substance	No. of analyses	Range(percent)	Arithmetic average (percent)
Alumina Al_2O_3	94	2,12 - 38.00	16.65
Chromium Cr	105	.03 - 2.10	.46
Cobalt Co	6	.010 - .016	.0126
Manganese Mn	131	.05 - 1.40	.34
Phosphorous P	101	.004 - .100	.041
Sulfur S	74	.020 - .390	.122

Alumina is coextensive with iron oxide in the laterite, 25 percent Al_2O_3 in zone A decreasing to 14 percent in zone C.

Chromium, presumably in chrome spinel (picotite) or chromite in the parent ultramafic rock, does not show a marked tendency to become concentrated at any particular zone, although data from test pit No. 1 indicate a slightly higher concentration, possibly mechanical rather than chemical, in the upper part of zone B (Velásquez, unpub. data, 1969).

Cobalt seems to have been neither enriched nor impoverished in the laterite. The average cobalt tenor in 6 samples is 0.0126 percent or 126 ppm, close to the 110 ppm of Co reported as typical in ultramafic rocks (Goles, 1967, p. 358). Given an average nickel tenor of 0.77 percent (fig.3), the Ni:Co ratio in the Uré laterite is about 61:1.

Manganese may have been slightly enriched in the Uré laterite because the average of 3,400 ppm of Mn is higher than the normal abundance of 1,040 ppm of Mn in ultramafic rocks reported by Goles (1967, p. 357); however, quantitative analyses of Mn in fresh serpentinite at Uré are lacking.

Phosphorous and sulfur also may have become slightly enriched in the laterite but IMN data are inconclusive.

Exploitability of the Uré laterite

The Cerro Matoso laterite is said to be appreciably richer (average 2 percent Ni) and more extensive (60 million tons) than the laterite at Uré (Velásquez, unpub. data, 1969). Logically, the exploitation of nickeliferous laterite in Colombia should begin at Cerro Matoso. Velásquez points out that after Cerro Matoso reserves were exhausted and the costs of the metallurgical plant were amortized, the laterite at Uré might then be exploited economically. Therefore it is a potential resource rather than one for immediate exploitation.

Mercury

Nueva Esperanza mine at Aranzazu

The Cía. Minera Nueva Esperanza S.A., an associate of Southern Union Production Co. of Dallas, Texas, operates the Nueva Esperanza mercury mine north of Aranzazu in the Department of Caldas. The mine is at the extreme south edge of quadrangle J-8. This is the only mercury mine active in Colombia since the closing of the Quindío mine in Tolima in 1940, and it has been exploited sporadically since its discovery by Roberto Botero, a local farmer, in 1948 (R. Wokittel, 1958). The following description is based on information gathered during a visit to the mine in August 1967, supplemented by data supplied by the company.

The workings and mill are near the bottom of a very steep west-facing slope, 200 m below the crest of Cuchilla de Manzanillo, a narrow north-trending ridge with summit elevation of about 2,200 m. The ridge is accessible by 7 km of dirt road north from Aranzazu, but the mine can be reached only by half a kilometer of trail descending into the steep valley of Quebrada Manzanilla.

After an initial period of desultory exploitation by the discoverer and his partner, the mine was acquired by Consorcio Minero Colombiano Ltda., a Bogotá syndicate, and operations were expanded. During the latter part of 1958, Consorcio leased the concession to Cía. Minera Chocó Pacífico S.A., who worked the mine as a source of mercury for amalgamation-recovery of gold and platinum mined by dredges in the Department of the Chocó. The dredging company gave up its lease in 1960, presumably because their venture had not been profitable. Consorcio then leased the mine to private individuals who worked on a reduced scale with indifferent success. Finally, in 1965, the Southern Union Gas Co., formed the Cía. Minera Nueva Esperanza S.A., with Consorcio Minero Colombiano Ltda. as a minority shareholder (A. Rivera, oral commun., 1967).

Native mercury occurs as tiny droplets disseminated along a shear zone striking roughly N.20°E., with steep east dip, concordant with the foliation of graphitic quartz-sericite schist correlative with the Valdivia Group. The mineralized zone is said to have an average width of 1.5 m (A. Rivera, oral commun., 1967), but is variable and vaguely defined. The mercury occurs in globules, mostly less than 1 mm in diameter, dispersed along foliation planes and fractures. Sparse flecks of cinnabar, local finely disseminated pyrite, and irregular veinlets or stockworks of milky quartz and calcite accompany native mercury in the mineralized zone. These minerals are believed to have been deposited by hypogene low-temperature fluids proceeding from Tertiary andesite intrusives in the district (Wokittel, 1958).

Six adits have been driven into the hillside at vertical intervals of roughly 20 m; virtually all of the current production is coming from the three lower levels designated Nos. 4, 5, and 6. More than a kilometer of underground galleries have been driven since the mine was begun, but many old galleries are now inaccessible.

A compressor with a capacity of 125 cubic feet per minute at 90 lbs. per square inch supplies air to rockdrills underground. Ore is broken with dynamite and trammed by hand in one-ton end-dump cars. About 60 tons per day are extracted, of which roughly half is waste. Underground operations have been hampered by the contamination of mine air with mercury vapor, a serious health hazard. Good ventilation is essential to success of the mine, and natural ventilation must be supplemented with electrically driven fans delivering air to the interior through 40 cm diameter plastic tubing. Workers underground are rotated to surface jobs at frequent intervals to avoid overly long exposure to the mercury vapor.

Ground support also has been a major operational problem and cost item. The host graphitic quartz-mica schist is structurally incompetent, and shearing coextensive with the mineralized zone has aggravated its natural weakness. The sheared schist yields plastically so that the walls and roof of galleries move inward, and supporting timbers must be replaced frequently, sometimes within intervals of a few days. Rails are twisted and displaced, disrupting ore-haulage. Reinforced concrete linings or closely spaced steel arches might solve the ground control problem, but at a very high cost.

The present mill was constructed in 1967 in an effort to improve upon the previous mill in which native mercury was recovered by hand-operated apparatus. The new plant comprises ore-bin, jaw-crusher, roller mills, jigs, mercury traps and various auxiliary equipment. Retorting or roasting, standard at other mercury mines around the world, is not practiced at Nueva Esperanza. Only native quicksilver is recovered, and associated cinnabar is discarded in tailing. The mill is alleged to have a capacity of 100 tons per day but was treating only 30 tons per day in August 1967. The low output may be attributable to operating adjustments during the initial shakedown period.

A total of 4,600 metric tons milled during 260 operating days in 1967 yielded 192.2 flasks (6,631 kg), equivalent to a recovered tenor of 0.144 kg of mercury recovered per metric ton of ore treated. True Hg tenor is appreciably higher than this because not all of the native quicksilver is recovered and the cinnabar is wasted. Assay control of mill heads and tailing is lacking, so a precise tenor and recovery factor cannot be given.

IMN has no data on reserves. The mineralized zone is said to have a strike length of 85 m (Wokittel, 1958) and has been developed for about 100 m down the dip. Late in 1968 an inclined winze was being sunk to a planned depth of 30 m to develop new ore below the No. 6 level. Results are not available. It is possible that the ratio of cinnabar to native mercury may increase with depth to where the loss of mercury as sulfide would become economically unacceptable. In this eventuality the present gravity system, which does not recover cinnabar, would have to be replaced by conventional roasting and distillation.

The recovered native mercury, said to be 99.97 percent pure, is poured into standard iron flasks of 76 lb (34.5 kg) net for delivery to market. Principal buyers include Planta Colombiana de Soda (soda ash-chlorine plant) at Zipaquirá, Pato Consolidated Gold Dredges Ltd., Cía. Minera de Nariño, and various paint, chemical, and pharmaceutical manufacturers. Virtually the entire output is consumed in Colombia, but a small proportion of the 1967 production was to be sold in the Latin American Common Market (A. Rivera, written commun., 1968).

Aguadas prospect

Very sparsely disseminated cinnabar and tiny droplets of native mercury occur in sheared graphitic quartz-mica schist and chloritic greenschist correlative with the Valdivia Group near the bottom of the steep-sided valley of Quebrada El Mico, at an altitude of 1,520 m, 2.5 km southwest of Aguadas, Department of Caldas. The area is in Quadrangle J-8, mapped by Facultad Nacional de Minas, and was not studied in detail by IMN. The first published reference to mercury in this locality was by Morer and Nicholls (1962) who describe it as the "El Socorro mine." A concession to explore for and mine mercury is said to be held by a syndicate of Caldas businessmen (A. Sánchez, oral commun., 1967). In 1966 three short exploratory adits were driven into the hillside to cross-cut north-striking vertical to steeply eastward dipping foliation of the schist. One adit is 30 m long on a bearing N.30°E., the second 18 m long on a bearing N.40°E., and the third was caved in and inaccessible in August 1967. All are at nearly the same elevation, a few meters above creek level. Half way in the 30-m adit, a single veinlet of milky quartz and calcite, 5 cm wide, concordant with the schist, contains sparsely disseminated flecks of cinnabar and a few very tiny globules of native mercury in cracks and in foliation in the adjacent schist. No mercury mineral was seen in the 18 m adit, located 40 m south of the 30 m adit, but a few specimens of vein-matter and graphitic quartz-mica schist containing sparse spots of cinnabar and tiny globules of native mercury were found on the dump. The third adit, on the opposite side of the creek and 250 m downstream southeast from the 18 m adit was inaccessible but said to contain sparse cinnabar and native mercury (M. Barsona, oral commun., 1967). Work was abandoned in 1966 with no mercury ever having been produced here. Morer and Nicholls (1962) considered the El Mico mercury prospect to have little if any economic value, and the present authors agree. However, the presence of mercury in each of three short adits separated by a horizontal distance of some 250 m, clearly suggests a geological environment favorable for mercury, even though mineralization was too weak to form exploitable deposits at this particular location.

Outlook for future prospecting

Several concessions to explore for and mine mercury within a belt 8 km wide and 35 km long between Nueva Esperanza mine and the Aguadas prospect have been granted in the past to various individuals or organizations by the Ministry of Mines and Petroleum. Personnel of IMN lack information on the ownership and current validity of these concessions, and have no knowledge of any mining works other than at the two above-described localities. However, this belt appears to be favorable ground in which to prospect for mercury. The terrane is very rugged with local relief of 500 m or more, but the region is fairly well populated and traversed by an all-weather trunk road. Accessibility therefore is not so formidable an obstacle here as in many other parts of the zone. The geologic mapping in quadrangle J-8 by Facultad Nacional de Minas, and that in the northern part of quadrangle K-8 by IMN will be useful as a general prospecting guide, but not sufficiently detailed by itself to permit selection of specific exploration targets. Exploration for mercury in the Aguadas-Aranzazu belt could best be accomplished in stages as follows :

1) Detailed reconnaissance; questioning of local residents; examination and appraisal of reported mercury occurrences; establishment of priorities giving emphasis to localities that show mineralization and a favorable geological environment, especially faults and shear zones in graphitic schists within a few kilometers of Tertiary andesite intrusives.

2) Geochemical analysis of soil and stream sediment samples to locate anomalous concentrations of mercury. The usefulness of small portable mercury vapor detectors in this work has been shown elsewhere (Hall, 1965), and has been demonstrated by preliminary tests made in the Aguadas-Aranzazu belt by IMN geologist Alfredo Andrade (written and oral communs., 1967). The use of this kind of apparatus also has been suggested by U.S.G.S. geophysicist W. J. Dempsey (written commun., 1968). A serious but not insurmountable handicap to this or any other geochemical technique is the strong downward creep and sliding of colluvium and eluvium in the exceedingly steep mountainous terrane; it may cover mineralized ground, and possibly displace anomalies hundreds of meters from their original sources. Great care would be needed in the interpretation of any anomalies discovered.

3) Direct methods, such as test pitting, driving underground galleries, or diamond drilling should be employed as soon as targets have been indicated by steps 1 and 2. Geologic mapping on a scale of 1:10,000 or larger should immediately precede or be carried out concomitant with these works.

Reconnaissance would require an estimated 6 to 12 man-months, followed by 16 to 50 man-months of more detailed work on specific targets. A first-phase exploration program leading to the discovery of a potentially exploitable mercury deposit probably would cost at least 1 million pesos (US $ 58,000 at exchange rate of 17.25 pesos to US $1), and might very well cost several times that amount. Moreover, a discovery cannot be guaranteed, and if made, would demand further capital investment of millions of pesos for mine development and construction of a recovery plant. Clearly, this kind of venture is best undertaken by a financially strong company with a competent technical staff, and preferably a record of past success in mercury mining.

Chromite

Las Palmas-Santa Elena

Chromite occurs very locally in a 4-km wide north-striking belt of serpentinite in schist and amphibolite correlative with the Valdivia Group, at Las Palmas and Santa Elena, 10 km by road southeast of Medellín. These small deposits have been known for some years (Singewald, 1949, p. 92-93; Wokittel, 1960, p. 151), but exploitation thus far has been sporadic and on a very small scale. The chromite occurs as seams and lenticles in serpentinite or dunite host, and in scattered float. The sparse surface exposures indicate reserves of only a few thousand tons of chromite of variable tenor. Small tonnages of material containing 30 percent Cr can be obtained by selective mining and careful hand picking. Present exploitation is spasmodic and primitive in crude surface pits. The past production of crude chromite has not exceeded 200 tons per year, used mainly for coloring beer bottles and for making chemicals and pigments. Recently a foundry in Medellín began adding crude chromite from Las Palmas to batches of steel in its electric furnaces to produce an alloy containing 1.5 percent Cr used to make grinding balls. Present consumption is said to be from 5 to 10 tons per week of crude chromite containing 25 to 30 percent chromium. Small lots of crude chromite ore have been beneficiated by Wilfley tables at the Servicio Minero pilot plant in Medellín to produce a 35 to 42 percent Cr concentrate used by the foundry to supplement the lump chromite. The results are said to be satisfactory to the company, but this mode of exploitation would not be considered economic in most industrialized nations. The known deposits cannot support a large-scale mining operation.

Prospecting for large orebodies

Several industrial firms in Medellín have expressed interest in further developing Las Palmas chromite deposits, but thus far have shown little inclination to accept the risks of investment in an exploration program having no guarantee of success. Exploration is further complicated by the problem of land ownership. The present surface-rights owners control the primitive small-scale mining on their land, and the IMN staff has no knowledge of any valid mining concession for chromite in this area.

The possibility is small of discovering large-tonnage hidden orebodies beneath the surface, but cannot be dismissed summarily. Probably direct exploration methods such as trenching, test-pitting, underground adits, and diamond core-drilling are preferable to indirect geophysical methods. Magnetometer surveys probably would be of little use because of negligible and non-predictable contrast of magnetic susceptibility between chromite and enclosing ultramafic rocks. Gravimetric surveys might be helpful (W.J. Dempsey, U.S.G.S., oral commun., 1968), but great care would be needed in making topographic and altitude corrections in the broken terrane. The density contrast between chromite (4.3 - 4.6) and serpentinite (2.5 - 2.6) is large, although associated unserpentinized ultramafic or mafic rocks with intermediate densities (3.0 - 3.2) could complicate interpretation of anomalies.

Manganese

The only significant deposits of manganese known in the zone are located in IIA, 4 km northwest of Santa Bárbara in quadrangle J-8, 50 km by highway south of Medellín. These have been described by Botero R. (1945) and also were studied by R. Wokittel (1955) and by IMN geologist Darío Velásquez H. (unpub. data, 1967).

Thin-bedded cherts intercalated with porphyritic tuff, greenstone, phyllite, quartzite, and marl crop out on the east side of the Quebrada La Loma at an altitude slightly above 1,300 m. The age of these stratified rocks is not known precisely; they are tentiatively correlated with the Cretaceous Quebradagrande Formation (Botero A., 1963, p. 44-54). The beds strike predominantly north and dip steeply east. Manganiferous lenses concordant with dark green, red, and black chert lenses have a stratigraphic thickness of 3 to 8 m and an undetermined but evidently not great extension along strike (Velásquez, unpub. data, 1967). Botero R. (1945, p. 314-316) identified the manganiferous material as mainly tephroite and braunite, with superficial coatings of pyrolusite or wad. Two samples were studied by X-ray diffraction at the Facultad Nacional de Minas by Feininger in June 1969. One sample of massive black manganiferous material proved to be wholly braunite. The other sample was of red chert coated with black botryoidal films tentatively identified as vernadite.

Hand-picked specimens may contain 50 percent or more of manganese, but bodies of minable size are highly siliceous with an average tenor of less than 30 percent Mn. Ten samples taken by Wokittel (1955) were analyzed as follows :

Composition of 10 samples (percent)

	Range	Average
SiO_2	44.6 - 85.6	70.4
Fe_2O_3	1.1 - 10.8	5.8
Al_2O_3	1.0 - 15.2	5.7
Mn	.4 - 29.1	9.4

Two samples especially selected by Botero R. (1945, p. 318) yielded 24 and 38 percent Mn, with 55 and 37 percent SiO_2 respectively. Wokittel, Botero R., and Velásquez agreed that the Santa Bárbara occurrences are not economically exploitable, and material of the above composition would not be classed as ore in other countries. However, a foundry in Medellín recently began to add crude Santa Bárbara "ore" to batches of steel in its electric furnaces to make manganese alloy used in ball mill linings and jaw crushers. Present consumption is said to be from 5 to 10 tons per week. This is the first reported commercial exploitation of the Santa Bárbara deposits.

The possible origin of these manganiferous lenses is briefly touched upon. Botero R. (1945, p. 316-317) assumed the precipitation of manganese carbonate from meteoric solutions rich in manganese bicarbonate, presumably derived from the leaching of nearby igneous rocks. He suggested that tephroite and braunite were formed after the original carbonate was oxidized, then attacked by silica-rich solutions. Wokittel (1955) proposed a hypogene origin with manganese oxides deposited in interstices of "quartzite" by solutions from an unknown source. He suggested that localized richer pockets may in part be a product of supergene enrichment.

Manganese deposits associated with marine sedimentary and volcanic rocks in other parts of the world are thought by some investigators to be syngenetic, related to submarine volcanism (Park and MacDiarmid, 1964, p. 379-381; Hewett, 1966; Sorem and Gunn, 1967). This concept may be applicable to the Santa Bárbara deposits. The manganiferous material and the chert, especially the dark red chert, occur together in a way that strongly suggests contemporaneous deposition, possibly around submarine springs related to volcanism on the ocean floor.

Copper

Sparse, small, and localized manifestations of copper minerals have been observed by IMN geologists during the course of the regional mapping, but no promising copper prospect was found in Zone II. Individual prospects are discussed briefly below. Sparse amounts of chalcopyrite are disseminated with pyrite and other sulfides in many gold-quartz veins. For example, ores at the La Bramadora and Marmato gold mines contain 0.1 percent or less of copper, mainly as finely disseminated chalcopyrite. It is probable that ores at most of the small lode gold mines in the zone have a similar tenor of copper, although specific data are lacking. At the present scale and method of operations it is wholly impractical to consider recovery of copper. Frontino Gold Mines Ltd. mills 550 tons per day of gold ore and recovers the small quantities of contained lead and zinc by flotation, but no copper.

Buriticá prospect

A detailed investigation was carried out by IMN intermittently between July 1964 and October 1966, of a prospect west of the Río Cauca near Buriticá, 140 km by road northwest of Medellín. Disseminated pyrite, and sparse malachite films on fractures in hydrothermally altered rocks suggest an environment at Buriticá favorable for concentrations of copper, and possibly other base-metals, gold and silver. The investigation included large-scale geologic mapping, diamond drilling, and analyses of channel samples and drill cores. Results were disappointing and only a brief summary of the geology and an appraisal of economic possibilities is given here.

Fine-grained pyrite is irregularly disseminated in the altered west-central part of a rudely circular Tertiary andesite stock, 2 km in diameter, intruded into Lower Cretaceous sedimentary and volcanic rocks and Upper Cretaceous (?) quartz diorite. The alteration products are mainly kaolin and propylite, and in places the rock has characteristics suggestive of an explosion breccia. Disseminated pyrite locally constitutes as much as 4 percent of the altered andesite host, but average tenor of pyrite is no more than 2 percent.

Thirty-four channel samples were cut in andesite at exposures that showed sparsely disseminated pyrite. Analyses of the samples are summarized below :

Metal	Range of Tenor	Arithmetic average tenor
Cu	.01 - .07 percent	.03 percent
Pb	.02 - 6.59 percent	.12 percent
Au	.0 - 4.0 g/ton	.34 g/ton
Ag	.0 - 5,648.0 g/ton	15.29 g/ton x

x - does not include two erratically high Ag assays

Two samples out of the 34, each with megascopically visible galena, gave silver assays of 5,648 and 1,175 grams per metric ton respectively, but the majority of assays for gold and silver were negative, or traces only.

Four completed diamond drillholes ranged in depth from 37 to 86 m, averaging 66 m; assays of the cores are as follows :

	Arithmetic average tenor			
Hole No.	2	3	4	5
No. of Samples	19	37	56	30
Cu, percent	.066	.046	.065	.083
Pb, percent	.081	.029	.061	.15
Zn, percent	.17	.10	.11	.16
Au, g/ton	0-tr.	0-tr.	0-tr.	0-tr.
Ag, g/ton	0-tr.	0-tr.	0-tr.	0-tr.

Results of analysis of a broad range of surface and subsurface samples show that the Buriticá prospect is of little economic interest. The tenor of sulfides is much too small to support any kind of commercial mining operation, and further study is not recommended.

Toledo prospect

A small showing of chalcopyrite with pyrite occurs in greenschist of the Valdivia Group in Quebrada El Bique, 1,200 m north of El Brujo at the extreme northern edge of plancha a-6, Plate I, 7 km by mule trail west of Toledo (Plate I, b-6). A mining concession for copper is rumored to have been applied for some years ago by a family named Peláez. A single short adit has been driven 4.5 m into the hillside, 20 m above creek level, to expose a few seamlets of sulfide that are concordant with foliation of the north-striking, steeply east-dipping host schist.

Total width of the mineralized zone is about half a meter. Specimens assaying 2.5 percent Cu can be taken by careful picking, but tenor over a minable width (1 m minimum) is estimated to be less than one percent of copper. No other base-metal minerals were seen.

The sulfide minerals probably represent mobilized syngenetic material redeposited along foliations and local shear-planes, or are wholly epigene deposits of hydrothermal magmatic origin. The slope above is completely covered by soil and brush, but judging from the character of the hostrock, the weak mineralization, and the absence of hydrothermal alteration, the probability of finding an exploitable orebody is very low, and further work is not recommended.

Anserma prospects

Two prospects containing copper minerals are known near Anserma, Department of Caldas. One is 2 km northwest of Anserma in a roadside quarry on the east side of the Río Risaralda, the other is 3 km southwest of Anserma on the west side of the Río Risaralda, reached by 2 km of trail. Both are very similar in character. Chalcocite, possibly supergene, with secondary malachite-azurite coatings fills fractures in localized weakly developed shear zones in Cretaceous (?) metabasalt. It is possible to pick specimens assaying 3 to 4 percent Cu, but the average tenor across a minable width (1 m minimum) is estimated at less than 1 percent of copper. The mineralized zones have no continuity but fade out within a few meters along the strikes. No further exploration is recommended at the Anserma prospects.

Copper prospects west of the Río Cauca

A large part of the area west of the Río Cauca, in the Western Cordillera is outside of the boundaries of Zone II as defined in this report, but will be studied by Colombian geologists in the near future, and it is appropriate that the following comments be included in this report.

Most copper prospects in the Western Cordillera, like those at Anserma, are in or associated with Mesozoic (Cretaceous?) basalt and greenstone. This is an interesting and possibly significant relationship. The abundance of copper in most basalts (8 to 300 ppm, average 123 ppm, based on 130 samples (Prinz, 1967, p. 278)) is significantly higher than that in the average igneous rock (70 ppm (Hawkes and Webb, 1962, p. 22)). The Western Cordillera prospects may have been produced by local migration and concentration of copper contained in the basaltic rocks themselves, as has been suggested for copper deposits associated with Precambrian basalt in Michigan, U.S.A. (White, 1968, p. 323). Nevertheless, that such a mechanism as postulated by White could produce copper deposits of economic size and tenor in the geologically young and little altered basalts of the Western Cordillera is doubtful. It is more probable that any concentrations of copper minerals that may be found associated with the Mesozoic basalts will be wholly epigene, deposited in faults or shear zones by ascending hydrothermal solutions residual from crystallization of basaltic magma that was forced upward from the earth's mantle.

Pyrite

Pyrite, FeS_2, is widespread in Zone II, but as tiny accessory crystals a fraction of a millimeter across, sparsely disseminated in a variety of rocks. It has not been found concentrated in massive deposits. Pyrite, rarely exceeding 10 percent by weight and usually accompanied by very sparse amounts of other sulfides, is disseminated in the quartz veins exploited for gold. Frontino Gold Mines Ltd. near Segovia discards about 40 tons per day of pyrite in tailing from ore containing an average of 8.6 percent of pyrite. Some years ago, the company considered building a pyrite roasting plant to make sulfuric acid as a byproduct, but their study showed that a minimum feed of 60 tons per day of pyrite was required for an economic operation, and the project had to be abandoned (M.E. Burke, Frontino Gold Mines Ltd., general manager, personal commun., 1968).

Small gold mines such as Marmato and La Bramadora extract an aggregate total estimated very roughly at 1,500 tons per year of pyrite with their gold ores. None of this is saved, and at the present scale and method of operations, its recovery is neither practical nor economic.

Geologists of IMN have reported showings of massive pyrite alongside the road, 1 km southeast of Ituango (Plate I, a-4). Thin nearly vertical lenses of fine-grained massive pyrite occur in a 4 m wide zone in host greenschist of the Valdivia Group. The lenses are much too small to be of economic interest, but their presence suggests a geological environment favorable for massive pyrite bodies. The area may deserve further investigation should the economic feasibility of a pyrite-roasting plant in Colombia be proven in the future.

Lead and zinc

The recovery of byproduct galena and sphalerite concentrates by Frontino Gold Mines Ltd. has already been mentioned under the section on gold and silver. La Bramadora gold mine has shipped about 120 tons per year of Wilfley-table bulk sulfide concentrate containing 2 or 3 percent each of lead and zinc to American Smelting and Refining Co. at Selby, California; however, the value of the concentrate is more in contained gold and silver than in base-metals. The ores at other small lode gold mines contain minor amounts of galena and marmatite or sphalerite but recovery is not practicable with the present methods and scale of operation. No deposits workable primarily for lead and zinc are known in Zone II.

NONMETALLIC RESOURCES

Cement raw materials

Portland cement industry in Zone II

The manufacture of portland cement is an important industry in Zone II, and the annual gross value of the consumed raw materials alone may exceed that of any other mineral commodity produced in the zone, excluding gold. Certainly the gross value of the cement manufactured from these raw materials is greater than the value of any other mineral or mineral derivative produced in Zone II. Table 3 lists the four cement companies operating in the zone, their daily clinker capacity, and approximate tonnage of finished cement produced in 1967. Brief descriptions of these operations are given in the text following the table.

About 1.7 tons of raw materials are needed to make one ton of finished cement (Clausen, 1960, p. 211). Consumption of cement raw materials in 1967 in Zone II is estimated as follows :

Raw material	Est'd metric tons used in 1967
Calcite marble	750,000
Argillaceous materials	172,000 1/
Iron materials	10,000 2/
Gypsum	28,000
Total	960,000

1/ includes 2,000 tons of sand at Nare
2/ consumed by Cementos Caldas

In addition to the above, an estimated 140,000 tons of subbituminous coal were burned in the kilns of El Cairo and Caldas and 210,000 barrels of fuel oil from Barrancabermeja in the Nare kilns.

Table 3

Cement production in Zone II, 1967 1/

Company	Plant location	Process	No.of kilns	Daily clinker capacity (metric tons)	Production finished cement (metric tons)
Cementos El Cairo	Sta. Bárbara, 60 km south of Medellín	Wet	4	1,000	280,000 2/
Cementos del Nare	West bank Magdalena river 225 km east of Medellín by rail	Wet	3	600	147,000 3/
Cementos Caldas	Neira, 20 km north of Manizales	Wet	2	650	100,000
Cía. Cemento Argos	Medellin	4/	4/	1,200 5/	218,000 6/

Notes :

1/ Data from individual company officials

2/ Clinker production only; 70 percent of El Cairo clinker is finish-ground at Argos' mill. Roughly 100,000 tons per year of finished cement made by El Cairo's own finish grinding plant.

3/ Includes 24,600 tons of white cement.

4/ Cemento Argos does not make clinker; operates finishing mill only, fed by clinker from El Cairo's kilns; also grinds some Nare clinker.

5/ Grinding capacity

6/ Finished cement from clinker produced outside.

Cementos El Cairo

This wet-process plant was constructed in 1943 near the town of El Cairo, 9 km southeast of Santa Bárbara, and has a daily clinker burning capacity of 1,000 metric tons. The quarry is in a lens of marble 350 m long and 120 m wide, that strikes northeast and dips steeply southeast. The lens is enclosed within schist correlative with the Valdivia Group. This calcareous lens may have been a bioherm formed in a locally shallow part of the great eugeosynclinal trough in which were deposited the fine grained sediments that later were metamorphosed to Valdivia Group schists. The metamorphism recrystallized the bioherm to marble, destroying all fossils. The marble is crushed and milled in a plant near the quarry and pumped as a slurry through 4 km of 8-in. steel pipeline to silos near the kilns. Marble reserves are limited but appear large enough to support the plant for at least another 10 years.

Argillaceous material providing alumina and silica for the raw mix is excavated from a hillside near the kilns, and consists of soil and saprolite derived by the decomposition of quartz-sericite schist. Typical analyses supplied by the company of the two main raw mix ingredients (in percent) are :

	Calcareous ingredient	Argillaceous ingredient
SiO_2	8.06	66.58
Al_2O_3	2.01	16.12
Fe_2O_3	1.19	6.08
CaO	48.37	3.03
MgO	1.17	1.36
Loss on ignition	39.10	5.40
Total	99.90	98.57

Subbituminous coal is trucked 58 km from Amagá, dried and pulverized at the plant to fire the kilns. Coal is consumed at a rate of 400 tons per day. About 100,000 tons per year of cement is finished at El Cairo's plant, but most of the clinker is trucked 60 km to Medellín to be finished in the plant of Cía. de Cementos Argos S. A.

Cementos del Nare S. A.

This plant, constructed in 1933 near the confluence of the Ríos Nare (or Samaná Norte) and Magdalena, is connected to Medellín by 225 km of narrow-gauge railroad. Two rotary kilns have a combined capacity to produce 500 tons per day of portland cement; one smaller kiln has capacity to produce 100 tons per day of white cement. A quarry is located on the banks of the Río Samaná Norte 15 km upstream from the kilns. Raw marble mixed with clayey soil is made into slurry at the crushing and grinding plant near the quarry and delivered to the kilns via a 13 km long double pipeline, one pipe 5-in., the other 6-in. in diameter. Clay-rich saprolite from a small pit near the plant is added to the raw mix when needed. A small amount of alluvial sand is added at times to raise silica to required stoichiometric proportions. Iron-free kaolin from La Unión is added to the marble slurry for white cement.

Reserves of marble in the Nare area are measurable in millions of tons and much of it is 95 percent $CaCO_3$ with less than 1 percent each of Mg and Fe.

An associated company, Colombiana de Carburo y Derivados S.A., operates an electric furnace with capacity to produce 35 tons per day of calcium carbide, CaC_2 (Gómez A., 1966). The furnace operates on electricity produced by Cementos del Nare's hydroelectric power plant near the marble quarries. Raw materials include quick-lime made by calcining marble in a small rotary kiln, and coke from Belencito, Boyacá, or anthracite coal from northeastern Santander. Production is about 10,000 tons per year of which 7,000 tons is consumed in the manufacture of polyvinyl chloride at the company's plant in Cajica, Cundinamarca, 30 km north of Bogotá, and the remainder is used in acetylene generators and in miner's lamps.

Cementos Caldas S.A.

This plant, constructed in 1959 near Neira, 20 km north of Manizales, Department of Caldas, has two rotary kilns, each of 325 tons per day clinker capacity. Because of limited market, only one of the kilns was in operation during most of 1967, although both were reported in service in August 1968. Four km east of the plant a lens of finely crystalline gray marble, 200 m long and 20 m wide dips steeply eastward, enclosed within quartz-sericite schists correlative with the Valdivia Group. The lenticular form and limited extent of this calcareous body suggests that it also may have originated as a bioherm as proposed earlier for the marble lens at El Cairo. Crushed marble is transported to the plant by 4 km of aerial cableway. Magnesia and silica are variable, requiring constant control and blending at the plant. Reserves are limited and may be exhausted by 1980.

Clay, trucked from an open pit 3 km east of the kilns, is derived from deeply weathered decomposed andesitic tuff. This material of volcanic origin is relatively rich in potassia in comparison to most argillaceous materials used in cement making. It is reported that 125 tons per month of kiln dust containing 5 percent K_2O and 40 percent CaO are sold as a byproduct to a compnay in Manizales that uses this dust as a raw material in the preparation of blended fertilizers.

As both the marble and clay are poor in iron, about 35 tons per day of ferruginous material must be added to the raw mix. This material, which contains about 33 percent Fe_2O_3, is taken from a one-meter thick mantle of loose volcanic cinder on the slopes of the dormant volcano, Nevado del Ruiz, 40 km southeast of Manizales, and is trucked 60 km to the cement plant.

Cia. de Cementos Argos S.A.

This company, founded in 1934, originally operated three rotary kilns in Medellín fed by calcite marble quarried near San José del Nus southwest of Maceo in IIB. The 120-km rail haul proved to be uneconomical, and two of the kilns were moved to Nare, and the third to El Cairo. The Argos plant was converted to a finish-grinding operation having a capacity of 1,200 tons per day, fed by clinker chiefly from El Cairo, but also from Cementos del Nare. About 4 percent of crude gypsum, from Mesa de los Santos in Santander or the Guajira peninsula, is ground with the clinker as a retardant.

Carbonate rock reserves in eastern Antioquia

Reserves of calcite marble and crystalline limestone are measurable in billions of tons in eastern Antioquia, subzone IIB, although very limited in subzone IIA. Figure 2 shows the distribution of carbonate rock bodies in a narrow belt between Segovia on the north and Aquitania on the south. Chemical data are lacking, but it seems probable that much of this carbonate rock would prove suitable for the manufacture of portland cement, as at Nare. Most of this region is sparsely inhabited in rugged terrane so that poor accessibility and distance from market and a suitable source of energy are handicaps to development at present.

Clay

Clay was little studied by IMN. General studies of clay in Antioquia were made at the Facultad Nacional de Minas in Medellín (Suescún and others, 1966, p. 3-53; Ellwanger, 1966, p. 55-132). Private companies such as Locería Colombiana S.A. and Erecos S.A. have made extensive studies of clay resources in Colombia but their data are unpublished. In general, the better quality clays used in industry occur in areas outside of that mapped by IMN.

A mantle of iron-stained saprolite overlies most rocks in Zone II, and is especially prominent on the Antioquian batholith. Good quality kaolin deposits are much less common than the saprolite mantle; that at La Unión is perhaps the most important. Small backyard brick-and-tile kilns using saprolite are so numerous as to constitute an important industry, although statistics are lacking. The majority of buildings in every city and town have brick walls and are roofed with curved fired tiles. These bricks and tiles are cheap and have been traditional with the population for centuries, so that their use in small buildings may be expected to continue well into the future.

Kaolín at La Unión

This deposit, located in IIA on the outskirts of the town of La Unión, 55 km by road southeast of Medellín, has been known and exploited for many years (Nicholls V., 1960). It is developed within the central part of a cupola of the Antioquian batholith that covers approximately 65 sq km, and is surrounded by amphibolite and schist correlative with the Valdivia Group. The cupola is separated from the main batholith by a 3 km-wide septum of schist. The clay deposit itself is limited to a few square kilometers near the center of the cupola. Previous workers have stated that La Unión kaolin is a residual product of weathering and decomposition of tonalite (Suescún, and others, 1966, p. 22-44; Nicholls, 1960). However the present authors consider that hydrothermal alteration played a role in formation of the kaolin at La Unión for the following reasons :

a) Depth. Suescún, and others (1966, p. 40) reported drillholes 45 m deep that did not encounter fresh rock. Dietrich Paetsch (oral commun., 1967), director of raw materials research for Locería Colombiana S.A., reported at least one drillhole 80 m deep in which there was no appreciable change in the kaolin. Complete kaolinization to these depths by subaerial weathering is unlikely.

b) Whiteness. The kaolin at La Unión is white or cream-colored. Saprolite produced by the normal weathering of tonalite is red or brown from the oxidation of iron in the accessory biotite and hornblende. Analyses of La Unión kaolin typically show less than 1.5 percent Fe_2O_3 in contrast to 3 to 8 percent in normally weathered tonalite. It is difficult to explain the whiteness and low iron content by weathering; on the other hand, bleaching is a common hydrothermal alteration phenomenon. It may be argued that the tonalite at La Unión is an alaskitic or felsic facies of the Antioquian batholith poor in mafic minerals. No direct evidence supports this idea; on the contrary, the batholith, which is noteworthy for its uniformity, normally contains more than 15 percent mafic minerals and between 5 and 8 percent combined Fe_2O_3 and FeO.

c) Localized occurrence. Extensive areas elsewhsee underlain by tonalite, subject to the same weathering, do not have kaolin deposits of like quality.

The material is dominantly kaolinite with lesser quartz. Igneous texture of the parent rock is perfectly preserved. The quartz grains are removed by washing and screening at the pit, and are used as ceramic silica. Another striking feature of the deposit is the presence of platy grains, 2 to 5 mm in diameter, perfectly pseudomorphic after mica, that are composed of pure kaolinite according to analyses by Paetach and others (1963). The altered mica probably was biotite, the main accessory in the Antioquian batholith tonalite. Muscovite is rare in the batholith. This complete kaolinization of mica at La Unión may be interpreted as additional evidence favoring a hydrothermal origin. Mica generally is resistant to weathering (Deer, and others, 1962, v. 3, p. 70), and often is preserved in saprolite as shiny flakes. Complete alteration of mica to kaolinite is common in zones affected by acidic hydrothermal fluids (Deer, and others, 1962, v.3, p. 208-209). The outer rim of the tonalite cupola logically would have crystallized first, entrapping hydrothermal fluids that could have deuterically altered the central core to kaolinite.

The following data concerning the vertical profile of the La Unión deposit have kindly been furnished by Dietrich Paetsch (oral commun., 1968): The deposit is overlain by a mantle 1.5 m thick of gray material amorphous to X-rays, probably mainly allophane, with some organic matter, and as much as 10 percent free quartz. This is underlain by a 1 m-thick, lighter-gray layer containing approximately 65 percent kandite, either kaolinite or metahalloysite or a mixture of these, halloysite which grades from 30 percent in the upper part of the layer to 15 percent in the lower part, 25 percent quartz, and 5 percent gibbsite. This second layer grades abruptly into the main body of white clay beneath, composed of approximately 60 percent kaolinite, 12 percent halloysite, and 27 percent quartz. The igneous texture so well preserved in the main body is only faintly discernible in the second layer and is not visible in the top layer. This profile could have been produced by subaerial weathering of the kaolinite body, the bulk of which was formed by hydrothermal alteration of tonalite.

Representative chemical analyses of La Unión kaolin follow:

		1	2
SiO_2		44.04	48.8
Al_2O_3		37.83	33.7
Fe_2O_3		1.05	.9
TiO_2		.74	.6
CaO		.38	1.0
MgO		.21	.5
P_2O_5		.38	n.a
K_2O		n.a	.5
Na_2O		n.a	.1
H_2O+		15.32	14.3
	total	99.95	100.4

1. Nicholls (1960, sample no. EN-207).
2. Washed and screened La Unión kaolin, analyzed at the laboratory of Centrales de Servicio Cornoa S.A. in Medellín.

Production in 1967 of kaolin from Locería Colombiana's main pit at La Unión is estimated at 19,000 metric tons; an additional 15,000 metric tons is taken yearly from other nearby pits. The material is trucked to Medellín for use in the manufacture of chinaware, wall-tile, electrical insulators, sanitary ware, and other ceramic products. Lesser amounts of kaolin are used as fillers, especially in pesticides, paints and plastics.

In 1967 IMN assisted Locería Colombiana S.A. in arranging for testing of crude La Unión kaolin as a possible source of high-grade paper-coater and paper- and rubber-filler clays by three large kaolin companies in the U.S.A. The results showed that crude La Unión clay is not suitable for these uses, but beneficiation might yield satisfactory products. Complete beneficiation tests were not made. Future research may prove the feasibility of processing La Unión clay to produce high-grade coaters and fillers. The reserve may be measurable in tens of millions of tons.

Other kaolin deposits

Kaolin clays occur in a number of places in Zone II, but none match La Unión clay in purity and whiteness, ease of exploitation and size of reserve. Kaolin at Carmen de Viboral, 13 km north of La Unión, is similar to the latter in mode of occurrence but is less pure. Carmen de Viboral formerly was the site of about a dozen small ceramic plants making inexpensive chinaware, vases, and decorative ware, but after establishment of modern large-scale ceramic plants in Medellín, all but two or three of the small plants were forced to close. Highly plastic kaolin clay is taken in small quantities from Guarne, 25 km by road east of Medellín, and transported kaolin derived from weathered Antioquian batholith is taken from open pits in alluvium near Rionegro, 40 km by road southeast of Medellín. Mudstone beds intercalated with coal seams at the western edge of Zone II along the east bank of the Río Cauca, as for example at Amagá and Sopetrán (Suescún, and others, 1966, p. 43), are composed of transported impure kaolin but quality is poor.

Weathered felsic tuff of Cenozoic age, partly decomposed to kaolin, was noted by IMN geologist Jaime Durán alongside the highway near La Ceiba 15 km north of Anserma, Department of Caldas. This material is high in silica (69 percent SiO_2) but low in iron (0.9 percent Fe_2O_3), and could conceivably be used in ceramics. Reserves may be large but have not been proven. Another deposit was observed by IMN geologist Jorge Muñoz 15 km by road west of Anserma, Department of Caldas, near Hacienda Monte Grande 200 m north of the main road toward Mistrató. The material is white, very finely gritty and nonplastic. It has been exploited sporadically on a very small scale for making ceramic tiles and cleansing powder in Manizales. The material is interpreted as a localized hydrothermal alteration product of Tertiary (?) hornblende diorite; reserves are not known.

Refractory raw materials.

The Erecos refractories plant in Medellín makes a thousand tons per month of refractory brick at ASTM specifications, in a wide assortment of compositions, shapes and sizes. Kaolin clay is the principal raw material, but other materials, both domestic and imported, also are used as shown in the following list :

Item	Est'd tons used per year	Source	Remarks
Kaolin	4,800	La Unión, Antioquia	contains >35% Al_2O_3
Kaolin	600	Guarne, Antioquia	highly plastic
Kaolin	4,800	Rionegro, Antioquia	good workability
Kaolin	1,200	Arcabuco, Boyacá	good plasticity
Diatomaceous earth	600	Zarzal, Valle	for insulating brick
Silica sand	120	Angelópolis, Ant.	for silica brick
Feldspar	120	La Ceja, Antioquia	glazing agent
Bauxite	3,000	Guyana (Alcán)	high alumina products
Corundum	10	Germany (Lonzawerke)	special heavy duty products
Bentonite	60	U.S.A. (American Colloid Co.)	for binding agent
Graphite	12	U.S.A. (Asbury, Vermont)	in furnace taps

Imported materials constitute only 20 percent by weight but roughly 40 percent of the value of the total raw materials used.

High-alumina clays and flint clays have not so far been recognized in Zone II. A thin patchy mantle of sandy kaolin-rich saprolite containing about 5 percent of gibbsite as veinlets and nodules occurs near Llanos de Cuivá (see "Bauxite"), but the crude material has no value as a refractory raw material, and it would be uneconomic to attempt to separate the gibbsite from its impure saprolite matrix.

Nonclay materials that might be used in basic refractories include chromite and associated high-magnesia ultramafic host rocks near Las Palmas and Santa Elena, 10 km southeast of Medellín (see "Chromite"). Dolomite near Amalfi (see "Dolomite") may be satisfactory as a basic refractory raw material but has not so far been used for this purpose. The demand in Colombia has not been great enough to economically justify the establishment of a special facility at the Erecos plant to make basic refractories from domestic materials. Potential ganister for silica brick occurs near Amalfi (see "Quartz and silica sand"). Andalusite, an aluminum silicate used in high-alumina refractory products, occurs in a number of places in the zone as rodlike crystals disseminated in aluminous sericite schist, and also as clasts in alluvium. However, these deposits are not commercially exploitable at present (see "Andalusite").

Coal

General statement

Although the study of coal was specifically excluded from the IMN program, subbituminous coal deposits are one of the most important resources in the zone and deserve mention in this review. During the field mapping, IMN geologists encountered lignitic to subbituminous coal seams in Tertiary clastic sediments, notably 10 km southeast of Puerto Antioquia (Plate I, a-1), 3 km east of Ituango (Plate I, a-4), 10 km south-southwest of Ituango (Plate I, a-5), near Toyugano village (Plate I, a-6), and 9 km north of Sabanalarga (Plate I, a-7). These are of negligible importance at present, either because of isolated location, or because the beds are thin or poor in quality. Economically exploitable coal beds occur along the western margin of Zone II in a north-trending belt 1 to 14 km wide, extending from Sopetrán on the north, some 70 km southward past the towns Ebéjico, Heliconia, Titiribí, Amagá, Venecia, and Fredonia (Grosse, 1926, p. 101-161). Coal in Antioquia is noncoking, except some seams near Titiribí which may have been affected by adjacent andesite sills. Reserves within the Amagá basin are measurable in hundreds of millions of tons (Grosse, 1926, p. 330-331). A description of the largest coal mine in the area follows.

El Silencio mine

The El Silencio mine, 2.5 km north of Amagá, is the most important mine in the district, and the second largest coal mine in Colombia. Industria Hullera S.A., operator of the El Silencio mine, is a private company owned jointly by Cementos El Cairo S.A., Coltejer, and Fabricato. The last two are large textile companies. The mine has been operating under its present ownership since 1940.

The workings, comprising many kilometers of underground galleries, are developed in an open syncline plunging 12° SSW. The three main coal seams range in thickness from 1.2 to 2.2 m, and are separated from each other by beds of sandstone and claystone as much as 14 m thick. Individual coal seams are commonly underlain by massive gray claystone (apparently of no particular value for fireclay, according to the mine management), and overlain by fine-grained massive gray silty sandstone. The sediments are of Late Oligocene age according to Van der Hammen (1958, p. 113).

The coal is black with a brownish-black streak, has a bright luster, blocky conchoidal fracture, hardness of 2.5, and specific gravity of 1.3. Quality is relatively good for coal of subbituminous rank. Grosse (1926, p. 126-127) gives proximate analyses of 20 samples from the Amagá basin, which are summarized below. One analysis of a recent sample from the El Silencio mine also is given.

	20 samples of coal from Amagá basin		Typical coal, El Silencio mine 1/
	average	range	
Fixed carbon	49.7	42-59	49.8
Volatiles	41.0	30-48	37.9
Moisture	8.1	4-11	9.4
Ash	3.0	1-6	2.4
Sulfur	.6	.4-1.2	.5
Calorific yield (cal/Kg)	5,800	5,070-6,270	6,120

1/ Analysis furnished by Industria Hullera, S.A., Medellin

The low sulfur and ash are noteworthy.

Main haulageways are horizontal adits 2.0 by 1.8 m, with single-track narrow-gauge rail. One-ton capacity side-dump mine cars are trammed by small diesel locomotives to haul timber and supplies to the interior of the mine but are not used for coal haulage. The 12° to 15° dip allows the long-wall mining system to be employed.

Longwalls of 180 m total length are made parallel to the dip by an electric-driven rotary coal-cutter which takes 60 cm wide cuts with each pass. A small charge of explosives is needed to break down the upper part of the seam not reached by the cutter. After a cut is completed, the roof supports are advanced and the cutter-machine and its conveyor are moved ahead for another pass. The roof over the mined-out portion of the seam is allowed to collapse behind the longwall. A high extraction factor is achieved by this system, and production is claimed to be about 4 tons per man-shift at the longwall and almost 2 tons per man-shift, overall. Broken coal is transported to the surface by a 1.8 -km-long electrically driven continuous belt conveyor of 200 tons per hour capacity.

Waste rock is picked off the moving belt by a pair of workers at the portal, but no other form of beneficiation is practiced, and unscreened run-of-mine lump coal is loaded from bins directly into 8-ton trucks for haulage to Medellín or El Cairo. The price per metric ton, f.o.b. mine, is 60 pesos (about US $3.50). Output is about 800 tons per day with a working force of 420 men working two 8-hour production shifts daily except Sundays and holidays. The El Silencio mine can easily increase current output by at least 50 percent, but is limited by the market and competition from numerous small mines nearby. The entire production is consumed in firing El Cairo's cement kilns, in generating steam used in the textile-manufacturing processes, and in Coltejer's thermal electric-generating plant in Medellín.

Reserves within the El Silencio concession are adequate to sustain current output of 200,000 tons per year for several decades (A. Chinchilla, mine manager, oral commun., 1968).

Other mines in the Amagá district

The Carbón San Fernando S.A. mine, a few km east of El Silencio, is the second most important mine in the Amagá district, and produces 250 tons daily. About 30 smaller mines are worked sporadically in primitive fashion by local campesino miners. The aggregate production of these mines, about 11,000 tons per month, is consumed by local industries and in household cooking. Production in the district could be increased greatly if there were an economic outlet.

Other coal deposits in Zone II

Additional deposits of subbituminous coal crop out south of the Amagá district, along the western margin of Zone II in the Department of Caldas, especially near Riosucio where one mine yields 30 to 50 tons per day to fire kilns of Cemento Caldas S.A. at Neira. Several small mines near Quinchía have been in operation for many years (Fetzer, 1941). The seams, presumably correlative with the Upper Oligocene at Amagá, are of coking grade, although friable and subject to high losses in fines (Wokittel, 1960, p. 69-73). Other small deposits have been observed by IMN geologists 10 km southeast of Quinchía where 2 m thick seams of Tertiary coal dipping steeply eastward crop out along the railroad on the east bank of the Río Cauca, and 1.5 km east of Aranzazu, where a 3.5 m thick zone of lignitic coal of poor quality is intercalated with Tertiary clastic sediments that dip 15° to 30° E in Quebrada del Sargento (A. Andrade, written commun., 1968).

Aggregate materials

General statement

Statistics are not available, but the annual gross value of crushed rock and alluvial sand and gravel for use as road metal and as aggregate for construction throughout the zone must be measurable in millions of pesos, and probably is exceeded by few other mineral commodities. Construction raw materials were not especially studied by IMN, but the geologic maps, Plates I, II, and III, should be useful in future searches for these materials.

Crushed rock

Roadside quarries opened by the Ministry of Public Works or by private construction contractors usually are worked with a single portable air-compressor and one or two rock drills. Use of explosives is kept to a minimum. Most small municipal quarries are entirely manual, worked by groups of campesinos who laboriously pick rock from the face and crush it by hand. A wide variety of rock materials are taken, including Cretaceous Antioquian batholith tonalite, a good aggregate material when not too decomposed, Paleozoic amphibolite and schist, which tends to be friable and to break into platy fragments, Paleozoic gneiss, Mesozoic greenstone or metabasalt, and even Mesozoic serpentinite, the latter a very poor aggregate in concrete but useful as a sub-course fill on roads because it crushes and compacts readily under the roller. In many cases little attention is paid to the kind of rock or its quality, the main requirements being convenient location and ease of extraction. Quality control is practiced at large construction projects such as dams or paved highways.

Alluvium

Medellín and its suburbs are by far the largest consumer of aggregate materials in the zone. The bulk of these materials is taken from the banks of the Río Medellín, especially in pits near the suburb of Caldas, south of Medellín, and near Bello and Girardota, north of the city, and from the Quebrada Iguaná on the west side of the city. Poorly sorted sand and polymict gravel commonly are used without treatment. Some few users, concerned with the quality and strength of the concrete they intend to make, insist upon washing, screening, and grading to insure properly designed mixes. For example, Cía. de Cementos Argos operates a modern ready-mix batching plant adjacent to its cement-finishing plant, with the capacity to make 400 cubic meters daily of ready-to-pour concrete, prepared to ASTM specifications and delivered to its customers by a fleet of nine mixer-trucks. Alluvium from the Río Medellín is washed and graded prior to use. Alluvial materials also are used in asphalt paving. One batching plant operated by the city of Medellín produces 60,000 metric tons per year of hot paving mix from crushed gravel taken from the Río Medellín and petroleum asphalt railed 300 km from refineries at Barrancabermeja.

Weathered igneous rock

Several factories in Medellín make hollow cement block and pipe using finely-crushed semi-decomposed Tertiary (?) granodiorite taken from their own quarries near the city and mixed with domestic portland cement. These plants can produce several hundred tons daily of blocks and pipe with modern automated high-pressure molding machinery, and constitute a thriving industry. Decomposed granodiorite also has been washed and screened to obtain "sand" for wall plaster and mortar. This material contains a clay component which is said to have a pozzolanic reaction with cement, yielding a high-strength concrete (H.vom Stauffen, mining consultant, oral commun., 1969).

Lightweight aggregate material

Apparently little attention has been given by the Colombian construction industry to lightweight aggregate materials, but two potential sources of these are known in Zone II.

Samples of black Cretaceous shale near Amalfi (Plate II, a-3), 144 km by road northeast of Medellín, bloat at 950°C, and represent a potential source of bloated lightweight aggregate. Further testing would be needed to prove feasibility, but the reserves of potentially bloatable shale are believed to be sufficient to support a commercial operation.

Hillslopes a few kilometers east of Manizales, Department of Caldas, are covered with a mantle of Holocene pumice fragments 0.3 to 3.0 cm across, ejected from nearby volcano Nevado del Ruiz (presently dormant). The white to light gray pumice floats on water until it becomes saturated, and conceivably could serve as a lightweight aggregate and insulating material. It has been used by Cementos Caldas to make pozzolanic cement (F. Aranas, plant manager, oral commun., 1967). Reserves are unknown, but an area comprising many hectares is covered with the pumice mantle to depths ranging between 1 and 3 meters.

Dolomite

Amalfi

An east-trending lens of marble 4 km northwest of Amalfi (Plate II, a-3), 144 km by road northeast of Medellín, is about 1 km long and ranges in width from 160 m at its eastern and to 300 m at its western end. It is enclosed in sericite schist correlative with the Valdivia Group. The bulk of the lens is fairly pure calcite marble, but the east end is dolomitic. Reserves of dolomite marble, based on a detailed study by IMN geologists H. Lozano and H. Restrepo, are only 600,000 metric tons, whereas the remainder of the lens comprises an estimated 39 million metric tons of calcite marble.

It is not clear why only a small part of the lens is dolomitic, nor whether it is primary dolomite, or secondary. This body may have originated as a bioherm reef, as suggested for nondolomitic lenses near El Cairo, Antioquia and Neira, Caldas, which are sources of cement raw material. Marmarization would have destroyed any fossils in the original carbonate. The dolomitic marble is white or cream colored and has a fine-grained (0.5 mm) sugary texture. Adjacent calcite marble in the same lens is medium-grained (2 to 4 mm) and gray. The two rocks are easily distinguished in the field. Analyses (in percent) of typical specimens follow :

Marble

	Dolomitic	Calcitic
CaO	33.29	55.51
MgO	18.07	.01
SiO_2	.42	.60
Fe_2O_3	.14	.11
Al_2O_3	.22	.05
Mn	trace	trace
Ti	trace	trace
P	nil	nil
H_2O –	.04	.00
Loss on ignition	46.77	43.28
Total	98.65	99.56

(Analyses made by Servicio Minero, Ministerio de Minas y Petróleos, Medellín)

Low silica, less than 1.5 percent SiO_2, and low iron, less than 0.4 percent Fe_2O_3, are characteristic of both materials. Not all of the dolomitic part of the lens is as high in magnesia as the above analysis; some parts contain only 6 to 12 percent MgO, equivalent to magnesian limestone rather than dolomite; theoretical dolomite, $CaMg(CO_3)_2$, contains 22 percent MgO.

Two separate quarries are in operation, one for calcite marble, the other a few hundred meters further east, for dolomite marble. Approximately 11,500 metric tons of dolomite were quarried in 1967, of which 5,900 tons were consumed in glass manufacture by the Cristalería Peldar S.A. factories in Medellín and Bogotá, the balance in unspecified miscellaneous uses. Transport from quarry to end-users is by truck to Medellín, and by railroad from Porcecito station to Bogotá.

El Jordán

Lenses of dolomitic marble in quartzite occur near the village of El Jordán (Plate III, c-11), 140 km by road east of Medellín. Diopside is a contaminant mineral in much of this material and presumably limits its potential for use as conventional dolomite. Reserve is unknown.

Limestone and calcite marble
(other than cement raw material)

Subzone II A

Carbonate rock is relatively sparse in II A compared to II B, and excluding marble lenses which feed the cement kilns at El Cairo and Neira described earlier, is restricted mainly to lenses in quartz-sericite schist a few kilometers south of the town of Cocorna, 50 km southeast of Medellin. The lenses are small, difficultly accessible, and have little economic potential at present.

Various beds of impure limestone and marl occur locally intercalated with Cretaceous and Tertiary clastic sediments, especially in Quadrangle J-8, but have small economic potential.

The Neira quarry of Cementos Caldas is a source of industrial quick-lime as well as cement raw material. A small vertical-shaft lime kiln, constructed adjacent to the quarry by Senores Jiménez and Martinez, and fired by diesel oil, has a capacity to produce 187 tons per month of bagged quicklime which is used mostly for wall-plaster by the construction trade in Manizales.

Subzone IIB

Reserves of carbonate rock in IIB are very great, measurable in billions of tons. In addition to the quarry worked by the cement plant at Nare, five or six small quarries are worked for lime north of the town of Segovia, 220 km by road northeast of Medellín. The raw marble is calcined in small homemade wood-fired vertical-shaft limekilns to make quicklime, CaO, which then is wetted to make slaked lime, $Ca(OH)_2$. The latter is trucked to Medellín, ground to 100 mesh, bagged and sold to industries in Antioquia, Caldas, Risaralda, and Quindío. Sales of bagged slaked lime are reported to range between 500 and 600 metric tons per month, mostly for water purification, agricultural lime, leather-treatment, bleaching and the manufacture of chemicals (L. Duque and B. Bran, lime plant owners, oral commun., 1968).

Raw lump marble, mostly from the calcite marble quarry at Amalfi (mentioned under dolomite), is ground by various jobbers in Medellín and sold as whiting and filler in a variety of industries, especially paints and plastics. Precise figures are not available, but an estimated 4,500 tons per year are consumed in this way. The Peldar glass factory in Medellín used 6,400 tons of calcitic marble from Amalfi in 1967.

Feldspar

La Ceja

Locería Colombiana S.A., the largest manufacturer of ceramics in Colombia, operates a small quarry in pegmatite enclosed in Paleozoic amphibolite, reached by 12 km of narrow dirt road south of La Ceja, which is 40 km by road southeast of Medellín. The deposit has not been especially studied by IMN. The pegmatite lens is 10 to 20 meters wide and some tens of meters long, extending to an unknown depth and is composed dominantly of feldspar with subordinate quartz and muscovite. The feldspar is commonly stained with small amounts of the oxides of iron and manganese, which reduces it to near-marginal quality for ceramic uses.

One analysis of almost iron-free material, kindly furnished by Centrales de Servicio Corona S.A., follows :

	Percent
SiO_2	73.00
Al_2O_3	15.65
Fe_2O_3	.05
CaO	1.50
MgO	.00
Na_2O	5.00
K_2O	3.60
Loss on ignition	.60
Total	99.40

The 73 percent silica in the above analysis contrasts with the 63 to 66 percent in most commercial feldspars and suggests that appreciable free quartz is present in the material supplied to the ceramic factories. Part of the potassia is in muscovite.

About 9,000 tons per year are quarried and sorted by hand and trucked to Medellín. Roughly two-thirds of the production is consumed in Locería's several ceramic plants while most of the remainder is sold to Cristalería Peldar S.A., glass container factory in Medellín. Small amounts are taken by lesser consumers for enamel frit and in miscellaneous filler uses.

Reserves at La Ceja are not known but are believed to be adequate to serve foreseeable domestic demand for some years to come. La Ceja spar is not high-grade, but thus far, better alternative sources have not been found.

Other deposits

Pegmatite lenses near La Pintada, 60 km south of Medellín, and Montebello, 35 km south of Medellín, have been exploited sporadically by primitive methods on a small scale for several decades but are of lesser importance than the previously described pegmatite south of La Ceja because of smaller size and inferior quality.

Geologists of IMN have located several potentially exploitable pegmatite lenses near the eastern margin of plancha a-5 (Plate I) alongside the road 18 km southeast of Ituango. These white irregular sackform lenses are several meters wide and possibly extend both vertically and horizontally for several hundred meters. The pegmatite lenses are enclosed in Paleozoic gneiss from which they may have been derived during regional metamorphism. The pegmatite is coarsely crystalline and is composed of albite with subordinate quartz and muscovite, and little else.

One sample was analyzed at the laboratory of Centrales de Servicio Corona S.A. as follows :

SiO_2	64.4
Al_2O_3	20.9
Fe_2O_3	.1
CaO	2.0
MgO	1.3
Na_2O	9.4
K_2O	.7
Loss on ignition	.8
Total	99.6

The analysis shows that the sample is "soda spar" of the commercial feldspar trade. Check samples taken by representatives of Locería Colombiana S.A. gave results less satisfactory than the above; however, their samples were of surficial weathered material and fresh material may give better results (F.Viertel, geologist for Centrales de Servicio Corona S.A., oral commun., 1968). Neither Locería Colombiana S.A. nor Peldar have shown much interest in Ituango feldspar on the grounds that higher haulage costs would make it non-competitive with La Ceja feldspar; nevertheless, the Ituango pegmatites clearly represent a potential resource.

Talc

Yarumal distric

Deposits of talc in mountainous terrane, 14 km by road northeast of Yarumal, and 128 km by road north from Medellín, were investigated intermittently from February 1966 to November 1967 (Hall and Estrada, unpublished data, 1969). The deposits have been known and exploited on a small scale at least since 1952. Locería Colombiana S.A., and Instituto de Fomento Industrial (IFI), an agency of the Colombian government, hold adjacent concessions in the area. The IFI concession encompasses the better quality and more conveniently located talc bodies. The talc is currently being selectively hand-mined and cleaned by local campesinos. Locería and other buyers purchase about 90 metric tons per week of lump talc directly from the miners. Officials of IFI have been considering establishment of a mine and beneficiation plant to exploit the deposits on a larger scale. The economic feasibility of this scheme appears dubious at the present time because the crude talc is of inferior quality and the combined costs of beneficiation and transportation would make the beneficiated product noncompetitive on the world talc market; the domestic market alone is not large enough to support a plant of economic size.

Lenses of steatitized Mesozoic serpentinite occur in a 400-m-wide, 15 km long band of quartz-feldspar-mica augen gneiss, a member of the Paleozoic Valdivia Group, (Plate I, d-6). Individual talc bodies range from mere seamlets a few centimeters thick to lenses 50 m wide and several hundreds of meters long. The larger talc bodies contain inclusions of gneiss and vary considerably in purity and degree of steatitization. Chemical analyses of hand-sorted and cleaned lump talc from stockpiles follow :

Talc samples

	1	2	Theoretical talc ($H_2O.3MgO.4SiO_2$)
SiO_2	53.75	60.10	63.50
MgO	24.91	29.20	31.70
Fe_2O_3	4.39	3.40	
FeO	.68	2.30	
Al_2O_3	7.24	.71	
MnO	.12	.05	
CaO	2.86	2.50	
S	n.d.	.08	
Na_2O-K_2O	.72	n.d.	
CO_2	n.d.	.28	
H_2O +	5.15	4.60	4.80
H_2O -	.17	n.d.	
Total	99.99	103.22	100.00

1. Analyzed at Servicio Minero, Ministerio de Minas y Petróleos, Medellín.
2. Analyzed at Tuscaloosa, Alabama laboratory of U.S. Bureau of Mines.

Geological studies and data from 12 diamond drill holes (average depth 60 meters) made by IMN between November 1966 and November 1967 indicate a reserve of 6 million metric tons projected to a depth of 200 m within the area studied, and an additional 14 million tons inferred within the 8 km extension of the talc zone toward the village of Cedeno, 13 km airline northeast of Yarumal.

About half of the 4,500 metric tons produced annually is used in saggers and kiln furniture by Locería Colombiana S.A., and the balance, ground to fine powder by Triturados Impalpables S.A. and several smaller grinding mills, is used as a filler in paints, plastics, and rubber goods. Small quantities are used in cosmetic and pharmaceutical preparations, in cleaning printer rollers at textile plants, dusting candies to prevent sticking, and in other miscellaneous uses.

The greatest obstacle to expanded production of Yarumal talc is the relatively high iron content which adversely effects both natural and fired colors. The iron is chiefly in secondary limonite films on fractures, and in primary accessory chlorite and actinolite identified in thin section and by differential thermal analysis. Preliminary beneficiation tests made by H.P. LeVan and I.L. Feld, U.S. Bureau of Mines Tuscaloosa Research Laboratory, show that flotation may reduce total Fe from 4.2 to 3.5 percent, but with high loss in tailing. The economic feasibility of beneficiating Yarumal talc is dubious at the present time, in part because the domestic demand for talc is too small to support a plant, and also because processing and transport costs almost certainly would be too high to allow beneficiated Yarumal talc to compete in the world market. Colombia's industrial base will continue to grow, with increased demand for talc, and the domestic market eventually may be large enough to support a mine and beneficiation plant of economic size.

Other deposits

Other deposits of talc and talcose material have been reported, for example, in plancha e-5 (Plate I), associated with serpentinite near the Las Brisas asbestos prospects, and in plancha b-6 (Plate I), associated with greenschist at Hacienda Cacagual, along the highway 16 km north of San Andrés de Cuerquia. These deposits are too small or poor in quality to merit consideration as potential sources of commercial talc.

Decorative stone

Greenschist

A moderate-sized decorative stone industry, Piedra Esmeralda de Colombia, Ltda, is quarrying greenschist of the Valdivia Group 1 km north of the town of Valdivia, 165 km by road north of Medellín. Rock at the quarry is thinly laminated and splits readily into large slabs of fairly uniform thickness. Sparse fractures and joints are perpendicular to the lamination of the rock and aid quarrying. Blocks are marked out by closely spaced vertical holes drilled by hand. The holes are stuffed with straw which is set afire, thermal shock causing the block to crack along the line of holes so that it can be wedged out from the face, ready for splitting and trimming. This technique is slow but has the advantage of preserving blocks intact; no explosives are used. Blocks are split parallel to the lamination into slabs of desired thickness, then machine-cut and trimmed in a shop adjacent to the quarry. A considerable amount of quarry-run rock is trucked to Medellin for dressing in the company's shop. The stone, composed of finely crystalline epidote, chlorite, actinolite, and albite, is hard and costly to polish, but some slabs have an especially attractive appearance after polishing. About half of the company's sales are of crude undressed slab.

The stone is used for facades, patios, interior wall trim, and the like. Only a small quantity of polished stone is sold because of its cost. Medellín is the main market center, but shipments are made to other parts of the country. Desultory attempts to export this material have been unsuccessful. Reserves of greenschist are very large in IIA, but material of a quality equal to that at the Valdivia quarry is more limited; however, reserves appear adequate to support any foreseeable future demand.

Other types of decorative stone

Marble abounds in parts of IIB, but little information is available about the marketability in Colombia of this marble as a monumental, building or decorative stone. Poor accessibility to most of the high-quality marble bodies is a handicap to exploitation. Marble chips from the Amalfi and El Cairo quarries embedded in cement mortar, are used to make so-called "mosaic" flooring and terrazo tile (baldosas).

Although little used as a decorative and monumental stone, the tonalite of the Antioquian batholith would appear to have potential value in these uses because it has the composition, appearance, and texture of similar granitic rocks used in buildings and monuments elsewhere in the world. Zones of sound unweathered rock with widely spaced uniform vertical joints should produce marketable stone. We have no information on the quality of polish which the tonalite will take, nor on the difficulty in polishing. Quarrying and dressing would demand the services of experienced technicians and special equipment, and a market would have to be assured before establishing a plant.

Quartz and silica sand

Vein quartz

One large and several smaller mineral grinding plants in Medellín process raw lump milky quartz from various veins and lenses, notably near El Retiro 30 km south of Medellín. The veins and lenses occur in quartz-sericite schist correlative with the Valdivia Group and in the Antioquian batholith, and probably represent fracture fillings by silica-rich hydrothermal solutions residual from crystallization of the batholith. The quartz is a source of industrial silica. Finely ground, it is used in scouring powders and soaps, as a filler in paints, bitumen and as asphalt compounds, and the like. The quantity consumed is small, estimated at about 100 tons monthly.

Silica sand

Cristalería Peldar S.A. in Medellín produces 4,000 tons per month of soft-drink and beer bottles, tumblers and assorted glass containers. The chief raw material is silica sand, but sand available in Zone II contains excessive iron, and the company must buy most of its sand from sources outside of Zone II, near Sabana de Torres in the Department of Santander, requiring a rail haul of 380 km. The Sabana de Torres glass sand is taken from Holocene alluvium derived from Tertiary sandstone (D.E. Ward, written commun., 1968). The superior quality of this sand justifies the costs of transport from Santander. In colored glass products where slightly higher iron content is not critical, the company economizes by using sand taken from poorly consolidated Tertiary sandstone near Titiribí, 60 km by road southwest of Medellín. This sand is washed and graded at a small plant before being trucked to Peldar. Consumption is estimated roughly at 150 tons per month.

Mineral grinders and jobbers, such as Triturados Impalpables S.A., also use sand from Titiribí to be processed as foundry molding sand, filtering agent in water-purifying plants, and miscellaneous uses. Precise figures are not available but consumption in these uses is estimated to average about 400 tons per month.

Ganister for silica brick

The Erecos ("Empresa de Refractarios Colombianos S.A.") refractories plant in Medellín makes about 10 tons per month of silica brick using sand from Titiribí. A potential source of good quality ganister is the Cretaceous quartz-pebble conglomerate near Amalfi (Plate II, a-3). Massive beds as much as 5 m thick are composed almost wholly of pebbles of white quartz 1 to 4 cm in diameter in a tough silica matrix. Chemical analyses are not available, but SiO_2 content is visually estimated at not less than 95 percent and the white color suggests a very low iron content. Tests are needed to evaluate this material as ganister, but probably it would prove suitable for making silica brick.

Quartz crystals

Singewald (1950, p. 175-177) describes potential sources of optical and piezo-electric quartz crystals in Colombia. Two occurrences in Zone II are mentioned, one at Santa María, 6 km east-northeast of Maceo, the other at Frontino Gold Mines Ltd. near Segovia. He says "..... at Santa María the deposit proved to be too small,, and at Segovia large clear crystals were much too scarce, for either locality to be regarded as a potential source..." (Singewald, 1950, p. 176). No other localities of high-grade quartz crystals were found in Zone II.

Asbestos

La Solita-Las Brisas

All asbestos (chrysotile) occurrences in the zone are in IIA. The largest is at La Solita-Las Brisas in plancha e-5, (Plate I), 10 km north of Campamento, and has been known since before 1944. Canadian Johns-Manville Co. Ltd. carried out an exploration and evaluation program from 1952 to 1953, including geologic mapping, ground magnetometer surveys, test pitting and diamond drilling. Later, in 1964, another company, Nicolet Industries Inc., with executive offices in Ambler, Pennsylvania, U.S.A. acquired an interest in the concession with Colombian partners, Asbestos Colombianos Ltda. First-phase exploration drilling was completed in March 1967, proving an estimated 2.5 million tons of rock with recoverable fiber content of 5 percent, mostly Quebec-classification Groups 4 and 5, based on 5 drill-holes aggregating 1,200 m depth (H. Harris, exploration manager, Nicolet Industries Inc., written commun., September 1968). The deposit is designated "Las Brisas" by Nicolet to distinguish it from "La Solita," the name originally applied by Canadian Johns-Manville Co. Ltd. (both names are taken from creeks which drain the asbestos-bearing zone).

In May 1967 a limited airborne magnetometer survey was made over this area and other selected serpentinite targets in the region; however, results of this survey are not known at IMN. The 14 km access road was improved and diamond drilling resumed at Las Brisas in mid-1968. Early in 1969 a total of 11 additional holes had been completed, aggregating 1,800 m depth, of which 330 m were in serpentinite containing about 4 percent of silky to semi-harsh chrysotile fiber, suitable for a broad range of asbestos products (H. Harris, written commun., February 1969), No estimate of the additional proved reserve is available; exploration drilling is continuing.

According to Harris, the Las Brisas body comprises a stockwork of cross-fiber chrysotile veinlets 1 to 20 mm wide in a zone that strikes northwest and dips about 45° SW., in a strongly sheared serpentinite mass of the same strike.

Nicolet Industries, Inc. and its associates, Asbestos Colombianos Ltda. have applied to the Government of Colombia for permission to open a mine and construct a mill to produce 25,000 tons per year of finished fiber, the greater part of which is to be used in asbestos cement products, an industry now dependent upon imported fiber. A small amount of short fiber not marketable in Colombia may be exported (H. Harris, oral commun., June 1969).

Other asbestos prospects. Chrysotile asbestos prospects of lesser potential are known at Las Nieves (Plate I, d-4), and El Búfalo (Plate I, e-3). These are generally similar to Las Brisas but access is poorer and the deposits are more limited in extent and lower in fiber content. Quality, however, is suitable for asbestos cement products. Both were explored by Canadian Johns-Manville Co. Ltd. in 1952-53. The prospects are in isolated serpentinite bodies as shown on Plate I.

Canadian Johns-Manville also explored a fourth prospect designated "La Polca" about 1.5 km north of La Solita-Las Brisas, on the north side of the Río San José. However, this lies within the same serpentinite body as La Solita-Las Brisas and may be considered a continuation of the same deposit.

Other asbestos prospects of small to negligible potential have been reported 8 km due east of Sabanalarga (Plate I, a-8), and 2 km north of Briceño (Plate I, c-5). The Sabanalarga prospects, although apparently very small, contain fiber of fair quality. That at Briceño is merely fibrous antigorite (picrolite) along slickensided surfaces.

Wollastonite

Wollastonite, $CaSiO_3$, has come into prominence in the United States as an industrial mineral since 1949, especially as a ceramic raw material in fired floor and wall tiles, and in the manufacture of rock wool. It is not a rare mineral, but exploitable deposits are scarce. The principal commercial operations are at Willsboro, New York and Blythe, California (Ladoo, 1960).

Geologists of the IMN investigated deposits of wollastonite west and southwest of Maceo (Plate II, c-7), from August to October 1965 by means of large-scale geologic mapping and 5 shallow (20 m avge) diamond drillholes. The program was handicapped by poor core recovery (Néstor Castro, unpub. data, 1966). Similar wollastonite deposits at San José del Nus, a few kilometers south of the drilled area, were exploited sporadically on a small scale for several years prior to 1966. The wollastonite at both sites is of contact-metamorphic origin in irregular lenses and seams in locally quartzose calcite marble roof pendants near the eastern margin of the Antioquian batholith. The drilling indicated a reserve of 16,000 tons of wollastonite-rich rock as seams, mostly less than a meter thick, in quartzitic calcite marble host in an area less than one hectare, on the southwest bank of Quebrada La Calera, 4 km west of Maceo.

Wollastonite at San José del Nus had been used between 1963 and 1966, interchangeably with marble with which it is associated, as decorative chips in cold-process cement-base mosaic or terrazo floor tiles. The quarries have been virtually abandoned since 1966 because the terrazo tile company found it more economical to use marble chips from Amalfi and El Cairo. The wollastonite was never used as a fired ceramic raw material.

The prospects are favorable for locating reserves greater than those indicated by IMN drilling if uses as a ceramic raw material could be developed for the wollastonite near San José and Maceo. No other potentially exploitable sources of wollastonite are known in Colombia.

Andalusite

Andalusite in schists

Andalusite ($Al_2O_3 . SiO_2$), together with its polymorphs, kyanite and sillimanite is used in the manufacture of artificial mullite refractories and electrical procelains. Andalusite of regional metamorphic origin is particularly common in Zone II as sericitized porphyroblasts 0.5 to 1 cm in diameter and 2 or 3 cm long, in quartz-sericite schist in planchas a-1 and a-3, Plate II, in IIB, and in planchas a-4, b-5, b-6, c-3, c-4, e-1, e-2, Plate I, in IIA. Only rarely are the porphyroblasts fresh and not sericitized. Sericitized andalusite is of little economic value.

Placer andalusite at El Bagre

Extensive piles of sand and gravel tailing from gold dredging operations in the Río Nechí at El Bagre in northeastern IIB contain rounded water-worn crystals of relatively fresh andalusite. Less than 1 percent, perhaps less than 0.25 percent, of the tailing is andalusite, but if an economic extraction process could be developed, a large reserve exists disseminated in the millions of tons of dredge tailing along this reach of the Río Nechí.

Exploitability

The present potential domestic market for high-alumina refractory raw materials such as andalusite is estimated to be only a few hundreds of tons annually, far too small to support a mine and beneficiation plant at any of the known deposits, either in metamorphic rocks or in alluvium. Extraction and transportation costs would be too high to allow competition with known high-grade sillimanite and kyanite sources elsewhere in the world. The andalusite deposits of Zone II must be considered as a "potential" resource with little chance of commercial exploitation in the foreseeable future.

Bauxite

Bauxite has been reported in small deposits near Llanos de Cuivá (Plate I, c-8), 80 km by road north of Medellín (Singewald, 1950, p. 90). The most favorable of these was investigated by geologists of IMN with a series of 30 auger holes from 1.5 to 4 m deep (Londoño, unpub. data, 1966). Kaolinitic saprolite 1 to 4 m thick, derived from weathering of the Antioquian batholith, locally contains as much as 15 percent of gibbsite sporadically disseminated as nodules 2 to 20 cm across and as veinlets 0.1 to 1 cm wide. The crude material contains from 17 to 28 percent Al_2O_3 and as much as 68 percent of silica. One sample analyzed by X-ray had an approximate mineralogical composition of 50 percent quartz, 40 percent metahalloysite (?), and 5 percent gibbsite (D. Paetsch, written commun., 1967). Fist-sized nodules of gibbsite may contain as much as 54 percent Al_2O_3. However, the average tenor of gibbsite in the sandy clay saprolite is estimated to be only 5 percent. The low tenor of gibbsite and the thin patchy character of the saprolite mantle preclude economic exploitation.

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70-148

FIGURE 3. GEOLOGIC SKETCHMAP AND RESERVES OF NICKELIFEROUS LATERITE AT URE, DEPT. OF CORDOBA

(after Velasquez, 1969, unpub. data.)

70-148

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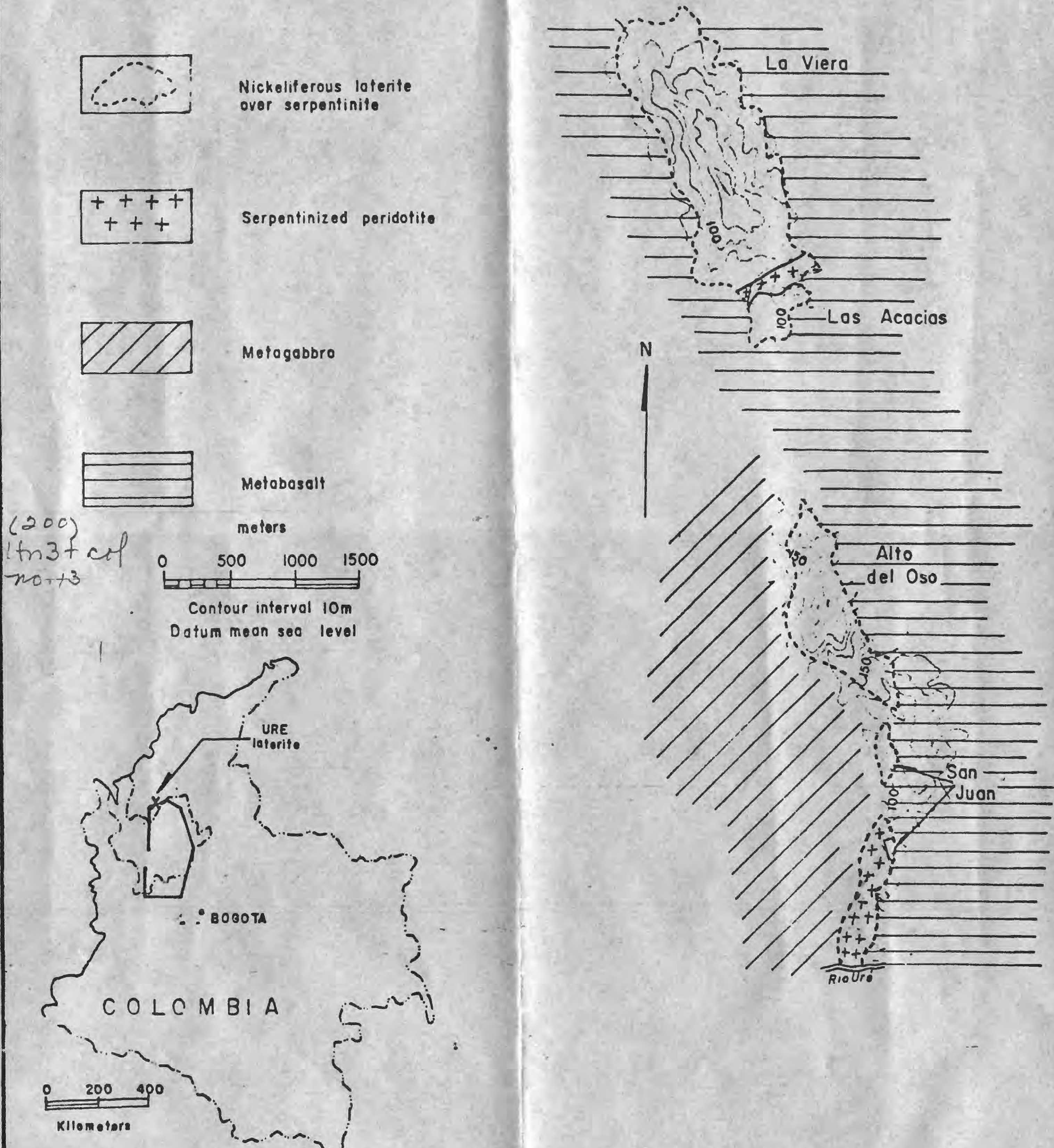

PROBABLE RESERVES

By Orebodies

Name	Area (hectares)	Average depth (meters)	Reserve (metric tons)	Weighted average tenor (percent) Ni	Fe
La Viera	149	5.9	15,482,200	0.78	26.4
Las Acacias	21	6.2	2,278,300	0.925	33.9
Alto del Oso	48	8.8	5,312,000	0.69	30.9
San Juan	6	5.9	578,800	0.88	25.9
Total	224	6.2	23,651,300	0.77	28.05'

By Zones (vertical profile, see fig. 4)

Zone	Approximate average thickness (meters)	Reserve (metric tons)	Weighted average tenor (percent) Ni	Fe
A	2.5	10,422,500	0.43	37.09
B	1.4	5,664,400	1.11	29.47
C	2.3	7,564,400	0.99	14.53
Total	6.2	23,651,300	0.77	28.05