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GEOLOGY AND MINERAL RESOURCES OF CENTRAL ANTIOQUIA AND PART OF CALDAS DEPARTMENT (ZONE IIA), COLOMBIA

By Robert B. Hall
U. S. Geological Survey

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Colombia Instituto Nacional de Investigaciones Geológico-Mineras

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ABSTRACT

This report summarizes the geology of an area of some 6000 square kilometers in the northern part of the Central Cordillera of the Colombian Andes. The area, in north-central Department of Antioquia, was mapped between 1964 and 1968 as part of the Inventario Minero Nacional (IMN) project. Mineral resources are summarized within a larger area, designated as subzone IIA of IMN Zone II, which comprises almost 22,000 sq km, including the area mapped geologically by IMN and additional areas mapped by other agencies.

The oldest formation is a micaceous paragneiss of early Paleozoic or possibly late Precambrian age. A thick geosynclinal sedimentary series accumulated during the Paleozoic Era and became regionally metamorphosed to greenschist (locally amphibolite) facies during the Permain or early Triassic; these schists and gneisses are designated collectively as the Valdivia Group. The Permian(?) orogenic episode included intrusion of concordant syntectonic plutons, mostly of tonalitic composition. Rocks of unequivocal Triassic or Jurassic age are not recognized.

The Cretaceous is well represented by both igneous and sedimentary assemblages. Eugeosynclinal alpine ophiolites comprising submarine basalt flows and numerous intrusions of gabbro and serpentinite are prominent in the Lower Cretaceous, together with flysch composed of marine shale and lesser sandstone and conglomerate. The Upper Cretaceous is represented along the west border of the mapped area by submarine basalt flows and pyroclastic rocks, locally interbedded with fine-grained clastic sedimentary beds, and lenses of dark laminated chert, at least part of which is radiolarian. The Late Cretaceous was marked by an orogenic event that profoundly folded and faulted all rocks, and in the Central Cordillera caused low-grade metamorphism, the overprint of which is hardly observable in pre-Cretaceous rocks elsewhere. The Late Cretaceous orogeny culminated with discordant intrusion of the epizonal tonalitic Antioquian batholith. Displacement along the great Romeral wrench fault may have begun in the Cretaceous.

Plutonism continued into the Cenozoic, exemplified by the hornblende-diorite Sabanalarga pluton. Intermontane basins were filled with molasse derived from the erosion of adjacent highlands; Tertiary sedimentation in marshy areas included organic carboniferous matter subsequently converted to lignite or subbituminous coal. The Sabanalarga fault system originated in the Late Tertiary; intermittent displacement continued on the older wrench faults such as the Romeral. Epeirogenic uplift, which probably began in the Pliocene and continued through the Pleistocene and Holocene, brought on renewed erosion which has sculptured the mountains into their present form.

Mineral resources in subzone IIA are varied but not of outstanding importance. Gold and silver mining, significant in past centuries, is minor today. Ferruginous laterite on serpentinite once considered as a potential source of iron ore is not economically exploitable. IMN has explored nickeliferous laterite at the extreme northwest corner of subzone IIA; this is a potential resource, exploitable only after exhaustion of the larger and richer nickel laterite deposit at Cerro Matoso, farther to the north and outside the boundaries of Zone II. Known deposits of mercury, chromium, manganese, and copper are small, with limited economic potential. Nonmetallic resources include raw materials for cement, including portland cement. Saprolite clay is widely used in making common red brick and tile, still a dominant construction material in all but the most modern multistory buildings. Aggregate materials are varied and abundant. Kaolin of good quality near La Unión is important as a ceramic raw mineral filler. Tertiary subbituminous coal beds are an important energy resource in western subzone IIA, and have a good potential for greater development. 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 to Colombia's thriving asbestos-cement industry which previously had been dependent on imported fiber.

INTRODUCTION

The Inventario Minero Nacional (abbreviated throughout this report as IMN) was a four-year geologic exploration program jointly financed under an agreement between the Ministry of Mines and Petroleum of the Republic of Colombia and the Agency for International Development, U.S. Department of State. The work of IMN, undertaken cooperatively by the IMN and the U. S. Geological Survey, began in September 1964, and continued until the end of 1968, after which a successor organization, the Instituto Nacional de Investigaciones Geológico-Mineras (INGEOMINAS) took over the function of IMN and also of the Servicio Geológico Nacional and the Laboratorio Químico Nacional.

The purpose of IMN was to study and evaluate the mineral resources of four selected zones in Colombia, designated Zones I through IV, that total about 70,000 km^2. One or more geologists of the U. S. Geological Survey worked in each zone as technical advisors. Field geologists and administrative personnel were Colombian and were provided chiefly by the Servicio Geológico Nacional and by the schools of geology of the Universidad Nacional in Bogotá and the Facultad Nacional de Minas in Medellín. Specialists in certain fields such as cartography, geophysics, geochemical analysis, and phosphate rock were provided by the U. S. Geological Survey. The IMN had three directors, the late Dr. Aurelio Lara, and Drs. Dario Suescun G. and Andres Jimeno V. Mr. Earl M. Irving of the U. S. Geological Survey served as Chief U. S. Advisor.

Zone II

Zone II covers about 40,000 km^2 (15,000 mi^2) principally in the Departments of Antioquia and Caldas, although small portions are in the Departments of Córdoba, Risaralda, and Tolima (fig. 1).

Owing to the large size of Zone II and the difficulty of transportation within most of it, the zone was divided arbitrarily by a median north-south line into subequal parts which were studied concurrently but independently. The west part constituted Subzone IIA and the east part Subzone IIB, hereafter referred to in this report simply as IIA and IIB, respectively. Each subzone had its own cadre of field geologists and U. S. Geological Survey technical advisor. Lawrence V. Blade served as technical advisor in IIA until early 1967 when Robert B. Hall took his place. Tomas Feininger served as advisor in IIB throughout the IMN program. This report covers Subzone IIA only.

Scope of this report

Only the geology of quadrangle H-8, and part of H-7, depicted on plate 1, is discussed in detail in this report. Prior to the present program, quadrangle I-8 south of plate 1 was mapped by Gerardo Botero A. and his students (1963) and a 12 to 15 km-wide area adjoining the Río Cauca was mapped by Emil Grosse (1926) in the early 1920's. Quadrangle J-8 was mapped by personnel of the Facultad Nacional de Minas under contract to IMN, concurrently with IMN mapping in quadrangle H-7 and H-8 (pl. 1). IMN geologists also mapped a 15 km-wide strip immediately west of quadrangle J-8 and the northwest quadrant of quadrangle K-8, south of J-8.

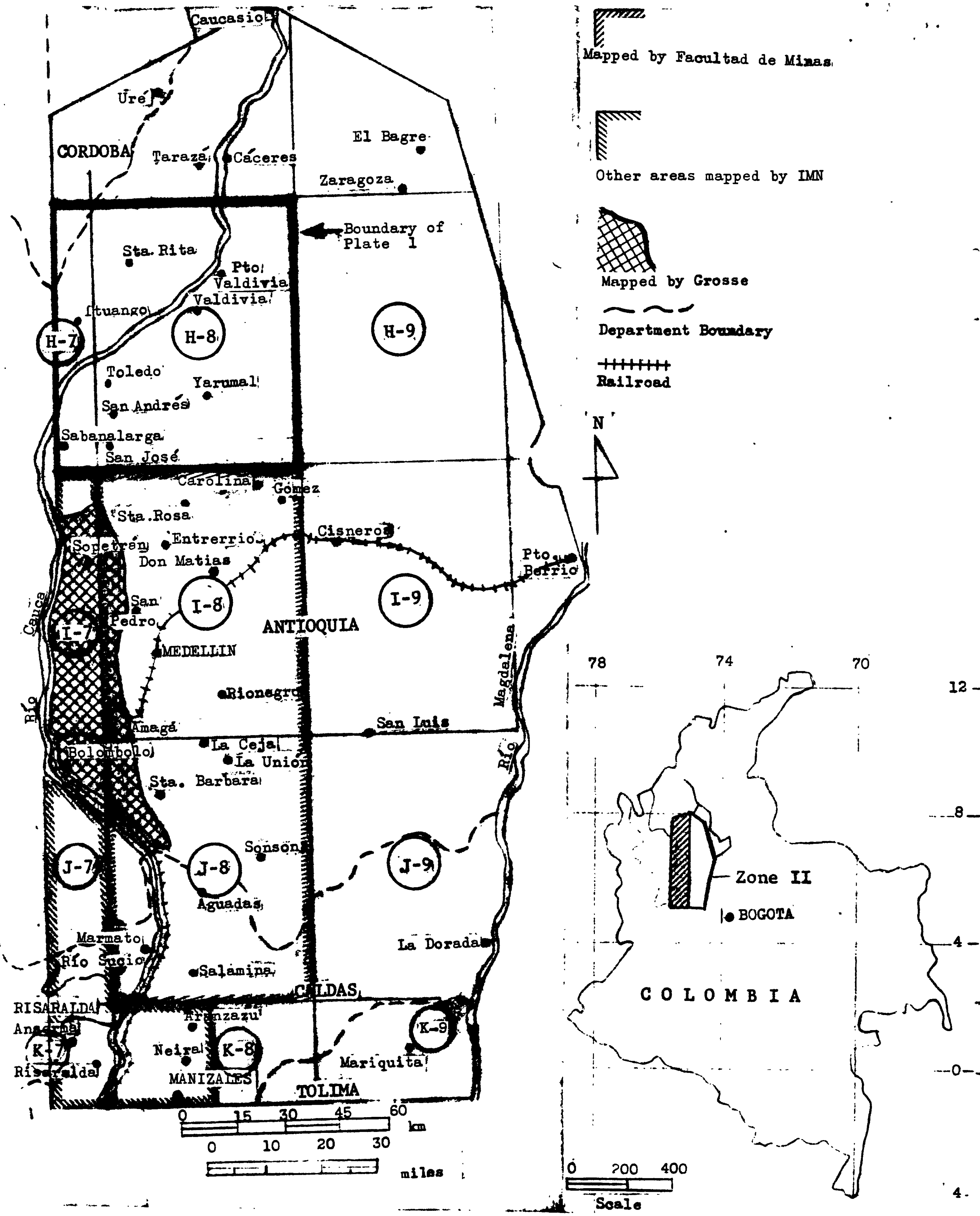

Figure 1. Index map showing location and status of geologic mapping, subzone II A, Colombia.

Although only the geology of plate 1 is discussed in detail, much of the introductory material that follows applies to the entire Subzone IIA.

Physical setting

Subzone IIA is rugged maturely dissected mountain country; slopes commonly are 20° to 40°. Local relief rarely is less than 250 m and exceeds 1000 m in many places. Relatively flat or gently rolling surfaces are found on the Tertiary and Quaternary sediments of the Río Cauca Valley in northmost IIA. Other narrow bands of flatland are formed over alluvial and colluvial deposits in valleys, the largest being in the Valley of Aburra where the city of Medellín is located. High broad surfaces of small local relief are formed on the Antioquian batholith at altitudes above 2000 m, a good example being the Llanos de Cuivá (pl. 1, c-8).[1/] Streams and rivers in the mountains flow through steep-walled canyons from 50 to 1000 m deep; the canyon of the Río Cauca southwest of Puerto Valdivia is more than 1200 m deep (pl. 1, c-3, d-3).

[1/] Reference to specific localities is made by rectangle coordinates on plate 1 as follows: individual "planchas," 10 km north-south by 15 km east-west of the Gauss net of Colombia, are lettered consecutively from left to right, "a" through "e," and numbered from top to bottom, 1 through 8, respectively. Thus for example, Ituango is in a-4 and Yarumal is in d-6.

Climate is equatorial highland or tierra templada type over most of the zone, becoming equatorial lowland humid or tierra caliente type below 500 m, where the mean annual temperature may be close to 28° C. The comparatively little true páramo or tierra fría in IIA is limited mostly to altitudes above 3000 m in the vicinity of Sonsón and Salamina, both in quadrangle J-8. Highlands between 2200 and 2800 m are common, and may be uncomfortably chilly at night. Rainfall and temperature data are given in table 1 for five selected points in IIA.

Virgin forest covered most of the area prior to colonization which began in the 16th century; much of this forest has since been felled. Extensive stands of largely untouched forest are west of the Río Cauca and north of the Antioquian batholith. Bedrock is deeply weathered so that fresh rock is covered by a thick mantle of clayey saprolite and soil. Outcrops are not easy to find and the best exposures generally are in road cuts, on steep slopes, or along the banks of streams and creeks where mechanical erosion has kept pace with chemical decomposition. Thick saprolite on slopes is susceptible to mass-wasting by soil creep or land slides and causes problems in road and building maintenance.

Culture

The largest city in the zone is Medellín, the capital of Antioquia, with a population of more than a million concentrated in the Valley of Aburrá. The second largest city, about one-eight the size of Medellín, is Manizales, capital of the Department of Caldas. Outside Medellín and Manizales the population is much less dense, and hundreds of square kilometers are very sparsely inhabited. Most towns have less than

Table 1.--Rainfall and temperature data for five cities in Subzone IIA.

Station	Elev. (m)	Average annual T (°C)	Average annual rainfall (mm)	Range of annual rainfall (mm)	Years of record
Caucasia	50	28	1681		1950-51, 1954-59, 1961-67
Valdivia	1200	19	2402		1951-53, 1959-1962
Santa Rosa	2640	15	1880		1950-53, 1956-1962
Medellín	1538	21	1350	1001-1722	1942-1967
Sonsón	2530	14	1816	1450-2712	1950-55, 1957-1961

Source: Departamento de Planeación de la Gobernación de Antioquia.

5,000 inhabitants. Except for a few trunk highways, transportation is arduous because roads are sparse or lacking in most outlying districts. Most secondary roads are one-lane, unpaved, and frequently become impassable during rainy periods. The yard-gauge Antioquian Railroad crosses Zone II from Bolombolo on the Río Cauca to Puerto Berrío in IIB on the Río Magdalena, passing through Medellín en route. Some of the larger towns such as Ituango and Santa Rita are served from Medellín by bus and light aircraft. For the campesinos living outside of the larger towns, foot or mule trails are the principal modes of transportation.

Previous investigations

Javier Cisneros (1878, p. 32-35) made the first recorded geologic observations in this region nearly a century ago during the survey of the route for the Antioquian Railroad, but this work is of greater historical than scientific interest. Don Tulio Ospina (1911) reviewed the geology of Antioquia as then known, and attempted to classify the rocks and mineral deposits. Emil Grosse (1926), a German geologist, published a set of detailed 1:50,000-scale colored geologic maps and a comprehensive treatise, still a highly respected reference, on the coal-bearing Tertiary basin east of the Río Cauca, near the west boundary of IIA (fig. 1). In 1936, Juan de la Cruz Posada published the first geologic map in color of Antioquia at a scale of 1:2,000,000. In 1946, the Servicio Geológico Nacional prepared ozalid copies of a geologic map of Antioquia depicting 11 rock units. Prof. Gerardo Botero A. and colleagues made the first comprehensive study of a large area (quadrangle I-8) in IIA (Botero A., 1963); the geologic map alone was republished at a scale of 1:200,000 (IMN, 1965). Other investigations both prior and subsequent to Botero's work have been limited mainly to summary descriptions of mineral deposits or prospects.

Present study

The primary objective of the IMN project was to locate and evaluate mineral deposits, but it was evident that the best hope for discovering new deposits lay in systematic fairly detailed geologic mapping, because the country had already been prospected, mainly for gold, for several centuries. Field work began in early 1965 under the direction of Zone Chief Hernán Vásquez and USGS advisor Lawrence V. Blade, and was completed in 1968 under the supervision of the present authors. The resulting geologic map (pl. 1) represents the combined efforts of 26 individual geologists, all but two of whom are Colombian.

Field and laboratory methods

Geologic observations were made mainly in stream beds or along trails and ridge crests where exposures were better and traverses could be made without excessive difficulty in the steep terrane, and plotted on 1:25,000-scale topographic maps of Instituto Geografico Agustín Codazzi, Bogotá. High-altitude 1:60,000-scale aerial photographs were used throughout the mapping and especially when topographic maps were not available for certain areas. Taissir Kassem, photogeologist, prepared a photointerpretive map of the zone, and this proved to be very helpful when combined with the field geologists' mapping.

Specimens collected in the field were examined under binocular microscopes in the Medellín office. Selected specimens were sent to Bogotá for thin sectioning.

Detailed studies, including large-scale geologic mapping and, in two cases, diamond core drilling, were made of certain selected mineral deposits; the results of these studies are given in the chapter on mineral resources.

The geochemical analytical facilities in Bogotá, including the atomic absorption spectrometer and emission spectrograph, were not installed in time to be of service.

Acknowledgments

The writers are indebted to many persons both in and outside the IMN and INGEOMINAS organizations. Much of the field work would not have been possible without the generous cooperation of finca owners and campesinos too numerous to list here. Thin sections were cut in in Bogotá, under the direction of Sr. Humberto Villegas. Three K-Ar radiometric ages were determined at the Denver laboratories of the USGS by Richard F. Marvin and coworkers. Wet-chemical analyses and fire assays for gold and silver were made in the laboratory in Medellín under the successive direction of Drs. Guillermo Serna, Pedro Hernandez, and Leonardo Restrepo. Chemist Jorge Vásquez made many analyses of nickeliferous laterite samples. Taissir Kassem's photointerpretations greatly aided the field mapping. Some of the staff geologists helped in data compilation; Humberto Gonzáles and Antonio Erazo helped with thin section studies, including point-count modal analyses; Hernando Lozano, Eduardo Alvarez, Francisco Mosquera, and Darío Velásquez assisted in many ways in the course of the work.

The following individuals and companies provided historical, analytical, operational, or production data: Mr. Hubert vom Staufen, Medellín mining consultant; Mr. Dietrich Paetsch and Locería Colombiana, S. A.; Sr. Antonio Rivera, Mr. Arthur Thompson, and Cía. Minera Nueva Esperanza, S. A.; Mina La Bramadora; Sr. Humberto Aguilar and Triturados Impalpables, S. A.; Sr. Bernardo Arbeláez and Talcos Medellín; Sr. J. Gonzalo Escobar and Erécos S. A.; Fabrica de Cal Super Nieve; Srs. Felix Arena, Guillermo Jiminez, and Cementos Caldas, S. A.; Dr. Ricardo Vásquez and Cía de Cementos El Cairo, S, A.; Dr. Alvaro Londoño and Cía. de Cementos Argos, S. A.; Dr. Hernán Garcés and Cristalería Peldar, S. A.; Dr. Alfonso Chinchilla and Industrias Hullera, S. A.; Sr. Guillermo Mora; Sr. Arturo Sanchez; Piedra Esmeralda de Colombia, Ltda.; Sr. Alfredo Ramirez and Planta Municipal de Mezclas Asfálticos; Srs. Alvaro Villa, Alfredo Cardona, and Fundición Técnica, S, A.; Sr. Alejandro Duque and Fabrica Furesa; Sr. J. Vollmost and Empresa Siderúrgica, S. A.; Fundición Esteban Alvarez y Cía; Sr. Sergio Gutiérrez and Fundiciones y Ensayes de J. Gutiérrez, Ltda.; Mr. Herbert I. Harris, Sr. Bernardo Alzate, and Asbestos Colombianos, Ltda.; Sr. José Marquez and Minas Nacionales de Marmato.

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Special thanks are due geologists L. V. Blade and Tomas Feininger, our USGS colleagues on the IMN project. Blade, the first USGS advisor in Subzone IIA, was instrumental in getting field work started during the critical early months of the project. We are indebted to Feininger for much of the introductory material used here, for generous help with petrographic problems, and for many suggestions which improved the manuscript.

GEOLOGY OF SUBZONE IIA

The index map (fig. 1) shows the status of geologic mapping in Subzone IIA including areas mapped by agencies other than IMN. The principal aim of the IMN program was the appraisal of mineral resources, and purely scientific topics were not studied in detail.

Paleozoic metasedimentary rocks

Micaceous gneiss

Micaceous gneiss underlies an area of about 150 km^2 in the north-central part of plate 1, west of the Romeral fault. Most exposures are limited to the banks of streams. The area underlain by the gneiss is rolling; relief is moderate, seldom greater than 100 m. Boundaries with adjacent units are covered and obscure, but the Valdivia Group schists, generally of lower metamorphic grade, apparently unconformably overlie the micaceous gneiss on the west. The contact with intrusive metatonalite, which engulfs large blocks of the gneiss, is highly irregular and was mapped very approximately because of numerous inclusions of gneiss in the metatonalite and abundant tongues or apophyses of metatonalite in the gneiss. The northeast-striking Romeral fault forms the southeast boundary of both gneiss and metatonalite in the north half of the area of plate 1. Bodies of amphibolite, most of uncertain origin, are spatially associated with the gneiss. Those amphibolites of mafic igneous origin are intrusive into, and therefore younger than the gneiss, but some para-amphibolite with the gneiss may be contemporaneous.

Megascopically, the rock is a gray medium-grained, allotriomorphic-granular, thinly layered quartz-feldspar-mica gneiss. Garnet and flakes of graphite can be seen with a hand lens. Composition ranges locally from quartzose to micaceous, and this variation is reflected on a minor scale by individual laminae in hand specimens.

Petrography.--Modal composition falls generally within the following range:

Mineral	Range (percent)
Quartz	30 to 60
Plagioclase (An_{20} to An_{40})	8 to 40
Biotite	7 to 23
Muscovite or sericite	4 to 20
Chlorite (mostly after biotite)	traces to 14
Epidote (mostly saussurite)	1 to 12
Garnet (almandine?)	trace to 10
Graphite	trace to 3
Microcline	0 to 3
Orthoclase	0 to 2
Andalusite	0 to 2
Magnetite-ilmenite	trace to 1.5

Mineral	Range (percent)
Pyrite	trace to 1
Chloritoid	0 to 1
Sillimanite	0 to 8
Tourmaline	0 to 0.5
Rutile (needles in quartz)	trace
Zircon	trace
Apatite	0 to trace
Sphene	0 to trace

Individual layers range between impure quartzite and mica schist and the bulk modal composition of the major mineral components probably falls about midway between the extremes shown in the above ranges. Mineral components as seen under the microscope are briefly described below.

The quartz is present in strained anhedra and granoblastic mosaics with sutured contacts and commonly has tiny rutile inclusions. Plagioclase is oligoclase or andesine (An_{20} to An_{40}), commonly clouded with sericite or saussurite. Microcline and orthoclase are locally prominent but typically are accessories in the amount of 2 or 3 percent only, and are absent in some specimens. Biotite and muscovite are subequal, the biotite being incipiently to completely chloritized. Zircons in biotite, some in crystals 0.25 mm long, are surrounded by pleochroic haloes. Partly chloritized garnets 2 to 12 mm in diameter, and flakes of graphite 1 to 3 mm long, are characteristic accessories and are present in minor amounts. Sillimanite is so abundant in a few specimens as to be almost an essential component, although it is commonly partially retrograded to sericite or muscovite. Tourmaline in crystals 0.2 to 0.4 mm long, yellow to yellowish-brown in thin section (dravite?), is a fairly common accessory.

Age.--The micaceous gneiss is the oldest unit recognized in the area (pl. 1). The metatonalite that intrudes both the micaceous gneiss and the adjoining Valdivia Group schists has been tentatively assigned a Late Permian age, based on two K-Ar analyses. The metamorphic grade of the micaceous gneiss is higher than that of the Valdivia Group schists, which, for reasons offered later, are assigned a Paleozoic age. Higher metamorphic grade implies deeper burial and greater age; therefore the micaceous gneiss probably is at least early Paleozoic (Cambrian? to Silurian?), and a Precambrian age cannot be ruled out.

Valdivia Group

The name Valdivia Group is given to an extensive suite of metasedimentary rocks that underlies more than half the area (6,120 km^2) shown on plate 1. The Valdivia Group comprises three units of schist, and three of gneiss, the latter distinguished on the basis of somewhat arbitrary criteria.

Schistose rocks predominate by a factor of about 19 to 1 whereas the gneisses constitute but 5 percent of the area mapped as Valdivia Group. The three schist units shown on plate 1 are: 1) mainly chlorite-actinolite schist; 2) mainly quartz-sericite schist; and 3) mixtures of these two types. Contacts between the units have been drawn rather arbitrarily, based on the individual judgment of at least

10 different geologists mapping in different areas, and therefore these boundaries are highly tentative. Some chlorite-actinolite schist layers are almost invariably intercalated locally in the areas mapped as quartz-sericite schist, and vice versa. Both kinds of schist are thinly laminated and break into thin platy fragments. For convenience, the name "schist" is used broadly to include not only true schists but thinly laminated fine-grained quartzite, silky-lustered phyllite, and argillite. Schistosity generally is concordant with original sedimentary bedding.

Gneisses of the Valdivia Group are subdivided on the basis of compositional and textural variations into three units as follows: 1) feldspathic gneiss exposed in a large wedge-shaped body between Toledo (b-6) and the west edge of b-3, and minor bodies of similar gneiss in c-2, c-3, c-4; 2) "lenticular" or augen gneiss in elongate bodies east and northeast of the large wedge of feldspathic gneiss (b-1, b-2, b-3, b-4, b-5, b-6); and 3) cataclastic gneiss in a narrow band south of Ituango (a-4), extending 23 km from a-4 into a-7. The subdivisions are somewhat arbitrary, and parts of any one unit may be locally indistinguishable from parts of others.

The schists are described first because of their greater abundance in the Valdivia Group, but there is evidence that the gneisses, especially the feldspathic unit, are of higher metamorphic grade and probably older than most of the schists.

Schist

Quartz-sericite schist.--This rock generally crops out as steep-sided banks of very dark gray to bluish-black or black, thinly layered, highly fractured schist or phyllite. The schist is friable and often breaks into thin platey slabs. The typical schist is composed of 50 to 85 percent quartz as fine-grained sutured mosaics in laminae 1 to 3 mm thick, and 10 to 25 percent of interlammelar micas including sericite, and biotite, and chlorite. Graphite dust is a common accessory, giving rise to the convenient field name "esquisto negro" (black schist). Other accessories include oligoclase or andesine, epidote, magnetite or ilmenite, commonly with leucoxene or sphene coronas, and zircon. Concordant lenses of milky quartz from a few centimeters to a few meters long are common in these schists, and probably represent metamorphic segregations. Abundant porphyroblasts 1 to 3 cm long of andalusite, partly or wholly sericitized, are strikingly conspicuous in some areas. As stated previously, intercalated chlorite-actinolite schist is present locally in most areas mapped as quartz-sericite schist, just as layers of the latter are commonly intercalated in the chlorite-actinolite schist.

Chlorite-actinolite schist.--The chlorite-actinolite schist is chiefly a typical greenschist. It is dark, medium, or light grayish green, fine grained, and finely laminated. The outward appearance of this rock in outcrops and roadcuts may be very similar to that of the quartz-sericite schist, but close examination generally reveals a greenish hue in contrast to the gray, black, or bluish black of the quartz-sericite schist. Films of black manganese oxide that commonly coat fractures in weathered exposures also help to distinguish chlorite-actinolite schist from quartz-sericite schist which does not usually show manganese oxide stain so prominently. Furthermore, the difference in competence is noteworthy. Fresh chlorite-actinolite schist is hard and less friable than the quartz-sericite variety; it is used as a decorative building stone, and locally for roadmetal. The quartz-sericite schist, because of brittleness of quartz laminae and ready cleavability along mica laminae lubricated by graphite films, is weaker than the greenschist and more prone to slide on steep slopes.

Laminae 0.5 to 2 mm thick composed of chlorite flakes and actinolite needles are separated by laminae of similar thickness composed of albite and minor epidote. Some laminae rich in yellowish-green epidote presumably have been formed by metamorphic segregation. Sphene and magnetite grains 0.2 to 0.8 mm in diameter are ubiquitous accessories and constitute from 1 to 4 percent of the rock. Sparsely disseminated pyrite is common. Secondary calcite veinlets 1 to 3 mm thick are more common in the chlorite-actinolite than in the quartz-sericite schists. Locally beds of the greenschist contain abundant porphyroblasts of actinolite 1 to 3 mm long, resembling grains of wheat, that impart a curious knotted texture. One especially notable band of this "fructschiefer" is 10 m wide and 1000 m long northwest of Santa Rita, near the western edge of b-2.

Intercalated schists.--Each of the areas mapped as quartz-sericite or chlorite-actinolite schist contain abundant intercalations of the other, and have been differentiated by the field geologists on the basis of the dominant rock type, which generally is more than 80 percent.

Large areas of IIA contain both types intercalated in subequal proportions, on a scale ranging from centimeters to hundreds of meters. These areas are mapped as "intercalated schists," and the preceding descriptions of the two main lithologic types apply equally to each rock type in this unit.

Intercalated marble.--Although quantitatively less than one percent of the Valdivia Group in IIA, and too small to be mapped on the scale of plate 1, layers and lenses 1 to 2 m thick of medium- to coarse-grained gray calcite marble are intercalated sporadically in both the quartz-sericite and the chlorite-actinolite schists. They probably were organic limestones. To the south and outside the area mapped, two large marble lenses, possibly bioherms(?), are enclosed in quartz-sericite schist; one is near Santa Bárbara in quadrangle J-8, the other near Neira in quadrangle K-8. The rare marble layers in the area of plate 1 have little economic significance.

Gneiss

Feldspathic gneiss.--The main body of feldspathic gneiss extends from south of Toledo (b-6) to the northwest corner of b-3. Its maximum width of 9 km is at the latitude of Ituango, and it narrows to a long neck 600 to 800 m across to the north. Relations with adjacent rock units are obscure because contacts are covered; a fault along the west boundary of the gneiss is inferred from photointerpretation (F. Mosquera, INGEOMINAS, oral commun., 1970). Schists seem to overlie the gneiss more or less conformably on the east. Smaller lenses of similar gneiss crop out near the east margin of b-2, b-3, and b-4. For convenience, these smaller lenses are considered part of the same rock unit as the large lens, but again, the relation with adjacent schist is not clear.

The typical gneiss is gray, irregularly layered, medium- to coarse-grained allotriomorphic; the light-colored layers are composed principally of feldspar and quartz, and darker bands or layers contain relatively more abundant biotite and chlorite. The various gneissic layers or bands differ little in the kinds of minerals present, but differ in the relative proportions of dark to light minerals. The gneiss does not everywhere display layering; some parts merely show a faint gneissic lineation or north-south preferred orientation of crystals. Grain size increases from medium in the eastern part of the body to coarse in the western part. Oligoclase or albite feldspar dominates in the bulk composition, but locally quartz is equal to, or slightly more abundant than feldspar. Muscovite, sericite, and biotite are the other components, but are invariably subordinate to both feldspar and quartz except in thin schistose laminae. Oligoclase generally is lightly saussuritized and sericitized, quartz exhibits wavy extinction and fracturing, and biotite is incipiently to strongly chloritized. The gneiss, however, is more notable for its accessories than for its essential mineral components. The accessories include epidote, microcline, tourmaline, chloritoid, cordierite, andalusite, rare sillimanite, zircon, sphene, apatite, almandine garnet, graphite, pyrite, and magnetite (although the paucity of opaques in most of the gneiss is noteworthy). The presence, even if only local, of cordierite and sillimanite indicates amphibolite-facies metamorphism, distinctly higher than the greenschist facies which characterizes the bulk of the Valdivia Group. The muscovite in some thin sections has a fibrous form which suggests that it is pseudomorphous after sillimanite, although unaltered sillimanite was identified in but few specimens. This gneiss therefore may be dimetamorphic, in that a second retrograde greenschist-facies metamorphism followed the original prograde metamorphism to amphibolite facies. Chloritization of biotite may have resulted from the same event.

Irregular lenses of albite-quartz-muscovite pegmatite near the western edge of the main gneiss body (eastern margin of a-5), 10 km southeast of Ituango, are potential sources of ceramic feldspar. These pegmatites may be a product of metamorphic differentiation in which pegmatite "juices" were generated and squeezed out of the host gneiss during metamorphism, to be injected at great depth along shear fractures or similar zones of weakness in the gneiss. The feldspathic unit is interpreted as a basal member of the Valdivia Group that was more deeply buried and perhaps subjected to greater heat and pressure during regional metamorphism.

Augen gneiss.--The augen gneiss forms two massive lenses. The larger is 1 to 3 km wide and 24 km long, located west of Santa Rita (b-2). It extends from the southeast corner of b-1 southward to the south edge of b-3. The smaller body has the form of an elongate band 300 to 1000 m wide and about 22 km long, extending from a point 2 km southeast of Toledo (b-6) northward to the east-central part of b-4,, 15 km east of Ituango.

In outcrop the rock resembles a cataclasized pebble conglomerate. Although a large part of the big lens west of Santa Rita lacks augen, elsewhere the typical gneiss exhibits a well developed flaser structure with phacoids or augen, 1 to 4 cm long, of coarsely granular plagioclase and quartz megacrysts separated by gnarly laminae of fine-grained feldspar, quartz, sericite, and chlorite. Feldspar is mostly albite or oligoclase but some specimens contain microcline. Accessory components include cordierite(?), chloritoid, epidote, sparse sphene, garnet and calcite; opaque minerals include magnetite and pyrite. Cataclasis is strongly developed, as shown by bent plagioclase twinning and deformed and heavily strained quartz grains. Locally, the gneiss is highly quartzose, approaching an impure quartzite.

Sillimanite is rare, but some fibrous muscovite-sericite aggregates appear to be pseudomorphous after sillimanite, possibly retrogressive from amphibolite facies. Field relations suggest that the augen gneiss lenses are interbedded members within the enormously thick Valdivia Group schist sequence, and originally may have been arkosic pebble conglomerate or similar coarse-grained arenitic sediments of a shallow littoral marine facies, in contrast to the fine-grained sediments that became schist. Grade of metamorphism is greenschist facies, but the rock may be dimetamorphic.

Cataclastic gneiss south of Ituango.--The term "cataclastic" is structural rather than stratigraphic or lithologic, but is used to designate this unit because cataclasis is the most prominent characteristic. The gneiss forms a belt 23 km long and 250 to 600 m wide from a point 8 km north of Sabanalarga (a-8), northward to a point 4 km southwest of Ituango (a-4). The gneiss belt is bounded on the west by chlorite-actinolite greenschist of the Valdivia Group, and on the east by hornblende diorite of the Sabanalarga pluton, although the contact on the west is faulted. The gneiss may be an interbedded member in the greenschist, but this is not proven. The rock is streaked dark gray and rather friable in sparse and poor exposures. Strong shear cataclasis appears to have been superimposed in regional metamorphic effects. Contacts are covered, but faults may lie along both sides of this linear body as well as within it, as in north a-6. The character of the pre-cataclasis rock is unclear, but it may have been similar lithologically to the augen gneiss previously described.

Under the microscope the rock has an allotriomorphic medium-grained texture. Quartz is the dominant component, occurring as anhedral megacrysts that are highly strained; lines of tiny closely spaced inclusions are tentatively identified as Boehm lamallae. The quartz megacrysts are in a fine-grained greenish-gray mylonite or micro-crush-breccia mosaic of plagioclase, epidote, and lesser muscovite, chlorite, sericite, and very sparse magnetite.

Origin of the Valdivia Group

Schists.--The quartz-sericite schist may have been derived from silt-sized clastic quartz grains, or possibly from chemically precipitated colloidal silica gel films, deposited with lesser amounts of clayey material that formed the micaceous laminae during regional metamorphism. The chlorite-actinolite schist may have been derived from volcanic ash deposited subaqueously during intermittent volcanism. It is instructive to review Nelson's comments (1957, p. 23-24) on the Cajamarca Group (in Department of Tolima south of Zone II), which is believed correlative with the Valdivia Group: "For a number of rocks, such as graphite schists, quartz-phyllites, quartzites, the original environment is obvious: they were deposited as an argillaceous or fine sandy facies in a marine basin under geosynclinal circumstances. Fossils have not been found, nor can they be expected to be found, owing to the metamorphic state of these sediments. The variable graphite content is perhaps the only organic relic. Less unequivocal is the origin of the greenschists and amphibolites. Their mineralogical composition cannot result from the metamorphism of argillaceous or fine sandy sediments, in view of their low content of silica and their high content of calcium and magnesia. Within the domain of sedimentary rocks only a dolomitic marl would correspond to the composition of the major part of the greenschists. It is not very probable that this rather scarce class of sediment should have formed so many layers with such constant repetition as to correspond with the actual successive layers of the greenschists in question. Chemical analyses show remarkable similarity in composition between the greenschists and amphibolities on the one hand and diabases on the other hand... This chemical similarity makes an igneous origin of the greenschists and amphibolites very probable. But we need not necessarily think only of volcanic flows of basic composition in order to explain the origin of these rocks. Volcanic tuffs produced during eruptions would answer the observed composition as well..; transitions between greenschists and other rocks of sedimentary origin... are explained easily in this way. During an eruptive phase the pyroclastic products dominated strongly over the normal sedimentation products in wide areas. When volcanic activity decreased, the normal sedimentation products again became dominant. It is obvious that according to the prevailing facies at the moment of eruption, all kinds of mixed sediments may be found... There are still other indications that point toward a tuffaceous origin. It seems doubtful whether metamorphism of a rather low grade as expressed by the mineral composition epidote-actinolite-chlorite-albite would have been able to destroy so completely every vestige of the igneous fabric and mineral composition of real diabase flows."

Nelson's concept seems valid for the Valdivia Group as well as the Cajamarca. One possible objection is that mafic tuffs of a composition that would yield the greenschists under low-grade metamorphism are rather rare. It may be speculated that the greenschists were formed by the metamorphism of submarine basalt flows, but it is difficult to explain the intimate intercalations of greenschists with quartz-sericite laminae, in some places measured in millimeters, by this hypothesis. The fine rhythmic laminations are best explained by Nelson's concept. Moreover, the argument is very strong that low-grade metamorphism would not be likely to destroy totally an original igneous texture everywhere within the enormously thick Valdivia Group. Nowhere in IIA do greenschists of the Valdivia Group preserve relics characteristic of massive basalt. On the contrary, the fine sedimentary laminae and intimately intercalated quartz-sericite schists of indisputable sedimentary origin are universal characteristics.

The clastic sediments that formed the quartz-sericite schist and the pyroclastic dust or ash were deposited in a deep trough. The wide extent, the thinly laminated bedding, fine-grained texture, and remarkably uniform composition of individual layers suggest deposition in a large basin of deep water. The graphite and pyrite suggest that deposition took place in anaerobic conditions.

Gneiss.--The coarse-textured paragneiss may have been formed from sedimentary materials of coarser grain than the material that formed the schists. The original sediment may have been polymict pebble conglomerate, arkose and arkosic sandstone, and graywacke deposited during intervals of rapid uplift and erosion of the source rocks, and in shallower parts of the basin nearer to the source. Some may have been beach deposits. Depth of the basin must have changed from place to place during the long history of the geosyncline.

Age and correlation

The age of the Valdivia Group, like that of most pre-Cretaceous metamorphic rocks in Zone II, is uncertain. A Paleozoic age is assigned here, based partly on field relations with other units, and partly on correlation with similar rocks in localities mapped by others south of the area of plate 1.

A syntectonic intrusive tonalite (now metatonalite) pluton of batholithic dimensions covers an area of 600 km^2 in the north-central part of plate 1, especially in c-1, c-2, c-3, c-4, d-1, and d-2. This intrusive has been assigned a Late Permian age based on K-Ar age determination of biotite (see "Igneous rocks"). Although contact relations are unclear because of poor exposures and cover, it is the concensus of the field geologists that the tonalite pluton intrudes the Valdivia Group, clear evidence of a pre-Permian age for the latter.

Grosse (1926, p. 20) considered rocks correlative with the Valdivia Group in the Antioquia area mapped by him as of Precambrian age. He quotes Prof. Steinmann who describes schistose rocks in Peru as unconformably overlain by fossiliferous Silurian beds, and this evidently influenced Grosse's decision to assign a Precambrian age to schists near the western margin of ILA.

Nelson (1957) favors a Paleozoic age for the Cajamarca Group which is lithologically similar to and here held to be correlative with the Valdivia Group. He says, "We consider a Paleozoic age as the most probable in view of stratigraphic position below not-metamorphic fossiliferous limestone of Triassic age, and in view of the finding of graptolites in a zone of lower metamorphism north of the area considered..." (Nelson, 1957, p. 14). "The age of the Cajamarca Group has not been established by means of direct paleotological evidence. This Group was assigned to the Paleozoic on account of its stratigraphic position below the fossiliferous Payande limestone of Upper Triassic age. Furthermore, graptolites have been found near Puerto Berrío and they indicate the presence of Ordovician in the Central Cordillera." (Nelson, 1957, p. 58).

A granodiorite stock which yielded a K-Ar biotite age of 215 ± 7 m.y. (Pérez A., 1967, p. 30) intrudes Valdivia Group schists near Amagá 20 km southwest of Medellín. This is clear evidence of a pre-Triassic age for the schists. The Ayurá-Montebello Group of quadrangle I-8 (Botero A., 1963, p. 55) was tentatively assigned a Paleozoic age (Botero A., p. 62-65); it can be correlated with the Valdivia Group of quadrangle H-8 and also with the Cajamarca Group that crops out some 150 km south of I-8. The present authors concur with Nelson and Botero A. in the opinion that this assemblage of metasediments was probably deposited during the Paleozoic era, although a more precise age is still undetermined.

Thickness

Total stratigraphic thickness of the Valdivia Group is not known, nor likely to be determined easily, because of complex folds and faults and lack of recognizable key beds. The thickness is at least 5 km and probably more. Nelson (1962, p. 193) has suggested a possible thickness of 13,000 m for the Cajamarca Group, and this figure seems not unreasonable for the Valdivia Group as well.

Kay (1955, p. 672-674) has tabulated the rates of accumulation of sediment (expressed as indurated rock) in 17 eugeosynclines, mainly in North America, ranging in age from Ordovician to Cretaceous. The estimated rates of accumulation range between 120 and 750 meters per million years, and average about 267 m per million years. Assuming an average accumulation rate (solid rock) of 260 m per million years, the time span represented by 13,000 m of Valdivia Group sediments could be as little as 50 million years, assuming that sedimentation was continuous and constant.

Cretaceous sedimentary rocks

Sedimentary rocks of Triassic and Jurassic age are unknown within the area shown on plate 1, although it is possible that some of the rocks described below as of Early Cretaceous age may be older than that.

San Pablo Formation

The Río San Pablo (e-8, e-6) is 22 km long and flows northward in a fairly straight canyon. The valley of Río San Pablo is coextensive with an elongated belt of quartzitic sandstone, argillite, phyllite, and conglomerate of the San Pablo Formation (pl. 1). This belt of clastic rocks ranges in width between 500 and 2000 meters; it is 30 km long, bounded on both sides by Cretaceous greenstones at its southern end and by Paleozoic greenschist at its northern end. The San Pablo beds strike north and in general dip steeply to the west. Total stratigraphic thickness is unknown but is estimated roughly at 1000 m, thinning at the northern end of the belt to 70 m.

Two facies are recognized in the San Pablo Formation:

1. Medium- to fine-grained quartzitic sandstone, argillite, and phyllite.
2. Conglomerates, both oligomictic and polymictic, with interbedded quartzitic sandstone.

Sandstone-argillite-phyllite facies.--This facies makes up the greater part of the San Pablo Formation. Fresh surfaces are dark gray, weathering to light gray or yellowish-brown. Some of the argillaceous beds weather to a reddish-violet hue. Sandstones are quartzitic, medium- to fine-grained, massive, with dark-gray argillaceous partings. The microscope reveals wavy extinction in many of the quartz clasts; accessory minerals are pale-green chlorite, albite, sericite, sparse tiny rounded grains of zircon, and magnetite. Pelitic beds, which range from thin to massive, are argillitic or phyllitic and have a satiny luster on bedding planes. The fineness of grain limits microscopic determinations, but recognizable components include silt-sized quartz clasts, some with wavy extinction, and albite, chlorite, sericite, and laminae of graphitic material that mark partings along bedding planes. The pelitic layers differ little from the arenaceous except for the finer grain size and higher proportion of organic pigment. Near the southern end of the belt, calcareous or marly beds crop out in the sequence. The beds of differing composition are repeated in a rudely rhythmic pattern. Argillitic to phyllitic character of the pelitic beds indicates incipient regional metamorphism of lowermost greenschist facies. The restricted outcrop belt of the San Pablo is a remnant of a formerly more widespread formation.

Conglomerate facies.--Coarse-grained quartzitic sandstones and conglomerate layers separated by intercalated phyllite or argillite are included in the conglomerate facies, which is more localized than the facies described above. Both polymictic and oligomictic conglomerate beds are present. Oligomictic pebble conglomerates form layers as much as 3 m in thickness at the confluence of Quebrada Delgaditas and the Río San Pablo (e-7). They are composed of rounded to subrounded pebbles and cobbles of gray to milky quartz in a coarse quartzitic sandstone matrix. Polymictic conglomerate layers are more common than oligomictic, and are composed of angular to well-rounded pebbles, cobbles, and rare boulders of quartz and quartzite, metagabbro, and greenstone in a well-indurated coarse graywacke matrix. Color is dark gray to greenish-gray, weathering to dirty brown. The polymictic layers appear more variegated than the oligomictic layers.

Relation to adjoining rock units.--At the southern end of the belt, near Guadalupe, beds of the sandstone-argillite-phyllite facies are in contact with the Antioquian tonalite batholith of Late Cretaceous age, and have been contact-metamorphosed to hornfels. Marly beds have been altered locally to skarn and garnet, wollastonite, and minor magnetite. Clearly the San Pablo is pre-batholith. At the north end of the San Pablo belt the contact with older greenschists of the Valdivia Group is evidently concordant. No sign of faulting has been observed. In the Quebrada San Vicente (e-7), the contact with greenstone (metabasalt) seems to be gradational; basalt flows 4 to 10 m thick are intercalated between sedimentary layers of the San Pablo Formation. The base of at least one flow contains a flow breccia with cobble-sized inclusions of sedimentary rock in a basalt matrix.

Origin and age.--Composition of the San Pablo, as well as its rhythmic bedding, suggest kinship with "flysch" facies in a geosynclinal depositional environment. The finer-grained materials presumably were deposited in fairly deep calm waters, whereas coarser materials, notably the graywacke conglomerates, represent detritus formed during periods of more intense erosion, transported rapidly for relatively short distances, and deposited in a near-shore environment. No fossils have been found, but the San Pablo is older than the Late Cretaceous Antioquian batholith. The intertonguing of the San Pablo with the greenstone sequence suggests contemporaneity of the sediments and basalts. The age of the greenstones also is unknown, although certainly Mesozoic, pre-batholith. The San Pablo is here assigned to the Early Cretaceous. No fossils younger than Albian are known in the Cretaceous rocks of IIB east of the San Pablo Formation. The La Soledad Formation, described below, contains fossils of early Albian age, and it is almost certain that the San Pablo is older than La Soledad, because the San Pablo contains intercalated basalt flows correlative with the adjoining greenstone belt, whereas the La Soledad sediments appear to have been deposited after the greenstone and are down-faulted against it (pl. 1, sec. B-B).

La Soledad Formation

The La Soledad Formation comprises a narrow north-striking belt of sedimentary rocks near the eastern margin of the area of plate 1. The formation is named after Quebrada La Soledad, 12 km northeast of

Campamento, where good exposures occur. Width of the belt ranges from 800 to 1800 m. The beds dip predominantly westward. Three facies are recognized: arenite, argillite-shale, and conglomerate.

Arenite facies.--The arenite facies is a basal unit forming a 500 m-wide belt along the east side of the formation for virtually its entire length. Bedding ranges from thin to massive, grain-size from fine to coarse, and color from light gray to dark greenish-gray. Most clastic grains are angular, composed predominantly of quartz, accessory plagioclase, and sparse detrital zircon in a silty chlorite-sericite matrix with carbonaceous pigment. Thin-bedded dark-gray argillite and thin-bedded light-gray to green cherty shale and porcelanite layers are interlayered locally. The cherty layers contain radiolarian remains, but are so poorly preserved as to be unidentifiable.

Argillite-shale facies.--Beds of the argillite-shale facies are dark gray, and are composed of clay- to silt-size grains of quartz, interstitial chlorite, sericite, with some organic matter. Pyrite forms a few very thin laminae parallel to stratification. Because of their laminated structure, the rock layers commonly exhibit micro-folding or wrinkling. Some unusual beds of breccia are composed of angular pebble-sized fragments of sandstone or phyllite in a black silty matrix. These breccias may represent turbidity-current deposits.

Conglomerate facies.--The conglomerate facies forms lenses within the argillite-shale facies (pl. 1). Beds 1 to 2 m thick are predominantly oligomictic, composed of subangular to rounded pebbles and cobbles of milky quartz in a well-indurated matrix of quartz sand with interstitial chlorite and sericite. Polymictic beds are less common than oligomictic, and contain cobbles of quartzite and phyllite or argillite in addition to those of milky quartz, in a coarse-grained graywacke matrix. Beds strike north, dip steeply westward. Maximum thickness of the conglomerate facies, 40 m, is observed in the Cañada Honda (southern edge of e-5), a tributary of Quebrada La Soledad, where pelecypod and ammonite fossils have been collected.

Age.--The Cañada Honda fossils were identified in 1966 as a lower Albian (upper Lower Cretaceous) assemblage by the late Dr. Hans Bürgl, a former paleontologist of Servicio Geológico Nacional in Bogotá. Fossils in lithologically similar sedimentary sequences in other parts of Antioquia, which probably correlate at least approximately with the La Soledad Formation, also have been assigned to the Lower Cretaceous, ranging possibly from Hauterivian to lower Turonian.

Undifferentiated Cretaceous rocks

Sedimentary rocks of presumed Cretaceous age have been mapped in the extreme northwest corner of the mapped area (a-1). These were not studied in detail, and only a brief description is given here. Dark fine-grained quartzose argillite is the dominant rock type, but sandy graywacke and polymict cobble to boulder conglomerate beds as much as 2 m thick are common. Angular to subrounded clasts in the conglomerate layers include dark green to black chert, gabbro and amphibolite, milky quartz, and metabasalt. Beds of laminated black chert 30 to 40 cm thick were observed in Quebrada San Vicente (not shown on the map). The sedimentary rocks are bounded on the east by a Cretaceous volcanic and greenstone assemblage in which are numerous intercalated lenses as much as 50 m thick of finely laminated chert, at least part of which is radiolarian. Strike of the sedimentary beds is predominantly N. 5° - 20° W., with steep westerly dips. Field relations suggest that these strata overlie the volcanic and greenstone assemblage to the east, but the difference in age may not be great.

Tertiary rocks

Tertiary sedimentary rocks are minor in amount in the area of plate 1, although Tertiary units are extensive in the southwestern corner of IIA.

Three Tertiary units are shown on plate 1:

1. Undifferentiated clastic sediments.
2. Alluvium, locally gold-bearing.
3. Laterite cap over serpentinite.

Undifferentiated clastic sediments

Poorly to moderately consolidated clastic sediments form a patch of 16 km^2 along the northern edge of plate 1 (d-1, e-1). The sequence comprises clay shale and thin-bedded friable sandstone and local gravel lenses, and is presumed to have been deposited in a terrestrial limnic environment. Thin beds of lignitic coal also occur, and are exploited locally on a small scale. These Tertiary beds also are a potential source of low-quality clays, sand, and aggregate materials, but poor accessibility in a sparsely inhabited region sharply restricts development at this time. The same sediments extend northward beyond plate 1, covering an area of hundreds of square kilometers. The beds dip moderately, rarely exceeding 20°, in contrast with older bedded rocks which have been strongly folded. Further study is needed to subdivide the Tertiary stratigraphically. No fossils have been found to date.

Several narrow north-trending belts of Tertiary shale, sandstone, and minor conglomerates have been mapped near the west edge of plate 1, especially in a-5, a-6, a-7, and a-8. These appear in narrow down-faulted wedges or grabens, and have been much more sharply folded than the broader patch of Tertiary sediments to the north. The Tertiary areas shown on plate 1 are mere remnants of a formerly extensive cover, the greater part of which has been removed by erosion.

Alluvium

Remnants of Tertiary alluvium form perched terraces or benches in the upper reaches of present stream channels and as fill in former channels, notably in e-5. They comprise silty clay and mudstone lenses of variable thickness intercalated with polymict pebble and cobble gravel. The higher topographic position of these materials and the greater degree of induration compared to modern alluvium shows that their deposition probably antedates the Pleistocene. During the past century, and probably earlier, some of these deposits were worked as gold placers, but activity today is small-scale, sporadic, and of minor importance.

Laterite cap on serpentinite

A laterite cap on serpentinite occurs in one locality on plate 1, at the northern edge of e-6, extending a short distance into the adjoining part of e-5. The laterite cap lies on serpentinite on a broad north-sloping ridge crest called Morro Pelón overlooking the valley of the Río Nechí. The area, which is underlain by dark red soil that supports sparse shrub and grass cover, has a rudely oval shape, a north-south length of 3000 m, and an irregular east-west width averaging about 600 m.

The laterite was first described by Benjamín Alvarado and others (1939, p. 61-64). Because of its possible importance as a source of iron and nickel, the Morro Pelón laterite was test-pitted and sampled by IMN in 1964-65. Results are discussed in the chapter on economic geology under the heading "Iron." The laterite is believed to have been formed later than (or contemporaneously with?) the alluvium during the late Tertiary (Pliocene?) in a time of relative tectonic quiescence in low-relief terrain that was subjected to deep secular weathering. Morro Pelón today is in high-relief terrain, sloping northward from a summit elevation of 1200 meters to the banks of the Río Nechí at an elevation of 600 meters. Erosion is active. This laterite, relatively enriched in iron and nickel, formed by the *in situ* decomposition of serpentinite, prior to the most recent regional uplift. The patch of laterite on Morro Pelón is but a remnant of a formerly more widespread mantle. Its hard surface crust, now only partly preserved, resisted erosion, with the result that Morro Pelón stands today as a topographic high.

Similar laterites, 90 km airline distance north of Morro Pelón and more extensive and richer in nickel, occur at Uré and Cerro Matoso in the Department of Córdoba some 37 km beyond the northern edge of plate 1. These are discussed in the chapter on economic geology under the heading "Nickel."

Quaternary deposits

Alluvium

Quaternary alluvium is found in the valleys of all rivers and their larger tributary streams, but only locally forms deposits large enough to be mappable at the scale of plate 1. The deposits accumulate notably where valleys widen and stream gradients diminish. Coarse gravel bars and terraces dominate along river courses, and pebbly sands and some intercalated silt or mud form the overbank deposits. Some alluvium includes colluvium produced by mass wasting of adjacent valley slopes. Older terraces may be sufficiently well consolidated as to stand in nearly vertical banks several meters high, but most of the alluvium is unconsolidated. The cobbles and bounders naturally reflect the kinds of rock upstream, and are helpful in deciphering the geology in areas of sparse and poor outcrop. Much alluvium in certain areas is gold-bearing, although placer mining within the area of plate 1 is limited today to sporadic hand panning.

Talus

Talus forms on hillslopes, and consists of subangular to subrounded boulders and cobbles of weathered rock enveloped in an earthy matrix.

which is quantitatively equal to or greater than the coarse-clast component. The high proportion of lithosol matrix is attributable to deep weathering and rapid chemical breakdown of rock to soil in year-round mild temperatures, high rainfall, and profuse vegetal growth. The moist earthy matrix creeps downslope by secular plastic flow, and over the years may transport large boulders for hundreds of meters. The talus is far more widespread than indicated by plate 1, on which only deposits of unusual prominence are shown. Talus and slide-material deposits range in depth from a few meters to 25 m or more, and handicap the geologist trying to map bedrock geology.

Igneous rocks

Amphibolite

Elongate bodies of amphibolite are associated with the old micaceous gneiss and the Puquí Metatonalite, especially in c-3, c-4, and d-3. These rocks are of uncertain origin and need further study. Some bodies are typical amphibolites whereas others preserve an igneous texture and may be akin to metagabbro or metadiabase in which the amphibole is a product of uralitization of pyroxene in mafic igneous rock. The origin of the typical foliated amphibolites composed dominantly of green hornblende with interstitial albite and epidote, and accessory sphene and magnetite, is unclear. Some bodies could conceivably be para-amphibolites derived by metamorphism of ancient sediment or pyroclastics, in which case the amphibolites may have been deposited more or less contemporaneously with the sediments that formed the micaceous paragneiss, with which they are associated. Because of its areal association with the micaceous gneiss and its relatively high grade of metamorphism, it is tentatively assigned an undifferentiated Paleozoic age and is the oldest igneous rock unit in the area.

Puquí Metatonalite

The Puquí Metatonalite takes its name from the Rio Puquí in d-2, 10 km north of Puerto Valdivia. This rock underlies an area of approximately 600 km^2 in the north-central part of plate 1, especially c-1, c-2, c-3, c-4, d-1, and d-2. It passes beyond the north edge of plate 1 and is overlain unconformably by Tertiary sediments on the north edge of d-1 and e-1. Topography is gently rolling with maximum local relief of 200 m.

Contact relations.--The metatonalite is closely associated with the older micaceous gneiss. Contacts between the two are gradational and drawn only approximately, because numerous inclusions of gneiss occur in the metatonalite; also migmatite consisting of lit-par-lit injections of metatonalite concordant with foliation in the gneiss is common near contacts. Relation of the metatonalite to the Valdivia Group to the west is less clear, but the concensus of the field geologists who mapped the area is that the metatonalite intrudes the Valdivia Group. The metatonalite body is bounded on the southeast for the greater part of its length by the northeast-striking Romeral fault.

Petrography.--Color is dark gray salt-and-pepper, commonly with a greenish tint. A gneissoid banding or foliation is common, although some outcrops appear massive, and have no evident orientation of crystals. Texture is medium to coarse grained, hypidiomorphic equigranular. Composition, although variable, is generally that of a tonalite, locally granodiorite; the "meta-" is prefixed to distinguish this tonalite from other tonalite bodies in the zone that lack gneissoid foliation and are less variable in composition. Although the effects of regional metamorphism are not pronounced in the metatonalite, metamorphic processes may have played a role in the origin of this rock.

Composition falls generally within the following range, as observed under the microscope:

Mineral	Percent (range)
Plagioclase (An_{30} to An_{50})	35 to 70
Quartz	23 to 40
Orthoclase	0.5 to 20
Biotite	2 to 18
Microcline	1 to 8
Muscovite and sericite	1 to 8
Epidote (saussurite)	1 to 5
Chlorite (mostly after biotite)	0.5 to 6
Pyroxene (hypersthene?)	0 to 8
Garnet (almandine?)	trace to 5
Magnetite-ilmenite	trace to 1.5
Pyrite	trace to 0.25
Zircon	trace
Apatite	trace
Cordierite	0 to 0.5
Sillimanite	0 to 0.5

The above minerals, and the range in composition are unusual for most species of plutonic rocks.

Plagioclase is oligoclase or andesine clouded by sericite and saussurite; locally megacrysts of plagioclase up to 6 cm across have been observed. Potassium feldspars typically are accessory, but in places are present in sufficient abundance to give the rock the composition of granodiorite; megacrysts of microcline 3 cm long occur on the east bank of the Río Cauca near Puerto Raudal in d-2. Quartz anhedra show undulatory extinction. Biotite is bright red-brown, commonly altered around edges or along cleavages to pale green chlorite; some flakes are wholly chloritized. Zircons, some 0.5 mm long, in biotite, are surrounded by pleochroic haloes. Garnet is a common accessory, and constitutes up to 5 percent of some specimens. Sillimanite as clusters of fine radial fibers 1 to 3 mm long is common, although less so than garnet. These latter two minerals may represent contamination from inclusions of the micaceous gneiss. Pyroxene, tentatively identified as hypersthene, occurs in metatonalite in d-1 at the north edge of plate 1, but was not observed in other parts of the body. Some crystals show the pale green to pink pleochroism characteristic of hypersthene, but have anomalous inclined extinction. However, inclined extinction has been reported in hypersthene in charnockites (Diaraj, A. H., 1966, unpub. data in IMN files). Cordierite was tentatively identified in a few thin sections, with garnet in one and with sillimanite in another.

Origin.--Presence of minerals such as sillimanite, hypersthene, and cordierite, and the relative abundance of garnet in a rock of igneous composition and texture suggests a possible metamorphic rather than conventional igneous origin, although all who mapped the rock in the field agree that it was intruded as a magma. Inclusions of quartzite and amphibolite are common, as well as of micaceous gneiss. Winkler (1965, p. 203), in discussing anatexis and the formation of migmatites, says, "At a given temperature, some layers will remain solid, whereas others will contain various amounts of melt. Layers consisting of quartzite or amphibolite remain solid during anatexis. If they fracture, the fragments are engulfed by more or less homogeneous melts." Winkler's concept of the survival of certain rocks during anatexis might also explain the presence of the above-mentioned metamorphic minerals. It is conceivable that the magma was formed at great depth by anatexis of a rock like the Puquí Gneiss and syntectonically emplaced in its present location. The feasibility of such an origin for tonalites and trondhjemites is demonstrated by Winkler (1965, p. 199).

Age.--Two K-Ar age determinations have been made on the metatonalite by the Geochronology laboratories with results as follows (R. Marvin, U. S. Geol. Survey, written commun., July 29, 1968):

Geochron Lab no.	Field no.	Mineral analyzed	Age (m.y.)	Period
B-1131	RH-JA-E1	biotite	239 ± 7	Late Permian
M-1132	RH-JA-E2	muscovite	214 ± 7	Early Triassic

The older age is believed to be the most nearly correct and is interpreted as the probable age of crystallization of the tonalite magma. Both are minimum ages for their respective samples.

Syntectonic intrusive gneisses

Two distinct intrusive gneiss units have been mapped (pl. 1): porphyroblastic adamellite gneiss and cataclastic tonalitic gneiss. Both rocks occur in sparsely inhabited rugged terrain and need more detailed mapping and study than was practicable during the IMN program. The cataclastic tonalitic gneiss resembled parts of the southern end of the adamellite body, and the two rocks may be correlative, although the adamellite has coarse megacrysts of potassium feldspar and a darker color. Both are classified as syntectonic intrusive gneiss because the cataclastic texture is thought to have been acquired, at least in part, at the time of intrusion, when still in a partially molten state or crystalline mush. Later tectonism also affected these rocks, and it is difficult to differentiate between protoclastic and secondary cataclastic effects.

Porphyroblastic adamellite gneiss.--The porphyroblastic adamellite gneiss forms a great elongate lens covering an area of roughly 300 km^2, extending from Campamento (e-6) northward 55 km to the north edge of e-1. Maximum width is 9 km near the north edge of e-3. Two small satellitic bodies have been mapped, one of rudely triangular shape 2 km long in the northwest corner of e-6, and a second lens-shaped body 4 km long near the east edge of e-2. The gneiss intrudes Valdivia Group schist and is intruded by Lower Cretaceous mafic and ultramafic bodies, especially in e-3, e-4, and e-5. A younger tonalite body bounds the gneiss on the east in e-3 and e-4, although this contact is interrupted by a lens of Lower Cretaceous(?) metagabbro near the south edge of e-3.

The typical rock is medium gray, has gneissoid texture and megacrysts of partly sericitized orthoclase 5 to 30 mm long in a medium grained cataclasized matrix of quartz, plagioclase, and mica. Plagioclase, mostly oligoclase, and orthoclase with lesser microcline are subequal at about 25 percent each, and the average quartz content is about 30 percent, giving the rock the composition of an adamellite. The composition is locally that of a tonalite in e-5 and e-6, but it was not practicable to map each facies separately. Brown biotite dominates over muscovite by about 3 to 1, but usually is partly to wholly chloritized. Tiny zircons in the biotite show prominent pleochroic haloes. Plagioclase shows fine albite twinning, commonly bent, saussuritized centers, and sericite-clouded rims. Quartz grains are heavily strained in fine-grained mosaics; they have sutured contacts, and mortar structure is common. The potassium feldspar megacrysts that characterize this unit in most places are an enigma. We interpret them as porphyroblasts formed under the effects of thermotectonic metamorphism during or shortly after intrusion, rather than as phenocrysts in a porphyry of conventional magmatic origin.

Cataclastic tonalitic gneiss.--The cataclastic tonalitic gneiss unit covers 25 km^2 in the southwest corner of plate 1, and has the form of a narrow curved wedge tapering northward where it is obliquely transected by the Romeral fault in a-8, b-8, b-7, and b-6. It is bounded on both sides by Valdivia Group schist which it intrudes, although the schist is separated from the tonalitic gneiss in western b-8 and southwestern b-7 by a narrow band of younger hornblendic metagabbro intruded along the contact between gneiss and schist. An elongate semiconcordant cupola of the Sabanalarga pluton intruded the center of the gneiss wedge in a-8 and b-8.

The cataclastic tonalitic gneiss is not homogeneous and includes dikes and irregular bodies of younger metadiabase and inclusions of strongly cataclasized quartz-mica paragneiss, the latter presumably of the Valdivia Group. The typical grayish-brown rock has gneissoid texture, and abundant 1 to 3 mm whitish spots of feldspar impart a porphyry-like appearance. The composition is generally that of a tonalite that has been cataclasized and altered. Subhedral andesine is saussuritized and sericitized, with abundant interstitial quartz, accessory microcline, muscovite, and biotite, the latter commonly partly to wholly chloritized; secondary magnetite flakes have formed along cleavage, and tiny zircons have prominent pleochroic haloes. Apatite and sphene are sparse accessories. Quartz is highly strained, and the larger feldspar and quartz grains are enclosed in a fine-grained mosaic of quartz, mica, and altered feldspar (mortar structure).

The cataclastic tonalitic gneiss is bounded on the west by the Romeral fault, and some parts superficially resemble parts of the Puquí Metatonalite, described earlier, that crops out some 10 km further north on the northwest side of the Romeral fault. Also, the gneiss body looks much like a fault-dragged block or wedge. Thus, the cataclastic tonalitic gneiss and the Puquí Metatonalite may be the same rock. If the two rocks are the same, this would be strong evidence for right-lateral displacement along the Romeral fault.

Porphyroblastic gneiss.--The unit here designated as porphyroblastic gneiss (pl. 1) forms small bodies northeast of Yarumal (d-6) in d-5, d-6, e-5, and e-6. This rock forms a narrow band between Yarumal (d-6) and Cedeño (d-5), 15 km long and roughly 400 m wide, striking N. 25° E. and dipping steeply east. This narrow band is better known than the other bodies because of exploration drilling for talc, 5 km northeast of Yarumal. Scattered lenses and irregular bodies of similar rock crop out east and northeast of the talc-bearing band, but no single body is more than 4 or 5 km in length or covers an area larger than 5 km^2.

The elongated talc-bearing gneiss band between Yarumal and Cedeño shows well developed thin gneissic layering, and gnarly foliae 0.5 to 2 mm thick of fine-grained quartz, mica, and albite. Oval porphyroblasts of albite and quartz 5 to 40 mm long give the rock an augen texture. Essential minerals include quartz, cloudy albite, and phlogopitic biotite; accessories include sericite, chlorite, epidote, zircon, magnetite, and pyrite. Strained quartz locally constitutes as much as 50 percent of the rock. The elongated band was intruded locally by thin lenses of Lower Cretaceous serpentinite that were steatized to talc.

The other bodies of porphyroblastic gneiss shown on plate 1 are less micaceous and do not have as well marked layering or foliation as the talc-bearing band, but generally appear as massive phaneritic igneous rock. White megacrysts or augen 5 to 30 mm across of quartz and plagioclase are common in these massive bodies; the augen are interpreted as epigenetic porphyroblasts induced by syntectonic metamorphism rather than as phenocrysts.

The age and relation of this rock to some of the adjoining units are enigmatic. Good exposures are rare, and contacts are soil-covered almost everywhere. It is not certain that all bodies mapped as porphyroblastic gneiss really belong to the same unit. The narrow talc-bearing band between Yarumal and Cedeño evidently is an upthrust slice between Valdivia Group schists on the west and the Lower Cretaceous Yarumal metagabbro stock on the east. The well developed micaceous gnarly foliae and gneiss structure may have been produced in this fault-bound slice during tectonic emplacement.

The lenticular or irregular form of some of the other bodies which are less micaceous and less well foliated suggests emplacement as intruding syntectonic magma. The spatial association of most of these gneiss bodies with metagabbro and serpentinite (pl. 1) also is enigmatic, although there can be no doubt that the porphyroblastic gneiss is older than the neighboring mafic and ultramafic rocks.

Age also is uncertain. This unit is here tentatively assigned a late Paleozoic (Permian?) age, more or less contemporaneous with the Puquí Metatonalite and the syntectonic intrusive gneisses previously described.

Lower Cretaceous metabasalt

Metabasalt underlies an elongate north-striking area of 135 km^2 near the eastern margin of plate 1 in e-4, e-5, e-6, e-7, and e-8. It attains a maximum width of 8 km at the latitude of Campamento (e-6), and has a length of 33 km. San Pablo Formation lies in the center of the metabasalt belt, and is interpreted as a synclinal fold, although the upper part of the metabasalt assemblage and the basal part of the San Pablo are intercalated and contemporaneous. The western half of the metabasalt belt is intruded by narrow north-striking lenses of metagabbro and serpentinite, and a long dike-like body of cataclasized granite. The southern end of the metabasalt belt is truncated by the Antioquian batholith.

Petrography.--Most of the metabasalt (greenstone) consists of massive basalt flows, probably submarine, and minor flow breccia. The rocks are dense, massive, holocrystalline, fine grained, and resistant to erosion so as to form topographic highs. Most of the unit has a spilitic composition, but the southern end of the belt is more nearly "normal" basalt. Some parts of this unit are flow breccias in which fragments as much as 25 cm across are enclosed in a matrix of the same composition. Texture is generally fine grained intersertal to subophitic, locally amygdaloidal. The typical rock is composed of 1 mm long pale-green faintly pleochroic slender prisms of actinolite arranged in sheafs and clusters, the stubby outlines of which suggest that the actinolite is a uralitic replacement of original pyroxene, probably augite. Uralitization seems to have been less active in the southern end of the belt where remnants of augite are preserved with calcic feldspar. Albite or oligoclase form 1 to 3 mm long euhedral laths with simple Carlsbad twinning. Albite also occurs as clear glassy anhedra associated with fine granular epidote, and in this form it is probably the product of saussuritization of originally calcic feldspar. Opaque accessories include as much as 4 percent of finely disseminated magnetite and sporadic minor pyrite or pyrrhotite. Locally the rock has spheroidal amygdules 2 or 3 mm in diameter filled with pale-green chlorite, some with calcite cores. Cracks and cavities less than a millimeter wide are filled with calcite or prehnite. Secondary quartz is sparse but not rare. Neither olivine nor serpentine were recognized in thin sections.

The sodic feldspars indicate that the name "spilite" is possibly applicable to this suite of metabasalts, although these rocks have been tectonically disturbed and it is difficult to distinguish between the effects of superimposed greenschist facies regional metamorphism and deuteric alteration or autometamorphism. The presence of epidote suggests that at least part of the albite is a product of saussuritization. Moreover, some geologists would restrict the name "spilite" to basaltic rocks that crystallized directly from a primary spilitic magma and have composition and texture not appreciably affected by later metamorphic processes. The problem of distinguishing between primary and secondary spilites is summarized by Amstutz (1968, p. 745): "Obviously there are transitions between 'normal' basalts, metamorphosed basalts, fresh spilites, and metamorphosed spilites. In these epigenetic transitions an interpretation is often very difficult or impossible."

Age and correlation.--The upper contact with the San Pablo Formation is marked by interlayered metabasalt flows, showing that deposition of clastic sediments and flows of basalt overlapped, although the greater part of the flows probably preceded deposition of the San Pablo Formation.

The San Pablo Formation considered together with the metabasalt is similar lithologically to the Quebradagrande Formation in quadrangle I-8, 15 km southwest of Medellín, described by Botero A. (1963, p. 44-54). The Quebradagrande has been assigned a probable Lower Cretaceous (Albian?) age, based on poorly preserved ammonite remains (Botero A., 1963, p. 54). Botero A. (p. 47) estimates the thickness of the Quebradagrande at 1270 m, including both metabasalt and sedimentary components. The metabasalts probably are not less than 2000 m in total thickness, although precise data are lacking.

The eastern metabasalt belt does not seem to contain intercalated lenses of radiolarian chert such as characterize the metabasalt belt along the western margin of plate 1. Those western metabasalt and associated cherts are tentatively assigned to the Upper Cretaceous. No fossils have been found in the eastern metabasalt belt or in the associated San Pablo Formation, but these rocks probably are not younger than Early Cretaceous, and the possibility of a Late Jurassic age, at least for the basal part of the sequence, cannot be ruled out.

Metagabbro

Masses of metagabbro are numerous in IIA, especially in the southeast quadrant of plate 1, and are considered as part of an ophiolitic suite comprising the previously described metabasalt and the serpentinites described in the section following. The largest single metagabbro body is northeast of the municipality of Yarumal and is designated the Yarumal stock. Because of its size, it is described separately. Numerous smaller bodies of metagabbro lie within a narrow north-trending belt about 45 km long and 5 km wide, east of the Yarumal stock. Nearly all these gabbroic rocks have been altered to some degree by uralitization of pyroxene and saussuritization of calcic plagioclase.

Yarumal stock

The Yarumal stock covers a rudely trapezoidal area of about 90 km^2 between Yarumal and Campamento (d-5, d-6, e-5, and e-6). It intrudes schists of the Valdivia Group, the syntectonic porphyroblastic adamellite gneiss, the porphyroblastic gneiss, and the Lower Cretaceous metabasalt. It is intruded by a small irregular body of Cretaceous cataclastic granite in western e-6, and by the Late Cretaceous Antioquian batholith (d-6, e-6). The rock generally is massive to moderately foliated, medium gray to dark greenish-gray, weathering brown. Texture is hypidiomorphic fine-grained, except near the central part of the stock where the grain size increases to medium or coarse. Composition is variable, especially the plagioclase-to-mafic mineral ratio, but typically falls within the following range:

Component	Percent
Plagioclase[1/] An_{45} to An_{75}	50 to 75
Augite, generally uralitized	15 to 45
Magnetite	1.5 to 3
Apatite	sparse accessory
Zircon	sparse accessory
Sphene	trace to 0.5

1/ Commonly partly saussuritized.

Plagioclase is clouded with saussurite, in some cases so strongly that twinning is virtually obliterated by very finely granular epidote and clear glassy interstitial albite. Unaltered augite is even more rare than fresh plagioclase, being uralitized to pallid, weakly pleochroic actinolite in sheafs and clusters of fibrous prisms. The sheafs themselves have stubby prismatic outlines inherited from the original euhedral to subhedral augite crystals. Magnetite is disseminated as anhedral grains attached to borders of uralitized augite crystals. Sphene is present in most specimens, as rims around magnetite grains and also is sparsely disseminated as discrete euhedra 0.08 mm long. Apatite and zircon are sparse accessories. Olivine is notably absent from the metagabbro, in contrast to the serpentinites and ultramafics with which the metagabbro is closely associated. Non-uralitic fresh hornblende is rare except in a hornblende diorite near the contact with the Antioquian tonalite batholith. This border rock which forms a vaguely delimited zone about 500 m wide is composed of fine-grained hypidiomorphic fresh andesine, 45 percent; brown hornblende, 40 percent; and accessory quartz. It is fresher than the metagabbro. The border rock is interpreted as a hornfels-facies hybrid, a product of reaction between gabbro and the intrusive tonalite.

Small localized bodies of serpentinite are in or adjacent to the Yarumal stock; for example, 10 km northeast of Yarumal (d-6), a north-trending oval body of serpentinite was mapped in the center of the stock, and two smaller lenses of serpentinite have been mapped along the north edge of the stock (d-5). The serpentinite-gabbro relationship is discussed later.

Structure of the Yarumal stock.--The outline of the Yarumal stock suggests that it may have a lopolithic or funnel-like form; however, contacts are covered and direction of dip of the contact can only be inferred. Cross section B-B' (pl. 1) shows the west contact dipping steeply toward the center, and the east contact is almost vertical. This indicates an asymmetric lopolith form, but this is unproven. Concordance of foliations in the gabbro with the regional trend indicates that tectonic stresses on the gabbro acted in the same direction as stresses that earlier affected the Valdivia Group.

Metamorphism.--It is difficult to estimate what part of the metamorphism in the metagabbro is attributable to deuteric or autometamorphic effects and what part to regional metamorphism, but the latter is believed to have been dominant. However, the gabbro was affected less than the older rocks it intrudes; for example, the Valdivia Group was regionally metamorphosed before the gabbro intrusion.

Small gabbro bodies

Numerous small bodies of foliated metagabbro lie within a belt about 5 km wide, located immediately east of the Yarumal stock, extending from a point 3 km north of the town of Guadalupe (e-8) northward 45 km to a point 4 km east of Puerto Valdivia (d-3). These smaller bodies are similar lithologically to the Yarumal stock, although variable in both texture and composition. Grain size ranges from coarse to fine, but averages 1 to 2 mm. Foliation and long axes of the bodies strike north parallel to the regional trend. Original pyroxene has been uralitized to a pallid brown, faintly pleochroic hornblende or actinolite, and the labradorite-bytownite feldspars have been saussuritized. Fresh unaltered gabbro occurs, however, in a few places. The pyroxene in these specimens is augite or diallage. Magnetite is the principal opaque accessory, ranging from less than 1 percent up to 3 percent. Pyrite or pyrrhotite and leucoxene are less common. Sphene is a common accessory as rims around titaniferous magnetite and as granular clusters along boundaries between uralite and saussurite. Most rocks have small amounts of chlorite. The epidote of the saussurite may be clinozoisite; individual grains are too small to give interference figures and the anomalous dark blue interference colors obscure the true birefringence. Quartz is present in some metagabbro specimens as a minor accessory, but probably is secondary, as are tiny veinlets of prehnite and calcite.

Several bodies of mafic rock on the northwest side of the Romeral fault are isolated from the cluster of metagabbro bodies east of Yarumal. One such isolated body on the boundary between b-3 and b-4 has a rudely oval shape, 4 km long by 1 km wide. The fine- to medium-grained gabbro is composed of about equal parts of highly saussuritized calcic feldspar and uralite (actinolite), and accessory sphene and magnetite. Another irregular metagabbro body elongated east-west, not well studied, covers roughly 12 km^2 in the northern part of b-1. The original augite has been uralitized to pallid amphibole which in turn has been altered in part to clinozoisite that has a bluish-gray anomalous interference color. Plagioclase crystals have been completely saussuritized to fine-grained epidote and interstitial glassy untwinned albite. The center of this metagabbro body has a 2 km^2 serpentinite core, analagous to the small serpentinite core of the Yarumal stock. The western end of the body is strongly cataclasized, with prominent secondary quartz. A north-trending metagabbro body, also poorly known, covers about 22 km^2 in the north-central part of c-1. At least part of the uralite in this body is green, strongly pleochroic hornblende in contrast to the pallid actinolite variety of uralite that is typical of the bulk of the metagabbro bodies shown on plate 1. It is uncertain whether or not these western bodies are related to the eastern bodies.

Hornblendic metagabbro

Elongated lenses of metagabbro in the southwest quadrant of plate 1 are distinguished from other metagabbro bodies by the presence of hornblende. The hornblendic metagabbro occurs in a-5, a-6, b-5, b-7, and b-8.

These bodies are generally similar to the metagabbro bodies already described except that the amphibole is predominantly hornblende instead of actinolite. At least part of the hornblende in these rocks may be primary and not uralitic.

The age of the metagabbro and hornblendic metagabbro is not known precisely. Contacts are covered, but the field relations indicate that these bodies were intruded as mafic magma cutting the Lower Cretaceous(?) metabasalt and older rocks. The Yarumal stock is intruded by the Late Cretaceous Antioquian batholith and by a small granitic body of Late(?) Cretaceous age slightly older than the batholith. These relations indicate a freezing of the mafic intrusions during Early Cretaceous time. The metamorphism that converted the gabbros to metagabbros must have followed shortly afterward because the Antioquian batholith shows few metamorphic effects.

Serpentinite

Serpentinites and related ultramafic bodies are closely associated spatially with the metagabbros, and are particularly abundant in d-4 and e-4, e-5, and e-6. The presence of small serpentinite bodies within or adjacent to the Yarumal stock in d-5 and d-6 has been mentioned. Thin discontinuous lenses of steatitized serpentinite too small to be shown on the scale of plate 1 are concordant with the foliation of the elongate body of porphyroblastic gneiss adjacent to the Yarumal stock (d-5 and d-6), and are mined for domestic ceramics industry (see chapter on economic geology). The close association of serpentinite with gabbro is cited by Thayer (1967, p. 222) as a characteristic of alpine intrusive complexes. Eleven serpentinite bodies have been mapped in the eastern part of plate 1; they are elongate, lenticular, or rudely elliptical aligned north-south, and range in size from one great dike-like body 15 km long and 1 km wide (e-5 and e-6), to small oval bodies only 800 m by 300 m. Contacts are covered, but field relations suggest that the serpentinite is intrusive, mainly along probable fault contacts between older units such as schist of the Valdivia Group, the syntectonic gneiss, and metabasalt. A few bodies of serpentinite also occur near the western margin of plate 1. Another large north-striking dike-like body is 1.5 km east of the municipality of Ituango (d-4), and has a width of 500 to 800 m for most of its 15 km length. Two smaller lenses are south of the Ituango lens, one in b-7, 5 km northwest of San José de la Montaña (b-8), another 8 km east of Sabanalarga (a-8).

Lithology.--Most of these rocks are serpentinites, but unserpentinized or partially serpentinized peridotites and some gabbroic or diabasic rocks are included. Detailed mapping would be needed to delimit the various facies more precisely. The serpentinites are mottled dark greenish-gray to almost black, fine-grained, commonly although not universally laminated or lineated, and have oriented streaks of lighter and darker components. The majority of hand specimens show at least one slickensided face. Antigorite is the main component, in flakes 0.1 mm long arranged as feathery aggregates in a characteristic reticulated gridwork, or as radial sheafs and clusters. Lizardite has been tentatively identified in a few specimens as 0.4 mm transparent plates with flamboyant extinction, like that illustrated by Faust and Fahey (1962, fig. 6). Chrysotile is a minor component of local importance, especially in the vicinity of the asbestos prospects at La Solita (Las Brisas) (e-5) and Búfalo (e-3). Cross-fiber veinlets 2 or 3 mm wide appear under crossed nicols as parallel fibrils of width and length with slightly higher birefringence (first order white) than the antigorite matrix. Chrysotile asbestos is discussed in the chapter on economic geology. A brittle, pale greenish-gray, harsh fibery "picrolite" superficially resembling chrysotile is present in many places as a minor component, and frequently is mistaken for true asbestos by the campesinos, giving rise to rumors of asbestos "mines" in the vicinity. Tiny isotropic patches associated with antigorite are thought to be amorphous serpentine or "serpophite" (Deer and others, 1962, v. 3, p. 183). In plane light all the serpentine minerals have the same clear transparency and very low relief.

Magnetite is an ubiquitous opaque component ranging from 2 up to an estimated 7 percent by volume, averaging roughly 3.5 percent. Chips of rock 2 cm across are picked up easily by an alnico pocket magnet and most serpentinite bodies would be expected to show as distinct anomalies from either ground or airborne magnetic surveys. Readings 1000 gammas higher than over adjacent rocks have been taken over serpentinite with a pocket magnetometer (J. E. Muñoz, oral commun., 1967). Systematic magnetometer surveys have not been made by IMN, but the serpentinite lenses would be expected to show accompanying slight negative anomalies along the flanks and distinct negative poles at their northern ends, induced by the earth's magnetic field, because they are located along 17° north of the magnetic equator (true latitude ca. 7° N.), with long axes aligned nearly parallel to the magnetic meridian. The magnetite commonly appears as lines of tiny anhedral grains following fractures or grain boundaries and presumably was formed during serpentinization of olivine. Picotite or chrome-spinel is another sparse but universal accessory, appearing as isolated, barely translucent, deep reddish brown anhedral grains 0.5 to 1 mm across, with opaque chromite veins and borders. Remnants of olivine, and a few of diallage or clino-enstatite, are observed in some thin sections. Olivine remnants locally have thin coronas of an unidentified alteration product as a buffer between them and the end-product antigorite. The coronas have relief and birefringence intermediate between olivine cores and antigorite matrix but are too fine grained to allow identification. Saussurite clouds, some with ghost plagioclase twinning, are present locally, but rarely as an essential component. Secondary calcite and prehnite are common but always sparse in amount. Chlorite and talc are sporadic accessories.

Locally some metagabbro in the serpentinite masses is composed of partially uralitized augite, heavily saussuritized calcic plagioclase, chlorite, and prehnite. Quartz is present in some of these gabbroic rocks; it is either primary or a secondary accessory. Some of the gabbroic facies have ophitic textures and may be classed as metadiabases. Border rocks of uncertain classification, rich in finely granular, cloudy, dark greenish-gray epidote, are near the contact of serpentinite with older greenschists and greenstones, especially south of the Morro Pelón laterite in e-6.

Origin and mode of emplacement.--The serpentinites have been derived from dunite, peridotite, and kindred ultramafic rocks, some of which may have been picritic, if the presence of saussurite is a valid indicator. It is not clear whether the serpentinites were emplaced in their present locations as serpentinites, or as ultramafic rock that was serpentinized afterward. The alpine environment and active tectonism, the prevalence of slickensided surfaces, and the fact that contacts, possibly faulted between distinct rock types, are favored locations for the serpentinites, would seem to favor the "watermelon seed squeezed between the fingers" concept suggested by Hess (1955, p. 402). The serpentinites may have been injected as relatively cool plastic crystalline mush along faulted contacts between disparate rock types. Tectonic stresses also followed emplacement.

Relation of serpentinites to metagabbros, "Alpine series".--Hess (1955, p. 402) cited Steinmann's work in 1905 in which he pointed out the classic association of spilitic basalt, radiolarian chert, serpentinite, and gabbros. This so-called "alpine series" or "ophiolitic suite" is characteristic of the eugeosynclinal domain (Aubouin, 1965, p. 151-159). Thayer (1967, p. 222-239) discusses the close association of gabbros with ultramafic rocks and serpentinites in alpine intrusive complexes, and cites six characteristics of the alpine ophiolitic suite. Four of Thayer's six criteria may be found in the mafic-ultramafic assemblage of IIA:

1. Close areal and structural association of ultramafites and gabbroic rocks.
2. Olivine dominant over pyroxene in ultramafite. Olivine is absent in the metagabbros of IIA, although antigorite, probably in large part after olivene, is abundant in serpentinite.
3. Presence of podiform chromite deposits in localized parts of the serpentinite belt. These are 75 km south of the area shown on plate 1, in a north-trending belt of serpentinite 2 to 5 km wide, east of the city of Medellín. The chromite-bearing serpentinites are almost surely correlative with the ultramafic rocks shown on plate 1.
4. Laminations and flow-streaking in serpentinites and foliations in metagabbros. Thayer (1967, p. 222) mentions "Flow-layering and related structures and textures that are characteristic of high-grade metamorphic rocks" as a criterion for distinguishing alpine mafic-ultramafic complexes. Metamorphism in the IIA ophiolitic complex is low grade and therefore departs from Thayer's criterion in this respect.

Thayer's fifth criterion (1967, p. 222), "Complicated structural relations between gabbroic and ultramafic rocks, such as intertonguing of major units along flow-layering" is not clearly applicable, although more detailed mapping might well prove the existence of these features. The intimate association of small serpentinite lenses with the Yarumal metagabbro stock has already been mentioned. The sixth criterion (Thayer, 1967, p. 222-223) "Distribution of soda-rich dioritic and granophyric rocks within or near gabbroic rocks, commonly hybrid and accompanied by much albitization and brecciation" also is not evident in the IIA suite. Albite-bearing rocks older than the metagabbros, such as greenschists of the Valdivia Group and the metabasalts, are adjacent to the metagabbros and the serpentinites but certainly are not diorites. The post-ophiolite Antioquian batholith is a quartz-diorite or tonalite having a 500 m wide contact zone of fresh hornblende diorite, probably a hybrid rock, separating the normal batholith from the Yaurmal metagabbro stock. Neither the batholith nor its hornblendic diorite contact zone are notably sodic.

Thus, four of Thayer's six criteria for distinguishing alpine intrusive complexes apply to the IIA mafic-ultramafic suite; the remaining two criteria do not apply so clearly, but further work eventually may demonstrate their applicability also.

Economic significance.--The serpentinites are of special interest economically because they include exploitable talc deposits 4 km northeast of Yarumal and potentially exploitable chrysotile asbestos deposits 10 km north of Campamento. The laterite mantle over serpentinite at Morro Pelón, 6 km northeast of Campamento, is enriched in iron and nickel, although too small and low in tenor to be exploited economically. More extensive nickeliferous laterites at Uré in the northwestern corner of IIA, 37 km beyond the north edge of plate 1, also are derived from serpentinites. Chromite has been found in small highly localized podiform bodies in serpentinite at Santa Helena and Las Palmas, 10 km southeast of Medellín. The above-mentioned deposits are discussed further in the chapter on economic geology.

Age.--The close spatial and structural association of the serpentinites with metagabbro indicates contemporaneity of the two; therefore, the serpentinites are assigned to the Lower Cretaceous with the metagabbro bodies.

Upper Cretaceous metabasalt and associated pyroclastics

A belt of metabasalt distinct from that described previously covers approximately 600 km^2 along the western margin of plate 1. This western belt of basalt flows and mafic pyroclastic is distinguished from the eastern metabasalt belt by differing petrographic characteristics, and by the presence of numerous intercalated beds of chert, some radiolarian, and fine-grained graywacke layers.

Metabasalt and associated pyroclastics.--The metabasalt unit comprises porphyry, devitrified glassy flow breccia, basalt agglomerate and tuff, and minor quartz diabase in a heterogeneous assemblage of pyroclastic, extrusive, and hypabyssal intrusive mafic material of predominantly tholeiitic composition. The metabasalt of the eastern belt is, in contrast, predominantly spilitic in composition. Although low-grade metamorphic effects in the western belt are less marked than in the eastern belt, the prefix "meta-" is also applied to the western unit, mainly because of the almost ubiquitous saussuritization of plagioclase and partial to complete uralitization of the original pyroxenes in the majority of specimens examined under the microscope.

Augite and pigeonite are the principal mafic components and plagioclase is mostly labradorite or andesine; spilitic rocks with euhedral laths of oligoclase or albite are present but less conspicuous here than in the eastern belt. Phenocrysts of augite or pigeonite, and labradorite occur in a pilotaxitic mesh of very fine grained (0.25 mm) calcic feldspar and partly to wholly uralitized clinopyroxene. Saussurite is conspicuous, accompanied by clear glassy interstitial albite. Locally palagonitic breccia is composed of greenish- or yellowish-brown rounded hyaline fragments 5 to 15 mm across in a matrix of the same composition. Pale-green chlorite with a deep Berlin blue interference color fills amygdales. Chlorite also marginally replaces some augite, and forms interstitial flakes less than 0.25 mm long in the groundmass. Magnetite is ubiquitous, sparsely disseminated as dust and subhedral or skeletal grains, some with rims of sphene. However, magnetite is slightly less abundant in these basalts than in the spilitic basalts of the eastern greenstone belt. Apatite and zircon are very sparse. Quartz also is sparse, but was observed in most thin sections, both as a primary interstitial component and as amygdular filling. Secondary calcite fills cracks and some amygdales. Olivine is absent in the western metabasalt belt, as it is in the eastern belt. Basalt tuffs cemented by calcite in a-1 contain carbonate fossil fragments 1 to 3 mm long. These include what appear to be remains of Foraminifera and delicate coral fronds, indicative of marine deposition.

The tuff itself is composed of broken euhedra of dusty andesine, some zoned, and sparse primary anhedral quartz. Original mafics apparently have been wholly altered to chlorite because some chlorite-filled spaces have euhedral outlines like pyroxene phenocrysts and probably are pseudomorphic replacements.

Interbedded chert and fine-grained clastics.--Lenses of intraformational medium-gray to black thinly laminated chert together with siltstone and fine-grained graywacke are intercalated with basalt flows and mafic pyroclastics. However, many of these sedimentary deposits are too small to show on plate 1. Only certain lenses encountered during reconnaissance traverses were mapped separately, and the sedimentary intercalations are more numerous in the extrusive mafics than indicated on the map, constituting an estimated 4 percent of the whole western metabasalt belt. Typically, the individual chert members range in thickness from a few meters to 30 m; individual beds are 5 to 30 cm thick. The beds are in turn composed of laminae 0.1 to 2 mm thick. Commonly, both bedding and laminae are remarkably straight, as if scribed with a ruler, but under the microscope the laminae are seen to be diffuse and gradational. Rhythmic layering is common but not universal, and some beds lack well-defined laminae. Tiny circular or oval objects, 0.6 to 1 mm long, are identified as poorly preserved radiolarian tests. In plane light they appear clear and glassy, dispersed in a dark nebulous matrix that is heavily dusted and clouded with diffuse brownish-black organic matter, but under crossed polarizers they are seen as mosaics of crystalline quartz, which although very fine grained (40 to 80 microns), are appreciably coarser than the cryptocrystalline matrix, which has an average grain size of less than 20 microns. The long axes of oval tests are oriented parallel to laminae. Tiny elongate objects of finely crystalline calcite 0.6 mm long may be poorly preserved Foraminifera.

Sedimentary material intercalated with the metabasalts also includes subordinate amounts of black carbonaceous siltstone and fine-grained graywacke composed of 50 to 65 percent of angular to subangular clastic quartz grains in a matrix of very fine grained clay minerals, mica, chlorite, quartz, feldspar, and organic pigment. Detrital magnetite and epidote are sparse accessories.

The chert beds and associated fine-grained clastic sedimentary material have not been mapped in detail, but are believed to be individual lenticular bodies of strictly local extent, although collectively they are widespread within the metabasalt assemblage. The sedimentary beds and associated volcanic effusives have been sharply folded, strike northward, and dip from 30° to vertical. The chert is cryptocrystalline and virtually unmetamorphosed, and original texture of the basalts is preserved almost intact. The mineralogical changes, such as saussuritization of calcic feldspars and uralitization and chloritization of pyroxenes, may be due as much to deuteric action as to lowermost greenschist facies regional metamorphism.

<u>Origin of the chert</u>.--In considering the origin of the chert, it is necessary to distinguish between the radiolarian tests and their silica matrix. These rocks are not simply formed by the accumulation of Radiolaria tests. In most of the cherts, the Radiolaria occupy no

more than 10 percent of the volume of the rock, the remainder of which is composed of extremely fine grained cryptocrystalline quartz. E. F. Davis' classic paper on the radiolarian cherts of California quotes an 1895 report by A. C. Lawson. Lawson's description (in Davis, 1918, p. 352) is equally applicable to the radiolarian cherts of Colombia: "In the slides having the radiolarian remains, the latter generally occur as casts of forms embedded in a matrix of silica which shows no evidence whatever of organic origin. The cavities of the Radiolaria have been filled with chalcedonic silica, and are in definite contrast with the non-chalcedonic matrix. The discrete character of the fossils is significant of their mode of accumulation. The silica seems to have been an amorphous chemical precipitate forming in the bottom of the ocean in which the Radiolaria thrived. The dead Radiolaria dropped into this precipitate, became embedded in it, and were so preserved."

The source of the precipitated silica matrix is a separate question. Both Lawson and Davis believed that the silica in the Franciscan cherts was derived from submarine siliceous springs related to volcanism (Davis, 1918, p. 352; 383; 384; 402-402). In discussing the chert beds associated with Tertiary diatomite deposits in California, Taliaferro said (1933, p. 54): "The cherts were largely formed by the rapid addition of silica to the ocean from siliceous waters which accompanied the outpouring of volcanic material."

The world-wide association of radiolarian chert with submarine mafic effusives clearly shows a cause-and-effect relationship wherein the igneous component has supplied the silica that caused both the proliferation of the Radiolaria in the ocean waters and the precipitation of colloidal silica on the ocean floor. The physical character of the effusives may govern the development of the chert, as it was noted earlier that chert was not found in the metabasalt of the eastern belt, which is composed mainly of massive flows.

Aubouin (1965, p. 123; 156-157) discusses the ophiolite-radiolarite association in connection with the development of geosynclines, and emphasizes that this association is a special characteristic of the eugeosynclinal domain.

Age of the metabasalt and chert.--The authors assign a Late Cretaceous age to this assemblage on the basis of indirect evidence. The Radiolaria and sparse Foraminifera in the chert are too poorly preserved to be useful age indicators, but very similar and almost certainly correlative cherts some 200 km to the south near Neira in the Department of Caldas contain slightly better preserved Radiolaria and sparse Foraminifera which have been examined by Professor G. Botero A. of the Facultad Nacional de Minas, Medellín. He has kindly offered the following information (written commun., 1968): The Radiolaria are probably of the genus *Stylodictya* which is of little use as an age marker because of its range from Jurassic to modern time. Six genera of Foraminifera were tentatively identified, including *Chrysalogonium*, *Dentalina*, *Globigerina*, *Textularia*, *Bigenerina*, and *Hastigerinoides*, which was tentatively identified as *H. watersi* Cushman, a species that Prof. Botero states is characteristic of the Austin Chalk in Texas, U.S.A., and which ranges from the Turonian to the Campanian, that is, early through middle Late Cretaceous.

Cataclastic granite

A dike of cataclastic granite rock 200 to 400 m wide extends from a point 2 km north of Guadalupe (e-8) almost due north 18 km to a point 4 km northeast of Campamento. An irregular body of rock 1 km east of Campamento is tentatively correlated with the long dike, as are two stubby lenses parallel to but several hundred meters east of the main dike (e-7). Several smaller lenses satellitic to the main dike are too small to be shown on the scale of plate 1.

Only a few thin sections of this rock were studied. Composition is that of a leucocratic granite or alaskite. Texture is medium-grained hypidiomorphic and cataclastic. Essential components include orthoclase, oligoclase, quartz, and chlorite which probably is an alteration product of biotite. Muscovite is accessory, and feldspars are clouded by sericite. Opaque accessories are sparse, limited to a few tiny dispersed patches of leucoxene and grains of magnetite and pyrite, the latter possibly epigene. Mortar structure is so well developed in some specimens as to form a microbreccia with 0.5 to 1 mm fragments of quartz and feldspar in a very fine grained matrix of ground-up chlorite, sericite, quartz, and feldspar.

The main dike and its satellite lenses have been intruded into metabasalt and metagabbro, but probably are older than the Antioquian batholith. The cataclastic granite is tentatively assigned a Late Cretaceous age.

The irregular-shaped body immediately east of Campamento is included with this unit, although it is slightly different in composition and texture. Locally it contains in addition to quartz and cloudy orthoclase, 1-cm megacrysts of albite, also slightly cloudy with sericite, and fresh red-brown biotite containing numerous tiny zircons with well-developed pleochroic haloes. Pale bluish-green pleochroic tourmaline (ilvaite?) is a noteworthy accessory. Border-facies hybrid rocks rich in greenish hornblende, interpreted as contact-metamorphic products from the adjoining Antioquian batholith, also are included in the Campamento body, and further detailed mapping would be needed to clarify relations.

Cataclasis is much more evident in the cataclasized granite dike than in the enclosing metabasalt and metagabbro, an anomaly that may be explained by postulating renewed post-dike movement on a pre-dike fault that cut the older mafics and provided a channel for the granite magma. Renewed movement along the fault would impose a cataclastic texture on the dike rock with little effect on the adjoining older mafic rocks.

Pescado stock

A pluton of tonalite or quartz diorite, here designated as the Pescado stock, covers a roughly elliptical area of 25 km^2 northwest of the Romeral fault (d-2). The name is taken from the Río Pescado which flows east along the long axis of the stock. The rock is massive, salt-and-pepper gray, and strongly resembles the Antioquian batholith in outcrop. Texture is fine to medium grained, hypidiomorphic equigranular. Modal composition varies, but typically is about as shown below:

Component	Percent
Quartz	20
Plagioclase (An_{25} to An_{50})	68
Microcline	4
Biotite	5
Hornblende	2
Chlorite	1
Apatite	trace
Zircon	trace
Magnetite	trace

Plagioclase generally forms euhedral interlocking prisms 1 to 3 mm long, with well-developed normal zoning. Locally, the calcic cores are strongly saussuritized. Microcline is a sporadic accessory, not present in all parts of the stock. Quartz is interstitial anhedral. Biotite is the dominant mafic, occurring as 1 mm euhedra strongly pleochroic from pallid brownish-yellow to dark brown with rare tiny zircon inclusions showing pleochroic haloes. Biotite is partly replaced locally by a pallid yellowish-green, weakly pleochroic hornblende. Biotite also is replaced by chlorite, especially in the specimens which show strong saussuritization of calcic cores of feldspars. Apatite is a sparse accessory as tiny euhedra 40 microns across, included in quartz or feldspar. The only primary opaque mineral is magnetite as anhedra 0.25 mm across; secondary magnetite accompanies chloritized biotite as elongate "flakes" parallel to cleavage.

Contact relations.--The Pescado stock discordantly intrudes the Puquí Metatonalite. The two tonalites have a similar bulk composition and cannot always be easily distinguished in thin section; however, little trouble was experienced in mapping the contact in the field, as it coincided closely with the contact as observed on aerial photographs. Contact-metamorphic effects were observed near the southwest corner of the stock where a dense compact light greenish-gray rock forms a transition zone a few meters wide between the Pescado tonalite and the Puquí Metatonalite. This rock is composed of poikiloblasts of prehnite 0.5 to 1.5 mm across, enclosing stubby 0.2 mm euhedra of diopside, irregular patches of finely granular grossularite, accessory epidote, tiny euhedral sphenes, and sparse euhedral quartz crystals 0.1 mm across.

Age.--A single K-Ar analysis on biotite concentrate (USGS laboratory sample D 1811 B) from the Pescado stock gave an apparent age of 95.6 $\pm$ 3.3 m.y. (R. Marvin, USGS, written commun., Nov. 7, 1968), or earliest Late Cretaceous (Cenomanian), and antedates the Antioquian batholith described later. To date, the Pescado stock is the only known felsic intrusive of this age in Zone II.

Felsic tonalite

A pluton of felsic tonalite covers an area of roughly 175 km^2 having the form of an elongated polygon with its long axis oriented N. 10° E., extending northward from the center of e-5 to the north edge of e-3. This rock is massive light-gray salt-and-pepper, medium-grained hypidiomorphic, similar in appearance both in outcrop and hand specimen to the rock mapped in IIB as Cretaceous adamellite (Feininger, Barrero, and Castro, unpub. data), and is presumed to be more or less contemporaneous with the latter. The IIB adamellite previously described contains potassium feldspar in amounts ranging from 7 to 25 percent, but the felsic tonalite of IIA contains only 2 to 5 percent of potassic feldspar. Composition typically is tonalitic with 1 to 3 mm euhedra of andesine and subordinate interstitial anhedral quartz. Brown biotite, the only mafic mineral observed, contains zircon inclusions that have prominent pleochroic haloes. Muscovite is a sparse accessory, and opaque minerals, especially magnetite, are very sparse.

The felsic tonalite is here assigned to the Upper Cretaceous on the basis of field relations. It intrudes the La Soledad sedimentary rocks, forming a hornfels aureole with andalusite porphyroblasts in argillaceous sandstone in e-4 and e-5, and the much older Valdivia Group schists in e-3 and e-4. The correlative adamellite in IIB has been intruded by the Antioquian batholith. The age of the felsic tonalite therefore is post-La Soledad, and probably pre-Antioquian batholith, or post-Albian to pre-Cambrian.

Confirming radiometric age data are needed.

Antioquian batholith

The arbitrary boundary separating IIA from IIB cuts the Antioquian batholith into subequal parts, and the description of one part applies almost as well to the other. Dr. G. Botero A. (1963, p. 69-81) has studied the Antioquian batholith, especially in quadrangle I-8, immediately south of the area of plate 1.

The bulk of the batholith is quartz diorite or tonalite, but two minor local facies also are shown separately on plate 1, as follows:

1. Hybrid dacite porphyry

2. Hornblende gabbro border facies

The Antioquian batholith is noteworthy more for its uniformity of composition and texture than for its variability. The fresh rock, best seen in road cuts and quarries, has the appearance of a massive, salt-and-pepper gray granite; it has hypidiomorphic equigranular medium-grained texture. The surface of the batholith has been profoundly affected by weathering and decomposition, even at high altitudes such as at Llanos de Cuivá (c-8, alt. 2750 m) or 10 km east of San Andrés de Cuerquía (b-7, alt. 2900 m). The zone of weathered, partly to almost wholly decomposed rock may extend locally to depths of 20 m, and rarely is less than 4 m deep. The phaneritic igneous texture, although blurred, commonly is preserved in the weathered rock, except in the upper 1 or 2 m of reddish earthy latosol or podsol capping. The weathered rock is mottled or variegated cream yellow, yellowish-brown, brown, pink, red, or reddish-brown. The product of weathering and decomposition is mostly kaolinite, or possibly halloysite, and locally, as in the vicinity of Llanos de Cuivá, nut- to fist-sized nodules of reddish gibbsite are dispersed in a sandy kaolin-clay matrix in the upper 2 or 3 meters of the weathered zone.

Terrain underlain by the batholith has low local relief, gently rolling without oriented ridges and valleys, in contrast with areas underlain by older rocks. In spite of this, it is not always easy to distinguish between batholith and other rock units on aerial photographs (T. Kassem, IMN photogeologist, oral commun., 1968). Major stream valleys, however, can be deeply incised and relief here can be appreciable to great.

Few modal analyses were made of thin sections of the batholith within the area of plate 1, but characteristic modal range of the batholith immediately south of plate 1 is presented below, extracted from Botero's data (1963, p. 75-76):

Component	Percent (range)
Plagioclase Ab_{55}-Ab_{65}	50-65
Potassic feldspar	0- 3
Quartz	13-30
Biotite	5-14
Hornblende	3-10
Accessories[1/]	0- 3

Potassic feldspars generally are sparse, but very locally amount to 5 percent or more, enough to merit classifying the rock as granodiorite. Botero A. (1963, p. 76) reports one locality 5 km east of

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1/ Includes apatite, ilmenite, leucoxene, magnetite, pyrite, and zircon.

Concepción, 36 km northeast of Medellín (in quadrangle I-8, south of pl. 1), where potassic feldspar is in excess of plagioclase, and therefore classed as a true granite. In general, however, the name tonalite or quartz diorite is applicable to the batholith as a whole.

The country rock around the northern end of the batholith displays a contact-metamorphic aureole 500 to 2000 m wide. Greenschists of the Valdivia Group have been converted to hornblende-oligoclase hornfels, and the quartz-sericite schists have been converted to quartz-biotite hornfels containing andalusite and rare sillimanite. In the Quebrada Herbecita within the batholith near the northwest corner of e-7, the batholith shows a gneissoid foliation, presumably flow-structure, near the contact with greenstone. Inclusions of the latter have been metamorphosed to hornblende hornfels, and form an intrusive breccia with tonalite matrix.

Hybrid dacite porphyry facies.--The lobate-shaped body of hybrid dacite porphyry in e-8 lies in the midst of a cluster of unassimilated xenoliths or roof pendants of San Pablo Formation. In outcrop and hand specimen, this rock is darker and finer grained, with a greenish tint not usually seen in normal batholith rock. The rock is dark greenish-gray and under the microscope is microporphyritic with scattered sparse subhedral andesine and very sparse 0.8 mm green hornblende prisms. The phenocrysts are seen to be in an allotriomorphic, very fine grained matrix of quartz grains in which are randomly dispersed tiny green hornblende needles. Megacrysts of mosaic quartz are present in some specimens. Feldspar phenocrysts are heavily clouded, partly by incipient saussuritization, and also by unidentified dust, probably an iron oxide. This unit is classified as a quartz-rich dacite porphyry, and is interpreted as a hybrid rock resulting from palingenesis and assimilation of the San Pablo Formation by the invading tonalite magma.

Hornblende gabbro border facies.--The only area of hornblende gabbro border-facies rock has the form of a small lens 1.5 km west-northwest of San José de la Montaña (b-7, b-8). The lens is oriented north-south, is 2000 m long, and the maximum width is 200 m. It is bounded by quartz diorite of the batholith on the east and schist of the Valdivia Group on the west. The dark greenish-gray rock is moderately foliated and has a medium-grained hypidiomorphic texture. The two essential minerals are labradorite (53 percent) and olive-brown hornblende (42 percent). Feldspars are fresh with well developed albite twinning but little zoning. Hornblende forms prisms averaging about 7 mm in length. Accessory minerals include fresh apatite as 0.05-mm euhedral inclusions in hornblende, and anhedral magnetite along hornblende grain boundaries and as inclusions in chloritized hornblende crystals. This rock is classified as a hornblende gabbro and presumably is either a magmatic differentiate of the batholith or a hybrid border rock.

Age of the batholith.--Professor Gerardo Botero A. (1963, p. 81) cites a K-Ar analysis on biotite made at the laboratory of Lamont Geological Observatory and reported by Dr. J. L. Kulp, giving an age of 79 ± 3 million years (Late Cretaceous, Campanian). The sample came from near the hydroelectric power station at Río Grande in quadrangle I-8, about 50 km by highway north of Medellín. Pérez A. (1967, p. 31) assigns an age of 73 ± 3 m.y. (Campanian-Maestrichtian) based on six biotite K-Ar analyses made at the geochronological laboratory of the University of São Paulo in Brazil.

Tertiary Sabanalarga pluton

The name Sabanalarga is given to an elongate north-trending pluton of hornblende diorite near the western margin of plate 1 (a-4, a-5, a-6, a-7, and a-8). Igneous rocks that are believed to be closely related to the Sabanalarga pluton also occur in a-1, a-2, a-3, and b-8. Collectively, the pluton and its correlative facies cover an area of about 260 km^2. The principal pluton east and northeast of Sabanalarga (a-8) is hornblende diorite having a length of 30 km and maximum width of about 10 km. Near where it is crossed by the Río Cauca in a-5, it narrows to 500 or 1000 m, and continues northward as a large dike through a-5 to a point 2 km southwest of Ituango in a-4. Here the lithology changes from the dominant hornblende diorite to hornblendite, continuing northward through a-4 into a-3 where it widens abruptly into a bulbous stock 3 km wide, the western two thirds of which is composed dominantly of hornblendite, and the eastern third of hornblende diorite. Two satellite bodies lie east of the main pluton, one oval body of hornblendite in a-8 about 8 km southeast of Sabanalarga, and another oval body in a-7 composed of tonalite or quartz diorite. Each is roughly 4 km north-south by 2 km east-west. Both intrude greenschist of the Valdivia Group and are surrounded by hornfels aureoles in the latter rocks. Astride the boundary between a-8 and b-8, a third and larger satellite of hornblende diorite 8 km long by 2 km wide intrudes cataclastic tonalite gneiss. Other small plutons correlative with the Sabanalarga pluton are in a-1 and a-2 in the northwest corner of plate 1. The largest of these is a body of tonalite that intrudes metabasalt and extends from the center of a-2, 18 km N. 15° E. to the north edge of a-1. A smaller lens of hornblende diorite in the southeast corner of a-1, 4 km north-south with maximum east-west width of 800 m, lies along the contact between metabasalt and schist of the Valdivia Group.

Relations with surrounding formations.--The pluton at Sabanalarga is bounded on the west mainly by metabasalt of Cretaceous age and by greenschist of the Valdivia Group. The north end of the main pluton in a-6 and its narrow extension north of the Río Cauca in a-5 is bounded on the west by the cataclastic gneiss of the Valdivia Group. Contacts are covered, but it is very probable that this contact has been faulted. The main pluton, including the northerly extension, is bounded on the east by greenschist of the Valdivia Group; the contact on this side is clearly intrusive as the greenschists have been contact metamorphosed to hornblende-hornfels, and local quartz-mica schist intercalations contain andalusite porphyroblasts. Roof pendants of greenschists have been mapped within the main body in a-7 and a-8. North-trending grabens 200 to 1000 m wide containing younger Tertiary sediments have been downfaulted into the main body in a-6, a-7, and a-8.

Hornblende diorite.--The hornblende-diorite is medium-grained hypidiomorphic equigranular, commonly subophitic in texture; it is medium gray, with hornblende crystals interspersed in plagioclase. Under the microscope the euhedral to subhedral feldspar laths are in the range andesine (An_{40}) to bytownite (An_{80}), and commonly constitute from 50 up to 70 percent of the rock. Fresh feldspar is rare, as the majority of specimens are clouded by saussurite and minor sericite. Zoning is not conspicuous. Hornblende, invariably strongly pleochroic from a pale yellow to deep olive-green, is the other essential mineral. Judged by color, much of the hornblende seems to fit the description of ferrohastingsite given by Deer and others (1963, v. 2, p. 264). Common accessories include anhedral interstitial quartz (to 5 percent), chlorite, sphene, apatite, and zircon. Magnetite is an ubiquitous minor opaque accessory; pyrite is less common but not rare. Biotite to 4 percent, commonly altered to chlorite, is a sporadic but not characteristic accessory.

Hornblendite.--The hornblendite crops out in three main localities as follows: 1) An oval body 8 km southeast of Sabanalarga (a-8); 2) narrow marginal zone along the contact between the main pluton and greenschist (especially a-6); 3) dike-like extension west of Ituango (a-4) that continues northward to form the stem and western half of a bulbous stock (a-3). Texture is characteristically medium-grained hypidiomorphic but ranges from fine-grained to coarse-grained pegmatitic. Hornblende comprises 50 to 80 percent of the rock, with calcic feldspar as the other essential mineral. Alteration of hornblende to chlorite along cleavages is evident in some specimens, and also sericitization and saussuritization of plagioclase. Very tiny euhedral crystals of sphene and apatite are numerous. Magnetite, both as granular clusters and as disseminated 0.1 - 1 mm anhedra, included within or along the edges of hornblende crystals, may constitute from 2 to 6 percent of the rock. Pyrite and pyrrhotite are common opaque accessories, but less abundant than magnetite. The hornblendite and hornblende diorite facies grade so imperceptibly into each other that boundaries between them are drawn arbitrarily.

Tonalite.--Tonalite makes up an oval stock east of the main pluton in a-7 as well as in parts of the main pluton, especially near its eastern margin in a-6. The tonalite facies of the main pluton is not mapped separately, but the oval stock and the long body in a-1 and a-2 are mapped separately. The tonalite is distinguished from the hornblende-diorite by coarser texture, greater quartz content, as much as 40 percent olive-green biotite as a characteristic component, a lesser amount of hornblende, andesine dominant instead of labradorite, and sparser opaque minerals. The hornblende is commonly but not invariably altered to epidote. Biotite in the north tonalite body is chloritized, and the plagioclase heavily saussuritized, with cataclasis evident. Porphyritic texture may be developed near the contact with enclosing schists, with plagioclase phenocrysts up to 2 cm across in a fine-grained hypidiomorphic groundmass. One specimen of tonalite in a-2, more mafic than the ordinary, shows a microscopic symplectic intergrowth of quartz "worms" in fresh green hornblende, the latter also containing an unusual abundance of 0.05 mm euhedral inclusions of apatite. The tonalite bodies are interpreted as felsic differentiates from magma of the main pluton.

Origin and age.--With the exception of the tonalite, the bulk composition of the Sabanalarga pluton and related rocks is much more hornblendic than that of the other major plutons shown on plate 1. It is debatable whether or not the higher hornblende content can be ascribed to a more mafic magma or to contamination by invaded rocks, especially by metabasalt and greenschist. Contact relations of the hornblendite with greenschist of the Valdivia Group suggest that it may be a hybrid resulting from the assimilation or paligenesis of greenschist by invading magma. Gradation from hornblende diorite into hornblendite and finally into hornblende-hornfels as the contact is passed between igneous intrusion and greenschist hostrock, is a characteristic relationship, and boundaries are gradational and drawn arbitrarily in the field.

No radiometric analyses have been made on any of these rocks and their age is not known precisely. For the present the Sabanalarga pluton is correlated with similar diorite intrusions south of Sabanalarga, to which Grosse (1926, p. 83) assigned an early Tertiary age. The Sabanalarga rocks are post-metabasalt and are tentatively assigned an early Tertiary age; however, penecontemporaneity with the Late Cretaceous Antioquian batholith cannot be discounted. Neither the Sabanalarga pluton nor the Antioquian batholith show obvious effects of regional metamorphism.

Andesite porphyry

A lens of andesite porphyry 3 km long and 150 m wide, parallel to, and presumably controlled by, the Romeral fault, is shown on plate 1, in the northeast corner of d-2. The typical rock is gray, fine-grained, and porphyritic; andesine phenocrysts 1 to 3 mm long are set in a felty groundmass of 0.1 to 0.6-mm lath-shaped andesine crystals. Normally zoned crystals have saussurite-clouded interiors and sericitized sodic rims. Groundmass plagioclases show simple Carlsbad-twinned laths. Quartz is sparse. Flakes of pale green chlorite dispersed in the groundmass may have been derived from the alteration of hornblende or biotite. Interstitial calcite is a prominent constituent, probably a secondary filling in miarolitic cavities. Anhedral magnetite grains 0.1 mm in diameter, commonly with sphene rims, are dispersed in the matrix as the principal opaque accessory. Locally pyrite forms blebs 3 mm across.

The andesite is a hypabyssal intrusive of undetermined age. Most similar porphyritic andesite epizonal intrusions elsewhere in Antioquia have been assigned by previous workers to the Tertiary, and this age is tentatively assigned to this body. Numerous unmapped dikes of similar andesite ranging in width from 0.5 to 3 m cut the micaceous gneiss and Puquí Metatonalite on the northwest side of the Romeral fault in d-2, and are presumed to be comagmatic with the andesite porphyry.

METAMORPHISM

Regional metamorphism was less carefully studied in IIA than in IIB, and the reader is referred to Feininger and others (in press) who describe the geology of IIB, for a more complete account of metamorphic petrology, and the significance of certain minerals in metamorphic facies, a part of which has application to the rocks in IIA. Only a few general observations are offered here.

Regional metamorphism generally is of lower grade in the area of plate 1 than in other parts of Zone II, but the significance of this difference is not yet clearly understood. It may be related to the position of the rocks within the geosyncline relative to succeeding dynamic and thermal events. The area of IIA lies entirely within the eugeosynclinal domain; IIB is nearer to the continental craton, and along its eastern side the rocks have miogeosynclinal affinities, including large volumes of carbonate rock which is notably sparse in IIA.

The greenschist facies grade of regional metamorphism is characteristic of the greater part of plate 1, including the bulk of the Valdivia Group. A part of the feldspathic gneiss of the Valdivia Group is interpreted as belonging to the amphibolite facies. The micaceous gneiss also is of amphibolite facies.

South of the area of plate 1 in quadrangle I-8, Botero A. (1963, p. 57-61) and his colleagues have mapped extensive amphibolite which he classified as intrusive orthoamphibolite. One of the present authors (Hall) is inclined to the opinion that at least some of these amphibolities may be a product of contact metamorphism of greenschist facies rocks near the contact with the Antioquian batholith. The amphibolites in quadrangle I-8 to the south are distributed along the batholith contact more or less coextensive with quartz-mica schists that are equivalent to the Valdivia Group. Such extensive amphibolites were not observed in the area of plate 1, which lies generally north of the batholith and therefore is less likely to have been subjected to such intense contact metamorphism as correlative rocks in quadrangle I-8. Plate 1 shows a contact aureole around the north end of the batholith where greenschist has been contact-metamorphosed to amphibolite hornfels and quartz-sericite schist to quartz-biotite hornfels.

The Mesozoic ophiolites and Cretaceous sediments not adjacent to intrusive contacts have been only slightly metamorphosed and Tertiary rocks are virtually unmetamorphosed.

STRUCTURAL GEOLOGY

Only the most outstanding structural elements of IIA shown on plate 1 are discussed here.

Folds

Virtually all pre-Pleistocene layered rocks in IIA have been folded and tilted. Metasedimentary rocks of the Valdivia Group and Cretaceous strata have been profoundly folded. Synclinal and anticlinal axes are shown on plate 1 only wherever dip measurements are sufficient to allow this. The fold axes strike north parallel to the regional trend. The San Pablo Formation (e-5, e-6, e-7, and e-8) probably lies in a syncline, and the presumably younger band of La Soledad Formation east of the San Pablo (e-4, e-5, and e-6) also appears to lie in a syncline that is transected by a normal fault with the east side downthrown.

Faults

Faults and photogeologic "lineaments" are numerous in the area, but only the most prominent of these are described here.

Romeral fault

The most spectacular geologic structure of IIA is the Romeral fault which cuts diagonally from northeast to southwest across the quadrangle, and is traceable continuously for a distance of 300 km where it extends beyond the southern boundary of Zone II. The fault was first named by Grosse (1926, p. 292-294), who traced it for 80 km in the area mapped by him. However, it was not until field mapping by IMN and the Facultad Nacional de Minas, and after photo interpretations of Taissir Kassem were synthesized with Grosse's mapping, that the magnitude and continuity of this fault were recognized. Grosse named it for the Cuchilla Romeral, a ridge some 15 km southwest of Medellín. Grosse's designation, "Romeral," clearly has precedence over other names, and is here applied over the entire length of the fault in IIA.

The youngest rocks displaced by the Romeral fault in the area mapped by Grosse (1926) are terrestrial conglomerate, sandstone, and shale of middle Tertiary age. Clastic sediments and volcanic rocks of Tertiary age also are displaced by the fault in the southwest corner of Zone II. Rocks of Paleozoic age have been profoundly displaced by the Romeral fault in the area shown on plate 1. Small metagabbro and serpentinite bodies of Early Cretaceous age in b-7 also have been displaced by it. It is possible that movement on this fault had originated and that considerable displacement had taken place before the Tertiary.

Grosse (1926) interpreted the Romeral fault as a high-angle east-dipping reverse fault of largely vertical displacement. However, its great length and the sharp differences in lithology on opposite sides over a distance of at least 65 km as shown on plate 1 suggest that it may be a major wrench fault with great lateral displacement, comparable to the well-documented wrench faults in eastern IIB (Feininger, 1970).

Although the Romeral shows characteristics of a large wrench fault, the direction of displacement is not known with certainty. The wedge of cataclastic tonalite gneiss in the southeast corner of plate 1 looks like a block dragged by right-lateral displacement, and its petrographic characteristics are not greatly different from the Puquí Metatonalite lying on the opposite side of the fault some 30 km to the northeast. If the two tonalitic units are proven to be truly correlative, this would be strong evidence supporting right-lateral movement. Recent mapping by IMN geologists in IIB (Feininger, Botero, and Castro, written commun., 1970) shows strong similarities between rocks there and parts of plate 1 underlain by the micaceous gneiss and Puquí Metatonalite. If these two suites eventually are proven to be correlative, this would be evidence favoring left-lateral displacement. Displacement in either case, whether right- or left-lateral, probably is measurable in tens of kilometers.

Santa Rita fault

The Santa Rita fault cuts rocks of the Valdivia Group along its 75 km trace from 1 km east of Santa Rita (b-2), southward to a point 10 km southeast of Sabanalarga (a-8), where it joins the Romeral fault. Direction and amount of displacement are not certain, but the Early Cretaceous metagabbro lens on the boundary of b-3 and b-4, has been mapped as having right-lateral displacement of about 200 m along the fault.

The sinuous, narrow, northeast-trending band of lenticular gneiss in b-5 and b-6 is mapped as being obliquely transected by the Santa Rita fault without evident horizontal displacement. However, control is poor. Two small lenses of serpentinite, each about 500 m long, have been intruded along the fault 5 km north-northeast of Santa Rita. A lens of serpentinite 8 km due east of Sabanalarga (a-8), containing sparse veinlets of chrysotile, lies along the west side of the Santa Rita fault. The emplacement of the serpentinite appears to be associated with the fault, possibly indicating that the fault existed in the Cretaceous.

Sabanalarga fault

The Sabanalarga fault is a prominent north-striking fault near the western margin of plate 1. For the southernmost 25 km of its length on plate 1, its two subparallel branches form a graben several hundred meters wide in which are Tertiary clastic sediments associated with local coal layers. The mechanical forces that caused the Sabanalarga fault must have been fundamentally different from, and presumably later than, the forces that caused the Santa Rita and Romeral faults.

GEOLOGIC HISTORY

Precambrian and Early Paleozoic

The oldest formation exposed is the Micaceous Gneiss, whose age is unknown, but which has been tentatively classified as Early Paleozoic, almost certainly pre-Devonian. A Precambrian age for the gneiss cannot be ruled out. Based on mineralogical composition, which includes a preponderance of quartz and mica, and accessories such as graphite and sillimanite, the Micaceous Gneiss is believed to be a paragneiss derived from ancient sedimentary deposits. The original character, source, and mode of deposition must remain conjectural for the present. The metamorphism is of a higher grade than that of the greenschist facies that characterizes the bulk of the younger Valdivia Group (post-Silurian?). This implies deep burial and metamorphism prior to formation of the geosynclinal trough in which the Valdivia Group sediments were deposited. A major unconformity probably separates the Micaceous Gneiss from the Valdivia Group, but contacts are covered and relations are obscure.

Middle and late Paleozoic

The Valdivia Group represents an enormous thickness of sediments, possibly as much as 13 km, indicating that a gently subsiding geosynclinal trough must have prevailed for a long time. The great prism of Valdivia Group sedimentary and volcanic rocks filling the trough, and the Micaceous Gneiss forming the floor of the trough, were subjected to extensive regional metamorphism, probably contemporaneous with intrusion of the syntectonic Puquí Metatonalite during a Late Permian(?) orogeny. Other syntectonic plutons more or less contemporaneous with the Puquí Metatonalite also were intruded during this major metamorphic-orogenic event.

Triassic and Jurassic

No known Triassic or Jurassic rocks are exposed in IIA. In general it appears that the area was undergoing erosion following the Late Permian(?) orogeny. Near the close of the Jurassic, a trough must have formed to set the stage for events during the Cretaceous.

Cretaceous

The Early Cretaceous was marked by outpourings of submarine basalt, at least part of which was spilitic, followed closely by deposition of flysch of the San Pablo Formation. Both rock types covered a much larger area than that represented by present exposures, which are mere remnants. Shortly after deposition of the San Pablo Formation a second tectogenic interval followed in which the San Pablo and older rocks were subjected to sharp folding, deep rifting, and syntectonic intrusion of small gabbro plutons accompanied by serpentinites, presumably from a source in the upper mantle. These formed an alpine intrusive complex similar to those discussed by Thayer (1967). The dikelike body of cataclastic granite (e-6, e-7, e-8) evidently was intruded shortly after the mafic-ultramafic intrusive episode.

The Romeral wrench fault may have developed at this time as a great fracture in the crust, and intermittent strike-slip displacements took place along it through the remainder of the Cretaceous and during the Tertiary. A few small gabbro and serpentinite bodies adjacent to the Romeral and Santa Rita faults suggest that the faults may have controlled their emplacement.

The gabbro-serpentinite alpine intrusive tectogenic episode was followed by a brief quiescent period when the La Soledad Formation was deposited, of which only a remnant is now preserved (east edge of plate 1).

The Late Cretaceous basalt (now metabasalt) and mafic pyroclastic assemblage shown along the west edge of plate 1 was deposited in a submarine environment, as shown by the initmately intercalated radiolarian chert layers. The relationship of the patch of flysch mapped in the northwest corner of plate 1 to the adjacent basalt-chert assemblage is not clear, but its position suggests that it overlies the basalt. The axis of submarine basalt outpourings and of flysch sedimentation is thought to have migrated from east to west across the zone, that is, the eugeosynclinal axis shifted toward the west from Early to Late Cretaceous time. The Pescado tonalite stock and the felsic tonalite were intruded during the early Late Cretaceous, but the culminating event was intrusion of the great post-orogenic Antioquian batholith in Campanian-Maestrichtian time.

Tertiary

Plutonism continued into the early Tertiary with emplacement of the Sabanalarga pluton and related rocks. A lens of andesite porphyry, tentatively assigned to the Tertiary, was intruded along the Romeral fault.

Sedimentation was active, at least in some areas, but we know little about the relative ages of the sparsely distributed remnants of the nonmarine Tertiary sedimentary units. Sedimentary basins covered large areas west of the Río Cauca, prior to the latest regional uplift and erosion. Some of the Tertiary sediments were deposited in a limnic environment as shown by lignitic local coal beds, and these sequences may be classified as "molasse," that is, sedimentary detritus from elevated cordilleran highlands was deposited in adjacent intermontane basins or troughs.

Alluvial deposits were formed by Tertiary streams draining the Antioquian batholith, many of which differ in course and direction of flow from the modern drainage. A few remnants have been preserved and some contain placer gold (e-5). Adjacent lowlands were subjected to deep secular weathering exemplified by laterite over serpentinite at Morro Pelón (e-5, e-6).

Regional uplift (epeirogenesis) presumably commenced in the Pliocene, continued through the Quaternary, and may still be going on. Palynologic data from organic clays associated with the Antioquia old land surface are needed to show more precisely the time that uplift began. The Sabanalarga fault (a-3 through a-8) may have come into existence in the late Tertiary; Lower Tertiary coal-bearing beds are preserved in a graben between it and associated faults (a-6, a-7, a-8).

Quaternary

Erosion sculptured the land into its present form as degradation was accelerated by regional uplift through the Quaternary Epoch. Some normal faulting accompanied the uplift. Vast quantities of rock debris were removed from highlands and carried by the Rió Cauca to the Rió Magdalena and thence to the sea. Quaternary alluvium fills the stream valleys; much of it is auriferous, although placer mining for gold is far less important today than it was in past centuries. Man's importance as a geologic agent has greatly increased since the beginning of the present century, with urban and industrial development and construction of roads and highways. These activities have contributed to air and water pollution, which, if allowed to increase unabated, will create problems for Colombia similar to those in more fully industrialized countries.

ECONOMIC GEOLOGY

Metallic mineral resources

Most of the known mineral deposits of actual or potential economic importance inside the boundaries of subzone IIA are described here. The mines, quarries, and prospects are shown on figure 2, including some active gold mines and a few of the principal abandoned gold mines. Not all abandoned mines shown on figure 2 are discussed in the text. It is impractical to locate the dozens of small abandoned gold mines and prospects on figure 2.

The mining industry of Antioquia was founded on the exploitation of gold, beginning in pre-Colombian times. Activity was accelerated during and following the Conquests, and continued with diminishing importance through the 19th century to the present. Nonmetallic minerals now play a more important economic role than metals in IIA, as exemplified by development of the portland cement, ceramic, mineral filler, and construction-materials industries.

Concomitant with the regional geologic mapping, IMN undertook special exploration projects to explore deposits or prospects about which few data were available. The most important of these are listed on table 2.

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 geologists' attention. Wholly concealed or "blind" deposits may be found in the future by geophysical, geochemical, or other sophisticated exploration techniques not employed during this investigation.

Gold and silver, lode mines

The production of gold and byproduct silver in subzone IIA is small in comparison to that in subzone IIB, primarily because of the dominance of two large operations, a lode mine, Frontino Gold Mines Ltd., and a placer, Pato Consolidated Gold Dredging Ltd. in IIB. Gold mining now is far less important to the Colombian economy than

Table 2.--Special IMN exploration projects in subzone IIA, 1964-1967.

Project Title and location	Commodity	Kind of work performed	Date
Buriticá, 3 km SE of Buriticá	Cu, Pb, Zn, Au, Ag	Detailed topographic and geologic mapping, diamond-drilling, sampling, assays, appraisal of resources.	July 1964-October 1966, intermittent
Morro Pelón laterite (pl. I, e-6)	Fe-, Ni	Test pitting, sampling, assays.	Dec. 1964-Feb. 1965
Yarumal (pl. I, d-6)	Talc	Detailed topographic and geologic mapping, diamond-drilling, sampling, analyses, reserve calculation, market study, appraisal of large-scale development potential.	Feb. 1966-Nov. 1967, intermittent
Llanos de Cuivá (pl. I, c-8)	Bauxite	Test-pitting, auger drilling, sampling, assays.	July- June 1966
Uré laterite 2 km W of Uré	Ni, Fe	Detailed topographic and geologic mapping, text-pitting, sampling, analyses, and reserve calculation.	Oct. 1966-Dec. 1967, intermittent.

it was in bygone centuries. The annual volume of present production of gold and silver in IIA is minuscule compared to the value of currently produced nonmetallic minerals and their derivatives. Even so, gold and silver are still paramount among metals produced in Zone II. A more detailed historical background of gold mining is given by Hall (in Hall, Feininger and others, 1970).

Silver in Zone II is a byproduct or coproduct of gold, because these two metals generally occur together in nature. Silver may be more abundant than gold in a given ore, but the value of gold is about 18 times that of the same weight of silver, so that gold is commonly the main source of revenue. There are no primary silver mines in Zone II in which silver is the metal of principal value.

Only major active mines, including a few placer districts, are discussed in this report. Vignette descriptions of small mines and prospects may be found in Restrepo (1937), and in the archives of the Ministry of Mines and Petroleum in Bogotá, and Medellín. The great majority of these are of little economic importance, and have been abandoned for many years.

Minas Nacionales de Marmato and private mines at Echandiá.--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 now held by Minas Nacionales de Marmato, a government agency, under the direct administration of the Ministry of Mines and Petroleum. The northern end of the mineralized area, the Echandiá workings, is under concession to private interests in Medellín. The two areas are discussed together here because they constitute a single geologic entity. Among lode gold mines in Zone II, their production is a distant second in importance after Frontino Gold Mines Ltd. in IIB (Hall, Feininger and others, 1971).

The mines are 150 km by highway south of Medellín and are located in quadrangle J-8 outside the area mapped by IMN. The mines are immediately north of the town of Marmato, in rugged terrane west of the Río Cauca, at an altitude of about 1400 m. Access is via 15 km of narrow road east-northeasterly from the municipality of Supía, Department of Caldas situated on the Medellín-Cali highway. The Echandiá veins are 500 m north of the Marmato mines.

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 Tertiary 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 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 in the rock might be secondary, related to vein formation (Fetzer, 1939, p. 7241). 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 galena, 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 Echandiá.

Recovery presently averages about 8 g of gold per metric ton, and slightly less than 8 g of silver, according to the mine manager (J. Marquez, oral commun., 1968). True tenor is higher, especially of silver, because metallurgical losses are large in the primitive mills. Silver tenor is appreciably higher than gold at Echandiá, which was described as a silver mine in the early 19th century (Restrepo, 1937, p. 89, 95). The host rock of the Echandiá veins is a 400 m-long roof pendant of quartz-sericite schist.

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 or ore milled (1939, p. 7253), and, with the Colombian peso on 1:1 par with the U.S. dollar at that time, and assuming 65 percent metallurgical recovery, the tenor of mill heads expressed in equivalent gold content is calculated at 15 g per metric ton.

This suggests that the tenor in 1939 was not much different than that reported in 1968.

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 about 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. 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 1 ton.

The ore is passed through stamp mills and Wilfley-type tables, and the concentrate is mulled and panned to recover about 60 percent of the gold. The pyrite-rich tailing from panning is batch-cyanided in small concrete vats. Metallurgical losses are high.

Production from the Marmato district for 1967 was reported by the Asociación Colombiana de Mineros as follows: gold, 71,312 g; silver, 60,823 g. About 80 percent of the above came from Minas Nacionales de Marmato and 20 percent from the private Echandiá 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.

La Bramadora mine.--This mine ranks third in importance in Zone II 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 e-7, plate 1, on the west bank of the Río Porce alongside the road 20 km south of Anori. An estimated 65 men work at La Bramadora, 50 in the mines, and 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 are 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, is 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 sorted by hand underground and at the adit portal, and is transported to the stamp mill by wheelbarrows or in burlap bags carried on the miners' backs. Ratio of ore to waste is estimated at roughly 1 to 1. 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-hour day, but this is rarely achieved.

Berlín mine.--No discussion of lode gold mines in Zone II would be complete without mention of the old Berlín mine, 25 km airline in a northwest direction from Yarumal (b-5, pl. 1). The mine formerly was accessible by 54 km of tractor road constructed by the company from the Yarumal-Valdivia highway, but this has long since become impassable to vehicles. The site can be reached today only by mule-trail. 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 Berlín deposit was not discovered until 1929 (Singewald, 1950, p. 131). During its relatively brief period of exploitation it rivaled the Frontino 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 Corporation, and operations were conducted thereafter under the name Timmins-Ochalí Mining Company. The old workings are inacccessible 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 strikes almost due north, with steep east dip, and is located along the contact between quartz-sericite schist on the footwall side and chloritic greenschist on the 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 about 1 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. 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; if displacement was left lateral, the vein formed at a location quite removed from the batholith; if displacement was right lateral, the batholith could well be the mineralizing source. 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 (pl. 1, 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 nearby Paleozoic metatonalite as the probable source of the Berlín vein.

Average mill-head 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 was reported as 710 Au and 270 Ag, 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 in view of the location of the mine, 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 1200 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 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

U.S. $1.125 per gram, had a gross value of U.S. $14,453,833.50. From these data the 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 more than 800 persons were employed at the peak of operations.

For the past several years mining has been resumed on a small scale, the concession having been acquired by private interests 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; tailings are cyanide-leached in small concrete vats. About 30 persons are employed.

Gold and silver, placers

Supía placer district.--Once an important gold-producing area in southwestern Zone II, this district today is exploited only sporadically by 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 Company immediately south of the town of Supía on the river of the same name has been described briefly by Singewald (1950, p. 135); most of the following information is extracted from his report. The dredgable part of the valley is 200 to 300 m wide, about 8 km long, with depth to bedrock of 5 to 6 m. Reserves are reported to have been 12 million cubic yards (9.2 million cu m), with values of 40 cents U.S.

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 U.S. $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 as much as 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 dredgable 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 reported to be gold-bearing. Some of the more extensive and favorably located gravel banks are potentially exploitable by hydraulicking or by drag-line dredging. Some of the principal streams, tributaries of the Río Cauca, that appear to be 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 U.S. $35 per ounce troy probably will be needed to stimulate exploration of these alluvial deposits.

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 World War II, 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. In 1966-67 an attempt was made by Senor 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-Tarazá-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.

Porcecito placer district.--The Porcecito district on the Río Grande above its junction with the Río Porce, 30 km east-southeast of the Santa Rosa de Osos, was mined by hydraulicking, and also by a 3-cubic-foot bucket-ladder dredge operated by Minas de Oro de Procecito, 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.

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; results are summarized later in this report. Neither deposit has present economic importance.

Medellín laterite

Ferruginous laterite derived from underlying serpentinite crops out on a west-facing mountainside overlooking the Aburra Valley northeast of the city of Medellín. Thickness of the richest part of the laterite mantle ranges from 1 to 5 m and averages nearly 3 m over an oval-shaped area of approximately 450 hectares (Restrepo A., 1959, p. 20). Reserves according to Restrepo are 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 as much as 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 from 13 to 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 A. (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

The Empresa Siderúgica S. A. iron and steel plant investigated the local laterite as raw material, and a mining concession 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 using Medellín laterite. However, the possibility of using Medellín laterite as iron ore continues to be remote, not only for technical reasons, but obviously because much of the laterite area is now covered with houses during the vigorous urban growth of the past 30 years.

Morro Pelón laterite

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 oval 2.7 km north-south by 1 km east-west along the boundary between e-5 and e-6 (pl. 1), the greater part being in e-6. The deposit occupies the crest of a broad north-striking ridge with its summit at an altitude of about 1440 m, sloping gently northward 3 km to the Río Nechi at an altitude of 700 m.

Eleven test pits excavated 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; a hard cap of iron oxides 10 to 40 cm thick at the surface overlies brown earthy laterite 1 to 5 m thick, which grades downward into dark-green or black decomposed serpentinite.

Iron tenor from 74 analyses (dry basis) ranges between 23 and 56 percent and averages 27.6; nickel tenor ranges between 0.23 and 1.21 percent, with an average 0.69 Ni. Although Morro Pelón was originally considered to be an iron prospect, 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 the 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; Park and MacDiarmid, 1964, p. 414-415). The present climate may mot 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 rdige, with its highest part 1440 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 preceded the latest regional uplift, which was gradual for a long period and may still be taking place. Uplift must have begun in late Pliocene or early Quaternary; the Morro Pelón laterite is tentatively assigned a Late Tertiary age on the geologic map (pl. 1). The pre-uplift origin 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 over a large region, and that the several laterite bodies in IIA are more or less contemporaneous.

Nickel

Nickeliferous laterites have been recognized in the Department of Cordoba for at least a decade. The most important locality is at Cerro Matoso, 30 km southwest of Montelibano, just north of Zone II. A project to exploit the relatively rich and extensive deposits at Cerro Matoso has been arranged between Hanna-Chevron Co., a joint venture of Hanna Mining Co. and Chevron Petroleum Corp., and Instituto de Fomento Industrial, an agency of 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 Cordoba, at the extreme northwest corner of the zone, were considered deserving of special IMN study. A team of two geologists and a topographer were assigned late in 1966 to make topographic and geologic maps, excavate test pits, and to take samples to delimit the laterite bodies and estimate reserves. During the investigation, 36 test pits were excavated; they range in depth between 3 and 13 m and aggregate 230 m in depth. 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 Vasquez, aided by personnel and facilities of the Servicio Minero Laboratory, Ministry of Mines and Petroleum, 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 figure 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 is 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 figures 3 and 4, is dark grayish green, composed of antigorite and lizardite with remnants of olivine and augite (diallage). Enstatite was tentiatively identified in some specimens, according to Velásquez (oral commun., 1969).

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.

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.

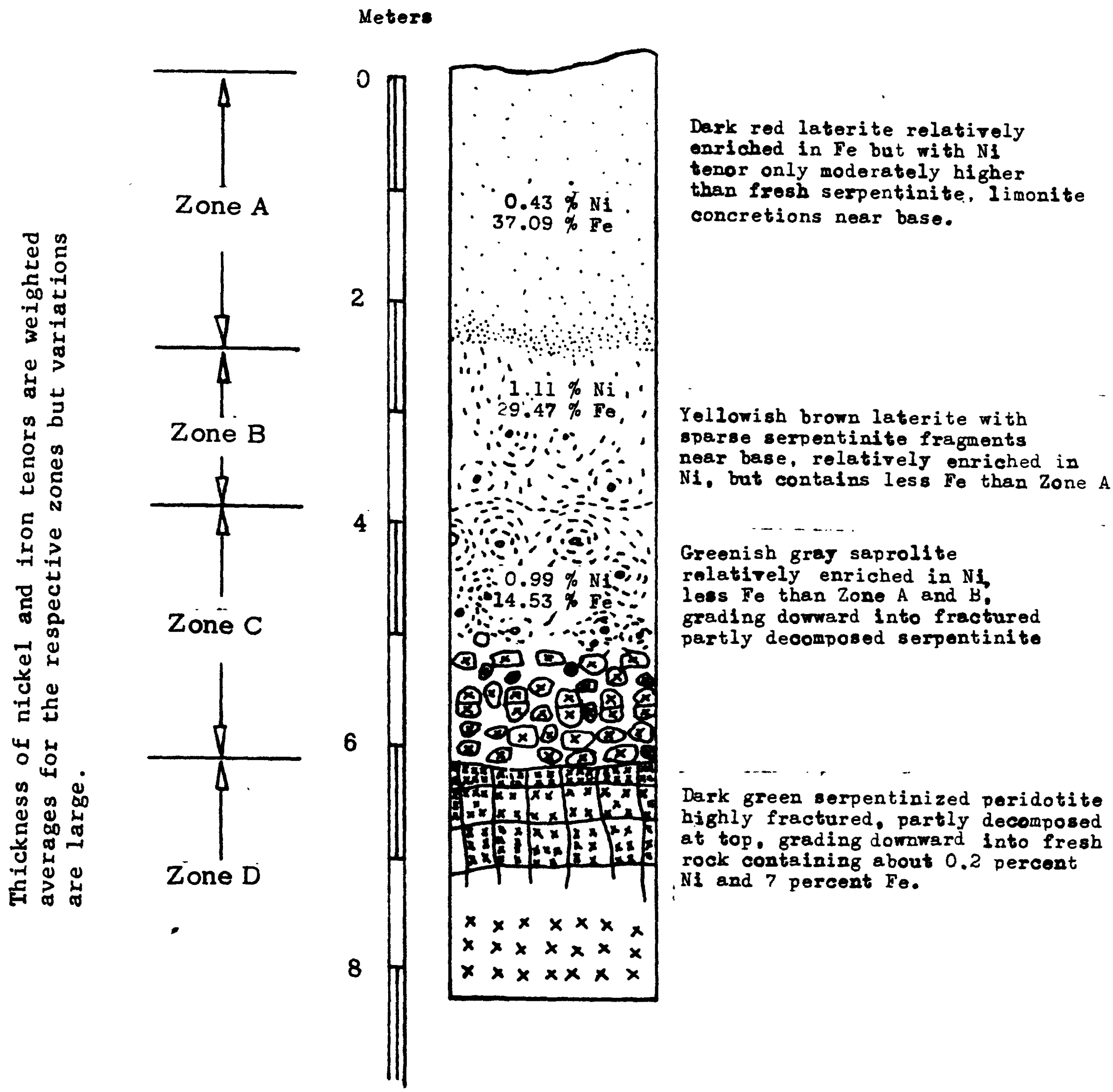

Figure 4. Characteristic profile of nickeliferous laterite at Uré (After Dario Velásquez H., 1969, unpub. data).

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 quite 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 figure 3 by zones. In view of the relatively low average nickel tenor of zone A, it will probably be more economical to strip it as waste, although this would sharply reduce reserves.

Origin

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

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 stage supposedly favors the exchange of Ni^{++} for Mg^{++} in the lower part of the laterite mantle.

A second theory suggests that originally neutral rainwater becomes acidic as it dissolves atmospheric carbon dioxide and humic 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 hydrated aluminum oxides. Although some residual nickel enrichment occurs here, a 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 tc 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. 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.

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)
Al_2O_3	94	2.12 - 38.00	16.65
Cr	105	.03 - 2.10	.46
Co	6	.010- .016	.0126
Mn	131	.05 - 1.40	.34
P	101	.004- .100	.041
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 chromite and chrome spinel (picotite) 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 H., 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. 4), 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 3400 ppm of Mn is higher than the normal abundance of 1040 ppm of Mn in ultramafic rocks reported by Goles (1967, p. 357); however, quantitative analyses of Mn in fresh serpentinite at Uré are lacking.

Phosphorus 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 H., unpub. data, 1969). Logically, the exploitation of nickeliferous laterite in Colombia should begin at Cerro Matoso. Velásquez points out that after Cerro Matoso reserves are exhausted and the costs of the metallurgical plant amortized, the laterite at Uré might then be exploited economically. Therefore it is a paramarginal resource rather than one for immediate exploitation.

Mercury

Nueva Esperanza mine at Aranzazu

The Nueva Esperanza mercury mine is 7 km north of Aranzazu in the Department of Caldas, 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 in 1948. 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 on 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 2200 m. The ridge is accessible by car from Aranzazu, but the mine can be reached only by half a kilometer of foot trail descending into the steep valley of Quebrada Manzanilla.

Native mercury occurs as tiny droplets disseminated along a shear zone of steep east dip, striking roughly N. 20° E., 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 intrusive andesite in the district (Wokittel, 1958).

Six adits have been driven into the hillside at vertical intervals of roughly 20 m; virtually all the current production is coming from the three lower levels designated numbers 4, 5, and 6. Many old galleries are now inaccessible. 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 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 was treating about 30 tons per day in August 1967.

A total of 4600 metric tons milled during 260 operating days in 1967 yielded 192.2 flasks (6631 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 sparse 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.

The recovered native mercury, said to be 99.97 percent pure, is poured into standard flasks of 76 lb (34.5 kg) net for delivery to the domestic market. Principal buyers include Planta Colombiana de Soda (soda ash-chlorine plant) at Zipaquirá and Cartagena, Pato Consolidated Gold Dredges Ltd., Cía. Minera de Narino, 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 are 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 1520 m, 2.5 km southwest of Aguadas, Department of Caldas. The first published reference to mercury in this locality was by Morer and Nicholls V. (1962), who describe it as the "El Socorro mine." A concession to explore for the mine mercury is said to be held by a syndicate of Caldas businessmen (A. Sanchez, oral commun., 1967). In 1966 three short exploratory adits were driven into the hillside to crosscut north-striking, vertical to steeply east dipping foliation of the schist. One adit is 30 m long, bearing N. 30° E.; the second, 40 m south of the 30-m adit, is 18 m long, bearing N. 40° E., and the third was 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 minerals were seen in the 18-m adit, but a few specimens of vein material and graphitic quartz-mica schist containing sparse spots of cinnabar and tiny mercury globules 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 said to contain sparse cinnabar and native mercury (M. Barsona, oral commun., 1967). Work was abandoned in 1966 without having produced mercury. The present authors concur with Morer and Nicholls V. (1962) that the El Mico mercury prospect has little if any economic value. However, the presence of mercury in each of the three adits, separated by a horizontal distance of some 250 m, clearly suggests a geological environment favorable for mercury.

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. Exploration for mercury in the Aguadas-Aranzazu belt could best be accomplished in stages as follows:

1) Detailed reconnaissance of localities that show mineralization and a favorable geological environment, especially faults and shear zones in graphitic schists within a few kilometers of Tertiary intrusive andesite.
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 commun., 1967). The use of this kind of apparatus also has been suggested by W. J. Dempsey (U. S. Geological Survey, written commun., 1968). A serious but not insurmountable handicap to his 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.
3) Direct methods, such as test pitting, driving underground galleries, or diamond drilling should be employed as targets are indicated by steps 1 and 2. Geologic mapping on a scale of 1:10,000 or larger should immediately precede these works.

Chromite

Las Palmas-Santa Elena deposits

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, 1950, p. 92-93; Wokittel, 1960, p. 151), but exploitation 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 ore of variable tenor. Small tonnages of material containing 30 percent Cr can be obtained by selective mining and careful hand picking. The known deposits cannot support a large-scale mining operation.

The past production of crude chromite has not exceeded 200 tons per year; the chromite is 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 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.

The possibility of discovering large-tonnage hidden orebodies beneath the surface appear to be small. 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 contrast of magnetic susceptibility between chromite and enclosing ultramafic rocks are negligible and difficultly predictable. Gravimetric surveys might be helpful (W. J. Dempsey, USGS, oral commun., 1968), but great care would be needed in making topographic and altitude corrections in the broken terrain.

Manganese

The only significant deposits of manganese known in the zone are located 4 km northwest of Santa Barbara 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 Dario Velásquez H. (unpub. data, 1967).

Thin-bedded cherts intercalated with tuff, greenstone, phyllite, quartzite, and marl crop out on the east side of the Quebrada La Loma at an altitude slightly above 1300 m. The age of these stratified rocks is not known precisely; they are tentatively 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 limited extension along strike (Velásquez H., 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 in June 1959 by X-ray diffraction at the Facultad Nacional de Minas by Tomas Feininger (oral commun., 1970). 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 selected samples 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 H. agree that the Santa Barbara deposits are not economically exploitable, and material of the above composition would not be generally classed as ore. However, in Medellín crude Santa Barbara "ore" has recently been added to batches of steel in electric furnaces to make manganese alloy for 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 Barbara deposits.

Botero R. (1945, p. 316-317) interpreted that the manganese formed by 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 by oxidation of the original carbonate and were accompanied by deposition of silica from silica-rich solutions. Wokittel (1955) proposed a hypogene origin, in which manganese oxides were deposited in interstices of "quartzite" by solutions from an unknown source, and suggested that localized richer manganese pockets were in part a product of supergene enrichment.

Manganese deposits associated with marine sedimentary and volcanic rocks in other parts of the world are thought to be syngenetic, related to submarine volcanism (Park and MacDiarmid, 1964, p. 379-381; Hewett, 1966; Sorem and Gunn, 1967). Taliaferro and Hudson (1943) describe syngenetic manganese deposits in the Franciscan Formation of California remarkably similar to the Santa Barbara 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, as postulated by Taliaferro and Hudson (1943).

Lead and zinc

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 Company 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 IIA.

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. 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. Ores at most of the small lode gold mines in the zone probably have a similar content of copper, although specific data are lacking. At the present scale and method of operations it is wholly impractical to consider recovery of copper.

Buriticá prospect

A detailed investigation was made 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, accompanied by gold and silver. The investigation included geologic mapping at large scale, 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 (Tomas Feininger, unpub. data, 1967).

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 prophylite, 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 in road cuts that showed sparsely disseminated pyrite. Analyses of the samples are summarized below.

Metal	Range of tenor	Arithmetic average tenor
Cu (percent)	.01 - .07	.03
Pb (percent)	.02 - 6.59	.12
Au (g/ton)	.0 - 4.0	.34
Ag (g/ton)	.0 - 5648.0	15.29*

*Does not include two erratically high Ag assays.

Two samples out of the 34, each with megascopically visible galena, gave silver assays of 5648 and 1175 grams per metric ton respectively, but the majority of assays for gold and silver were negative, or traces only.

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

Hole no.	No. samples	Arithmetic average tenor[1/] Cu (percent)	Pb (percent)	Zn (percent)
2	19	0.066	0.081	0.17
3	37	.046	.029	.10
4	56	.065	.061	.11
5	30	.083	.15	.16

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 no further study seems warranted.

Toledo prospect

A small showing of chalcopyrite with pyrite in greenschist of the Valdivia Group is in Quebrada El Bique, 1200 m north of El Brujo at the extreme northern edge of a-6 (pl. 1) 7 km by mule trail west of Toledo (pl. 1, b-6). 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.

1/ Gold and silver ranged from 0 to trace (g/ton) in all samples.

The sulfide minerals probably represent mobilized syngenetic material redeposited along foliations and local shear-planes, or are wholly epigene deposits of hydrothermal origin. The slope above is completely covered by soil and brush, but judging from the character of the host rock, the weak mineralization, and the absence of hydrothermal alteration, the probability of finding an exploitable orebody is small.

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. Hand-picked specimens may assay 3 to 4 percent Cu, but the average tenor across a minable width (1 m minimum) is estimated as less than 1 percent of copper. The mineralized zones have no continuity, and fade out within a few meters along strike. 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 the boundaries of Zone II as defined in this report, but the following comments are included here:

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 (3 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 deposits 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).

Pyrite

Small gold mines such as Marmato and La Bramadora extract an aggregate total estimated very roughly at 900 tons per year of pyrite along 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 along the road 1 km southeast of Ituango (pl. 1, a-4). Thin, nearly vertical lenses of fine-grained massive pyrite lie within 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.

NONMETALLIC RESOURCES

Cement raw materials

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 four cement companies, their daily clinker capacity, and approximate tonnage of finished cement produced in 1967.

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	Estimated 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

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.

1/ Includes 2000 tons of sand at Nare.

2/ Consumed by Cementos Caldas.

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 in IIB, 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	Medellín	4/	4/	1,200[5]	218,000[6]

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 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.

El Cairo quarry

This wet-process plant operated by Cementos El Cairo S. A. was constructed in 1943 near the town of El Cairo, 9 km southeast of Santa Bárbara, and has a daily clinker burning capacity of 1000 metric tons. The quarry is in a marble lens 350 m long and 120 m wide, that strikes northeast and dips steeply southeast. The lens is enclosed in schist correlative with the Valdivia Group. This calcareous lens may have formed in a locally shallow part of the eugeosynclinal trough; metamorphism recrystallized the limestone, 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-inch steel pipeline to silos near the kilns. Marble reserves are limited but appear large enough to support the plant at least until 1982.

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.

Neira quarry

The Neira quarry supplies the cement plant of Cementos Caldas S.A., near Neira, 20 km north of Manizales, Department of Caldas. 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. Reserves are limited and may be exhausted by 1980.

Crushed marble is transported 4 km by aerial cableway to a plant which has two rotary kilns, each of 325 tons per day clinker capacity. Magnesia and silica are variable, requiring constant control and blending.

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 potassium 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 company 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 by road to the cement plant.

Clay

General studies of clay resources in Antioquia have been made by the Facultad Nacional de Minas in Medellín (Suescún and others, 1966, p. 3-53; Ellwanger, 1966, p. 55-132). Private companies such as Lucería Colombiana S.A. and Erecos S.A. have made extensive studies of clay resources in Colombia but their data are unpublished.

A mantle of iron-stained saprolite overlies most rocks in Zone II, and is especially conspicuous 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 that use saprolite are so numerous as to make large contributions to the industry, although statistics are lacking. In every city and town most of the buildings have brick walls and are roofed with curved fired tiles. These bricks and tiles are inexpensive and have been traditional with the population for centuries; their use in small buildings may be expected to continue well into the future.

Kaolin at La Unión

La Unión deposit, 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 65 sq km^2 cupola of the Antioquian batholith, that 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 V., 1960). However, the present authors consider that hydrothermal alteration probably played a role in formation of the kaolin for the following reasons:

a) Depth. Suescún and others (1966, p. 40) reported drill holes 45 m deep that did not encounter fresh rock. Dietrich Paetsch (oral commun., 1967), director of raw materials research for Loçería Colombiana S.A., reported at least one drill hole 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 the 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 alternation 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) Localization. Extensive areas elsewhere underlain by tonalite, subject to the same weathering, do not have kaolin deposits of like quality.

d) Vertical profile mineralogy. 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.

Representative chemical analyses of La Unión kaolin are as follows:

		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

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

The material is dominantly kaolinite with lesser quartz. Igneous texture of the parent rock is perfectly preserved in the main body of the mass, below the surface-weathered zone. A striking feature 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 Paetsch and others (1963). The altered mica probably was biotite, the main accessory in the Antioquian batholith tonalite. Muscovite is rare in the batholith.

The quartz grains are removed by washing and screening at the pit, and are used as ceramic silica. This complete kaolinization of mica at La Unión may be interpreted as evidence of hydrothermal origin. Mica generally is resistant to weathering (Deer and others, 1962, v. 3, p. 70), and commonly is preserved in saprolite as shiny flakes. Complete alteration of mica to kaolinite, on the other hand, 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 deuterically altered the central core to kaolinite.

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.

Other kaolin deposits

No other kaolin clays in Zone II 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 that make chinaware, vases, and decorative ware; 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 southwest of Medellín. A layer several meters thick of a stiffly plastic bluish-gray transported kaolin having some of the characteristics of a ball clay was deposited in a Pleistocene lake basin at Llano de Ovejas, in the upland about 15 km north of Medellín. This clay is an important ingredient in the manufacture of sanitary porcelain in Medellín. Mudstone beds intercalated with coal seams at the western edge of IIA 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.

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 admixed in varying proportions, as follows:

Item	Est'd tons 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	Insulating brick.
Silica sand	120	Angelópolis, Antioquia	Silica brick.
Feldspar	120	La Ceja, Antioquia	Glazing agent.
Bauxite	3,000	Guyana (Alcán)	High-alumina products.

Item	Est'd tons per year	Source	Remarks
Corundum	10	Germany (Lonzawerke)	Special heavy-duty products.
Bentonite	60	U.S.A. (American Colloid Co.)	Binding agent.
Graphite	12	U.S.A. (Asbury, Vermont)	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 yet been reported in Zone II. A thin patchy mantle of sandy kaolin-rich saprolite near Llanos de Cuivá (see "Bauxite"), contains about 5 percent of gibbsite as veinlets and nodules, 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 employed 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 in IIB (Hall, in Feininger and others, in press) may be satisfactory as a basic refractory raw material but has not been used for this purpose. Potential ganister for silica brick occurs near Amalfi. 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, most of the andalusite is strongly sericitized and the deposits are not commercially suitable at present (see "Andalusite").

Coal

General statement

Subbituminous coal deposits are one of the most important resources in the zone and deserve mention although the study of coal was not a part of the IMN program. During field mapping, IMN geologists encountered lignitic to subbituminous coal beds in Tertiary clastic sediments, notably 10 km southeast of Puerto Antioquia (pl. 1, c-1), 3 km east of Ituango (a-4), 10 km south-southwest of Ituango (a-5), near Toyugano village (a-6), and 9 km north of Sabanalarga (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 crop out along the western margin of Zone II in the Amagá basin, in a north-trending belt 1 to 14 km wide, extending from Sopetrán on the north, some 70 km southward past the towns of Ebejico, Heliconia, Titiribí, Amagá, Venecia, and Fredonia (Grosse, 1926, p. 101-161). Coal in Antioquia is noncoking, except some 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), and since available data suggest that this coal has a relatively low sulfur content, IIA coal resources may assume a greater importance as energy demands and low-sulfur fuel requirements increase.

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^{o} south-southwest. The three main coal beds 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 beds 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 strata are of late Oligocene age, according to Van der Hammen (1958, p. 113).

The coal is black, has a brownish-black streak, 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; the low sulfur and ash are noteworthy.

	Typical coal, El Silencio mine[1]	20 samples of coal from Amagá basin[2]	
		Average	Range
Fixed carbon	49.8	49.7	42-59
Volatiles	37.9	41.0	30-48
Moisture	9.4	8.1	4-11
Ash	2.4	3.0	1- 6
Sulfur	.5	.6	.4-1.2
Calorific yield (cal/Kg)	6,120	5,800	5,070-6,120

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 houshold cooking. Production in the district could be increased greatly if there were an economic outlet.

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

2/ After Grosse, 1926.

Other coal deposits in subzone IIA

Beds 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 cement kilns of Cemento Caldas S.A. at Neira. Several small mines near Quinchía have been in operation for many years (Fetzer, 1941). The beds, presumably correlative with the upper Oligocene strata 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 Tertiary coal beds dip steeply eastward 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 poor-quality coal is interbedded with Tertiary clastic sediments that dip 15° to 30° E. in Quebrada del Sargento (A. Andrade, written commun., 1968).

Construction 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.

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 tonalite from the Antioquian batholith, which is a good aggregate material when not too decomposed; Paleozoic amphibolite and schist, which tend to be friable and to break into platy fragments; Paleozoic gneiss; Mesozoic greenstone or metabasalt; and even Mesozoic serpentinite; the latter is 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 large buildings, dams, or paved highways.

Alluvium

Medellín and its suburbs are by far the largest consumer of aggregate materials in Zone II. The bulk of these materials is taken from the banks of the Río Medellín, especially in pits near the suburb of Caldas, and near Bello and Girardota, and from the Quebrada Iguana west of the city. Poorly sorted sand and polymict gravel commonly are used without treatment. A 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.

Weathered igneous rock

Several factories in Medellín make hollow cement block and pipe using finely crushed semidecomposed Tertiary(?) granodiorite taken from their own quarries near the city and mixed with domestic portland cement. These plants, which can produce several hundred tons per day of blocks and pipe by means of modern automated high-pressure molding machinery, constitute a thriving industry.

Lightweight aggregate material

The Colombian construction industry apparently has given little attention to the use of lightweight aggregate materials, but these may deserve consideration in the future as more multistory buildings are raised in the large cities.

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, which floats on water until it becomes saturated, probably could serve as a lightweight aggregate and insulating material. It has been used by Cementos Caldas to make pozzolanic cement (F. Arenas, 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.

Bloatable clay and shale have not been investigated in IIA, but these probably exist in some places. Bloatable shale is known near Amalfi in subzone IIB, but has not been commercially developed.

Limestone and calcite marble
(other than cement raw material)

Carbonate rock is relatively sparse in IIA compared to IIB; with the exception of marble lenses that feed the cement kilns at El Cairo and Neira, it is restricted mainly to lenses in quartz-sericite schist a few kilometers south of the town of Cocorná, 50 km southeast of Medellín. The lenses are small, difficultly accessible, and have little economic potential at present. Most of the carbonate rock and lime used by industries in Medellín originates at quarries near Segovia and Amalfi in subzone IIB. 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.

Enormous reserves of carbonate rock of variable quality crop out along the east side of quadrangles I-9 and J-9 in IIB (see Hall *in* Feininger and others, in press).

The Neira quarry of Cementos Caldas is a source of industrial quicklime 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.

Feldspar

La Ceja deposit

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 potassium 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 kim 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.

IMN has located several potentially exploitable pegmatite lenses near the eastern margin of plancha a-5(pl. 1) along 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. They are 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:

	Percent
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; fresh rock may give better results (F. Viertel, geologist, 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 noncompetitive with La Ceja feldspar; nevertheless, the Ituango pegmatites clearly represent a possible future resource.

Talc

Yarumal district

Deposits of talc in mountainous terrain, 14 km by road northeast of Yarumal, and 128 km by road north of Medellín, were investigated intermittently from February 1966 to November 1967(Hall and Estrada, unpub. 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), 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.

Lenses of steatitized Mesozoic serpentinite crop out in a 400-m by 15 km belt of quartz-feldspar-mica porphyroblastic or augen gneiss (d-6, pl. 1). 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:

Chemical analyses of hand-sorted lump talc samples from stockpile
(in percent)

	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. Analysis by Servicio Minero, Ministerio de Minas y Petróleos, Medellín.
2. Analysis by laboratory of U. S. Bureau of Mines, Tuscaloosa, Alabama.

Geologic 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 may be inferred within the 8-km extension of the talc zone toward the village of Cedeño, 13 km airline northeast of Yarumal.

The greatest obstacle to expanded production of Yarumal talc is the relatively high iron content which adversely affects both natural and fired colors in ceramics. 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 42.2 to 3.5 percent, but with high loss in tailing. The economic feasibility of beneficiating Yarumal talc is dubious at the present time, but 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 e-5 (pl. 1), associated with serpentinite near the Las Brisas asbestos prospects, and in b-6, 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 causes 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.

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

In other areas of Colombia marble is used as a monumental, building, or decorative stone, but in Zone II very little. Poor accessibility to most of the high-quality marble bodies is a handicap to exploitation. Marble chips from the Amalfi and El Cairo quarries are embedded in cement mortar and used to make so-called "mosaic" and "terraza" flooring and terrazo tile.

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 are present in various areas.

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. Vein quartz is 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 4000 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 bring 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. An additional 400 tons per month (estimated) is used as foundry sand, water filtration, and miscellaneous uses. The company also uses pyrite concentrates from the Marmato gold mines for coloring purposes.

Asbestos

La Solita-Las Brisas deposit

The largest chrysotile asbestos deposit in Colombia is at La Solita-Las Brisas in e-5 (pl. 1), 10 km north of Campamento, and has been known since before 1944. From 1952 to 1953 it was explored by Johns-Manville Co., Ltd., of Canada, including geologic mapping, ground magnetometer surveys, test pitting, and diamond drilling. Later, in 1964, another company, Nicolet Industries Inc., at Ambler, Pennsylvania, acquired an interest in the concession with Colombian partners, Asbestos Colombianos, Ltd. 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 1200 m depth (H. Harris, exploration manager, Nicolet Industries, Inc., written commun., September 1968). The new deposit is designated "Las Brisas" by Nicolet to distinguish it from "La Solita," the name originally applied by Canadian Johns-Manville Co., Ltd.

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 1800 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 additional proved reserve is available; exploration drilling is continuing.

According to Harris, the Las Brisas body comprises a stockwork of cross-fiber chroysotile 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, Ltd., are constructing 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 wholly dependent upon imported fiber. A small amount of short fiber not marketable in Colombia may be explored (H. Harris, oral commun., June 1969).

Other asbestos prospects

Chrysotile asbestos prospects of lesser potential are known at Las Nieves (pl. 1, d-4), and El Búfalo (pl. 1, e-3). These are genrally 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-Manville Co., Ltd., in 1952-53. The prospects are in isolated serpentinite bodies as shown on plate 1.

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 satellite of the same deposit.

Other asbestos prospects of small to negligible potential have been reported 8 km due east of Sabanalarga (a-8), and 2 km north of Briceño (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.

Andalusite

Andalusite occurs in a number of localities as megascopic porphyroblasts 0.5 to 6 cm long in quartz-sericite schist, especially in b-3, b-4, b-6, and e-1, in amounts ranging from less than a percent up to several percent by weight. Elongate rod-like pebbles of andalusite 2 to 5 cm long and 0.4 to 1 cm across, weathered out of the schist, lie scattered on the soil surface or disseminated in the regolith in those areas where the schist contains abundant porphyroblasts. Some of these display the familiar chiastolite cross when broken. Most of the known occurrences probably were formed by regional metamorphism, but in southeast e-4, contact-metamorphic andalusite crystals occur in both Paleozoic quartz-sericite schist and Cretaceous shale of the La Soledad formation where these rocks have been baked to hornfels adjacent to the felsic tonalite intrusion. Much of the andalusite at all localities has been sericitized, wholly or in part, and therefore is of doubtful commercial value. These deposits may be a potential resource, but it seems unlikely that they can be exploited economically in the foreseeable future.

Bauxite

Bauxite has been reported in small deposits near Llanos de Cuivá (pl. 1, 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. 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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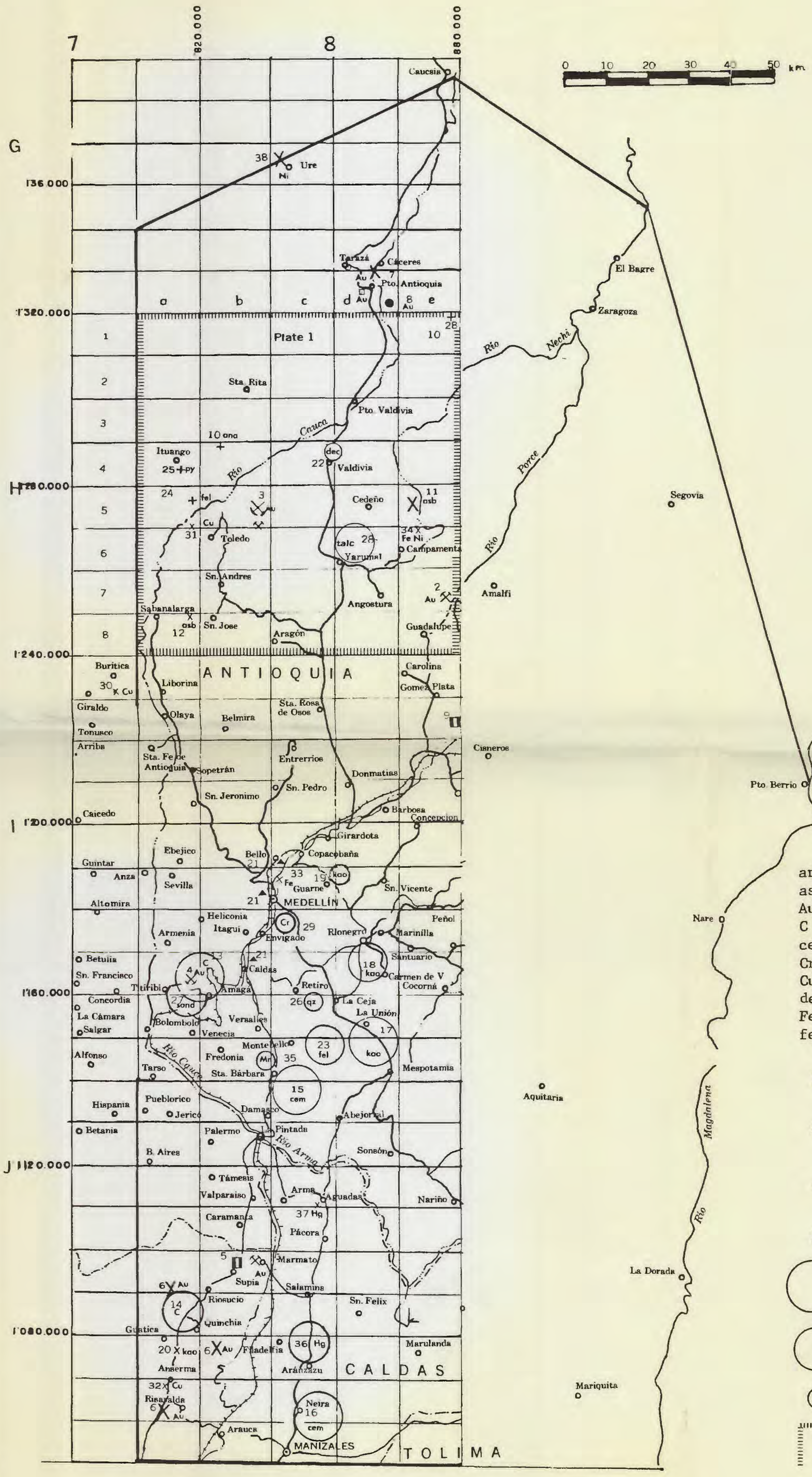

GOLD AND SILVER MINES AND PROSPECTS
(Note: No attempt is made to show all the abandoned small mines and prospects)

LODES

1. Minas Nacionales de Marmato
2. La Bramadora
3. Berlin
4. El Zoncudo

PLACERS

5. Supia Gold Dredging Co.
6. Alluvial prospects southwest of Supia, see text
7. Puerto Antioquia prospect and abandoned placer of G. Mora
8. Puri monitor
9. Minas de Oro de Porcecito

OTHER MINES, QUARRIES, AND PROSPECTS

10. Andalusite prospects, various, see text
11. Asbestos deposits, Las Brisas-La Solita
12. Asbestos prospect, Sabanalarga
13. Coal mines at Amagá
14. Coal mines at El Salado, Caldas
15. Cementos El Cairo
16. Cementos Caldas
17. Kaolin at La Unión
18. Kaolin at Rio Negro and Carmen de Viboral
19. Kaolin at Guarné
20. Kaolin prospects north of Anserma
21. Aggregate sources near Medellin
22. Decorative stone (greenschist) at Valdivia
23. Feldspar south of La Ceja
24. Feldspar outcrop south of Ituango
25. Pyrite prospect at Ituango
26. Quartz at El Retiro
27. Silica sand at Angelopolis-Titiribí
28. Talc northeast of Yarumal
29. Chromate southeast of Medellín
30. Copper prospect at Buriticá
31. Copper prospect west of Toledo
32. Copper prospects southwest of Anserma
33. Ferruginous laterite at Medellín
34. Ferruginous laterite at Morro Pelón
35. Manganese deposits at Santa Barbara
36. Mercury mine, Nueva Esperanza
37. Mercury prospect, Aguadas
38. Nickeliferous laterite at Ure, Córdoba

SYMBOLS

and	Andalusite	Hg	Mercury
asb	Asbestos	kao	kaolin clay
Au	Gold (byproduct silver)	Mn	Manganese
C	Coal	Ni	Nickel
cem	Cement raw materials	py	Pyrite
Cr	Chromite	qz	Quartz
Cu	Copper	sand	Silica sand
dec	Decorative stone	▲	Source of aggregate
Fe	Iron (laterite)	talc	Talc
fel	Feldspar		

LODE MINES

- ⚒ Producing lode mine >100 tons per day
- ⚒ Producing lode mine 10 to 100 tons per day
- ⚒ Producing lode mine <10 tons per day
- ⚔ Abandoned lode mine

MINE OR QUARRY

- Output = >100 tons per day
- Output >10 tons per day <100 tons per day
- Output = <10 tons per day
- Boundary of plate 1 published by Instituto Nac. de Investigaciones Geológico-Mineras

PLACERS

- Abandoned dredging site, < 9 cu ft
- Active hydraulic mine
- Abandoned hydraulic mine

PROSPECTS

- X Prospect of important potential
- × Prospect of small potential
- + Outcrop only

Figure 2.--Map showing location of principal mineral resource localities, Subzone IIA, central Antioquia and northern Caldas Departments.

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

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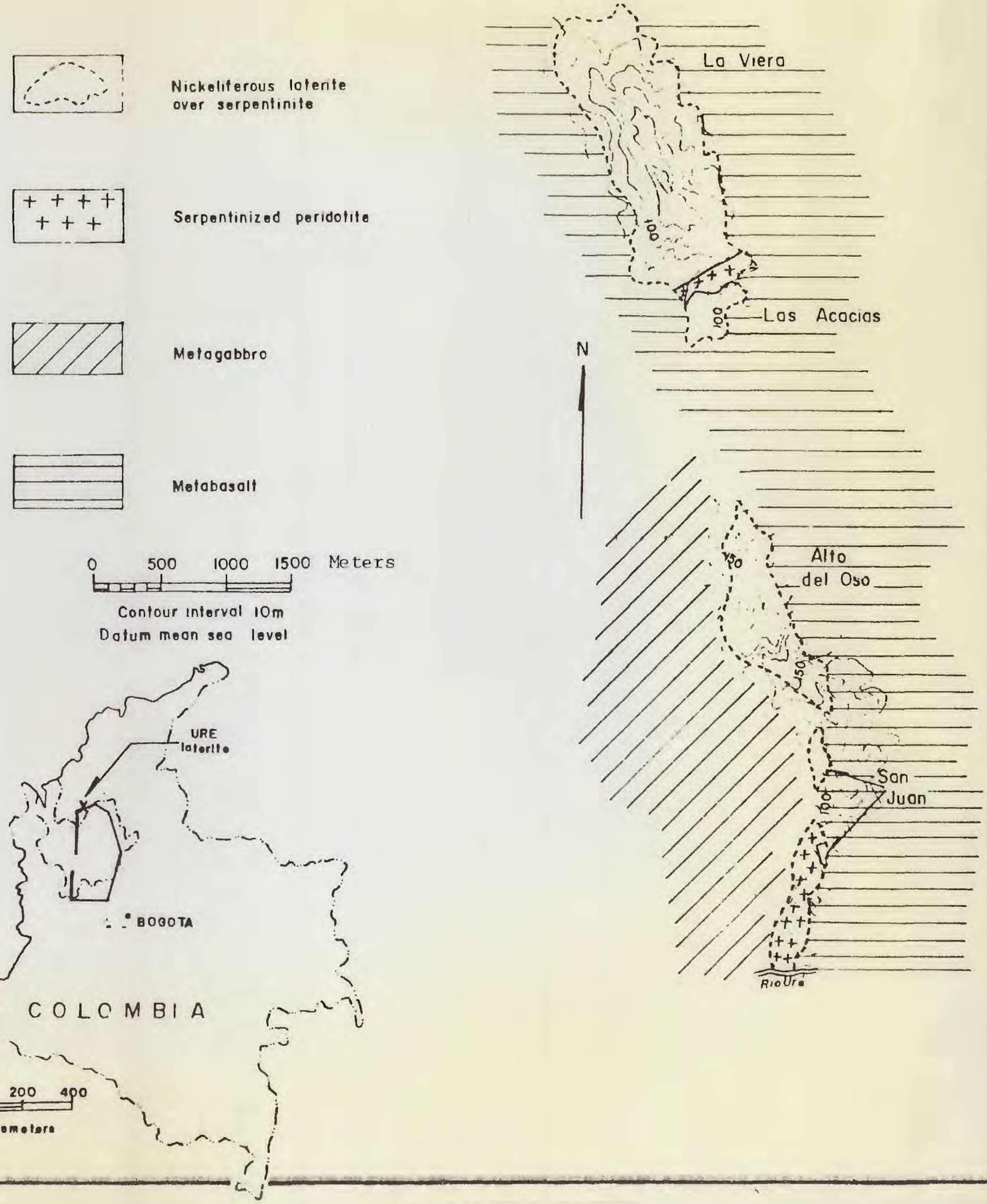
By Dario Velásquez H.



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