METALLOGENIC BELTS AND "IGNEOUS" ROCKS OF COLOMBIAN ANDES

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ABSTRACT. — The author considers three metallogenic epochs (Hercynian Cretaceous-Tertiary, and Pontic) of the Colombian Andes. Through geologic-petrographic reasoning, the origin of the « igneous » rocks, to whom the mineralizations are associated, is first defined as follows :

— The Hercynian granites of the Oriente Andino originated from melting in the meso-epizone of part of old migmatites and anatectic granites, themselves formed through solid-state granitization of calcareous shales ;
— The Cretaceous-Tertiary diorites of Occidente Andino were formed through quartz-alkalic metasomatism of ophiolitic rocks ;
— Melting of the Cretaceous-Tertiary diorites, followed by diapiric movement of the molten rocks, gave birth to the Pontic microdiorites.

It is then held that the ore bodies, viz. :

— Hercynian dykes with Fe, Cu, Pb, and Zn sulfides, all gold — and silver-bearing (whereas the contemporary ore bodies of Cordillera Real, Bolivia, are tin-bearing) ;
— Cretaceous-Tertiary dykes with chalcopyrite, gold bearing pyrites and marmatite, silver-bearing galena, and cinnabar ;
— Pontic subvolcanic dykes with chalcopyrite, auriferous pyrites and marmatite, argentiferous galena can be have originated through the action of residual solutions concentrating the dispersed metal content of the transformed rocks.

RÉSUMÉ. — Trois époques métallogéniques (hercynienne, crétacée-tertiaire et pontienne) peuvent être définies dans les Andes colombiennes. On rappelle d'abord la genèse des roches éruptives auxquelles les minéralisations sont liées en partant de bases géologico-pétrographiques :

— pour les granites hercyniens, fusion dans la méso épizone de migmatites et de granites d'anatexie plus anciens, formés eux par granitisation, à l'état solide, d'argiles marneuses ;
— pour les diorites crétacées-tertiaires, métasomatose quartzo alcaline de roches ophiolitiques par montées de solutions ;
— fusion de celles-ci suivie de diapirisme, pour les microdiorites pontiennes.

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On considère alors :

— les filons hercyniens à sulfures de Fe, Cu, Pb, Zn avec teneurs d'Au et d'Ag (comparés avec leurs contemporains à cassitérite de la Cordillère Royale de Bolivie) ;
— les filons crétacés tertiaires à chalcopyrite, pyrite et marmatite aurifères, galène argentifère et cinabre ;
— les filons subvolcaniques pontiens à chalcopyrite, pyrite et marmatite aurifères, et galène argentifère.

Tous ces gisements peuvent avoir été formés par des solutions résiduelles ayant concentré les éléments métalliques des roches transformées.

RIASSUNTO. — Prendo in considerazione tre epoche metallogeniche (ercinica, cretacico-terziaria, pontica) delle Ande Colombiane. Definisco dapprima, su basi geologico-petrografiche, uno schema genetico delle rocce « ignee » cui esse sono associate :

— fusione nella meso-epizona di compartimenti di migmatiti e graniti di anatessi più antichi, derivati questi da granitizzazione allo stato solido di argille marnose, per i graniti ercinici ;
— metasomatosi quarzo-alcalina in rocce ofiolitiche ad opera di soluzioni, per le dioriti cretacico-terziarie ;
— fusione di queste, seguita da diapirismo, per le microdioriti pontiche.

Sostengo quindi che i giacimenti

— filoni ercinici a sulfuri di Fe, Cu, Pb, Zn con tenori di Au ed Ag (confrontati con quelli coevi a cassiterite della Cordillera Real di Bolivia) ;
— filoni cretacico-terziari a calcopirite, pirite e marmatite aurifera, galena argentifera, cinabro ;
— filoni pontici subvulcanici a calcopirite, pirite e marmatite aurifere, galena argentifera.

possono essere derivati da concentrazione ad opera di soluzioni residuali del contenu metallico disperso nelle rocce trasformate.

From a geologic point of view, the Colombian Andes can be subdivided into two main parts : the Oriente Andino and the Occidente Andino, defined as follows : the Oriente Andino is the region folded and granitized during the Hercynian Orogeny, which was continental or miogeosynclinal during the Mesozoic Era ; the Occidente Andino is that eugeosynclinal region with basic Mesozoic volcanic effusions, which was granitized during the Cretaceous and the Tertiary.

The present paper deals especially with the mineralization related to the Hercynian granites in the Oriente Andino, with the Cretaceous diorite (Andean Diorite), and with a series of Tertiary (Pontic) subvolcanic magmatic bodies of the Occidente Andino ; but it does not deal with other Colombian mineralizations, such as the famous platiniferous one of Chocó, because no information on their primary source is available.

Oriente Andino.

The Oriente Andino in Colombia comprises the Eastern Cordillera, the Perija Range, the Guajira peninsula, the Santa Marta massif, the Magdalena Valley, and part of the eastern slope of the Central Cordillera. It is limited to the East by the « Llanos Orientales », and to the West by a north-south faulted zone, which passes through Colombia and continues into Ecuador.

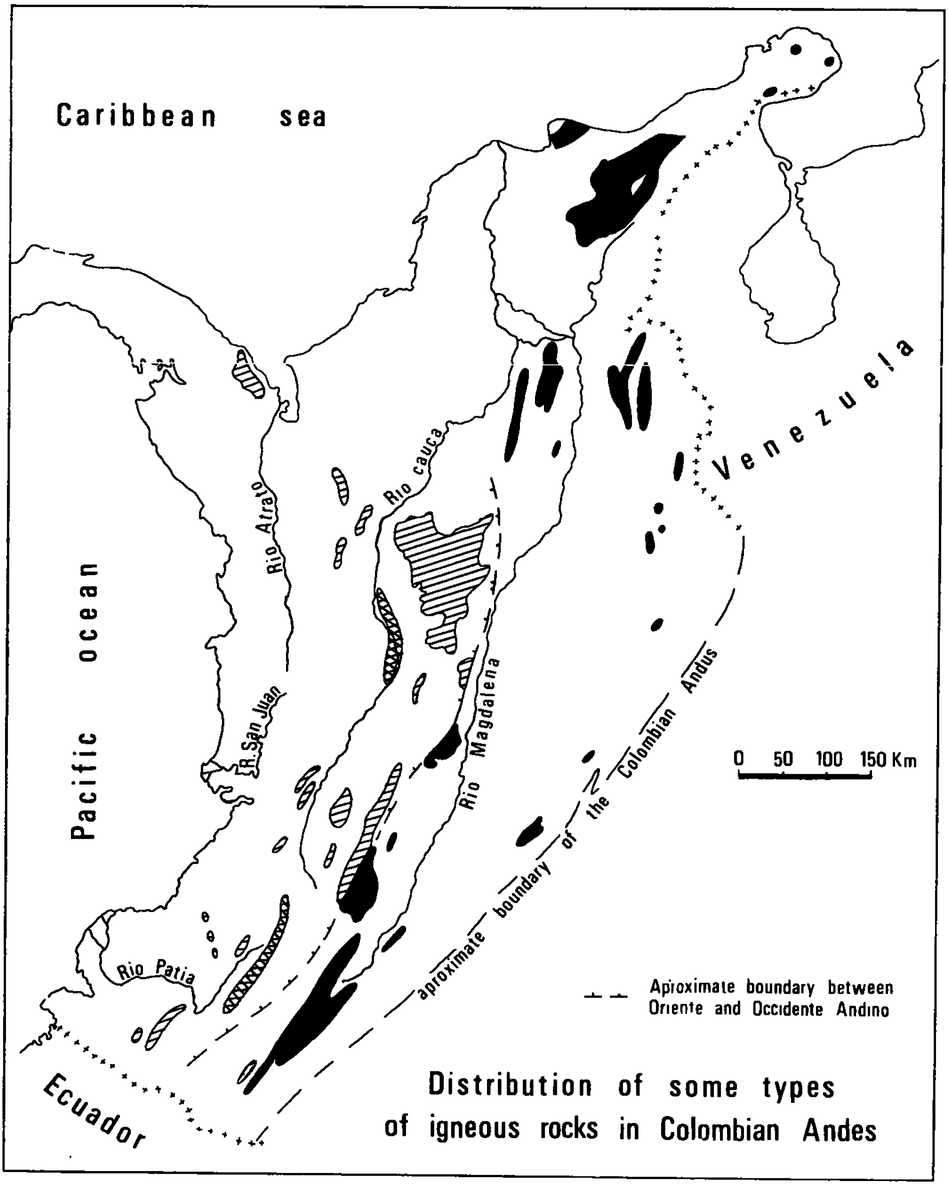
The area is underlain by ultrametamorphic, metasomatic, pre-Cambrian (caledonian in Guajira) amphibole-microcline-granites s. l. (migmatites and anatexites), which are covered by metamorphic pre-Devonian rocks, including muscovite-biotite gneiss, muscovite schists, sericite-chlorite schists, and micaceous quartzites.

The granites with microcline and unzoned plagioclase (migmatites) are very abundant (RADELLI, 1962 *a, c, d, e, f*) and they belong to the most important zones of axial culminations (RADELLI, 1962 *f*). These are, from north to south : Guajira peninsula, Santa Marta massif, Santander massif, Garzon massif. Those granites were formed through transformation and feldspatization of calcareous shales (RADELLI, 1965) and are surrounded by metamorphic zones, which are enriched in cafemic elements (amphibolites, cordierite schists, etc.), and represent a basic front derived from typical granitized zones.

Since, as previously pointed out (LJUNGGREN and RADELLI, 1963, 1964), unzoned plagioclase granites formation takes place at very low temperature in the solide state, there are no mineralizations associated with these Colombian rocks : there were no favorable conditions for mobilization and concentration of the metal content of the transformed sedimentary rocks.

In the Hercynian time an orogenic wave took place, beginning in the southern and central part of the country (Quetame, Floresta) in Upper Devonian-Lower Carboniferous, and developping progressively towards the north : Mississipian-Pennsylvanian in Santander, Permian-Lower Triassic in Perija, Santa Marta and Guajira.

In the orogenic zone at that time, many centers were strongly faulted and folded approximately in the meso-epizone, these movements increased the temperature by intergranular frictions so much that the rocks fused, especially the oldest, more rigid, granites (RADELLI, 1962 *f*). In this way magmas originated and, by squeezing, they were able to rise to higher levels of the crust. The crystallization of these melted bodies was typically magmatic with formation of zoned plagioclases and orthoclase, but some remnants of the microcline present in the oldest granites are still reco-



Crossed hatchings : Pontic microdiorites.
Oblique hatchings : Cretaceous - Tertiary diorites.
Black : Hercynian igneous rocks.

gnizable. Their chemical composition, as revealed by microscopic studies, is everywhere the same as that of the older granites with microcline and unzoned plagioclases (RADELLI, 1962 *f*).

These magmatic Hercynian granites belong to both sides of the Magdalena Valley. The most important massifs, in the Eastern Cordillera are : the granodiorites of Parashi, Ipapure, and Siapana in Guajira peninsula ; the monzonitic porphyric granite, the tonalites, and the granodiorites of Santa Marta ; the granites of Ocoña and of Paramo de Berlin in Santander ; the granites of Floresta ; the granites of Medina in the Quetame massif ; the monzonitic porphyric granites of Algesiras and Garzon, and the syenitic bodies of Altamira in the western part of the Garzon massif. In the Central Cordillera the most important massifs include : the granite of Ibagué, the granites of La Plata-Paez, the granite of Pitalito-San Agustin (Huila), the granite of Mocoa. The common association of these granites with, and their passage to microgranites and rhyolites is additional evidence of their « magmatic » origin (through melting). Microgranites and rhyolites that surrounded the diapiric granitic bodies rose in the liquid state to the surface. Very good examples of such very high diapiric intrusions are those of Ipapure in Guajira (granodiorite-microgranodiorite-rhyodacite), Santa Marta, Ocoña, and Ibagué (granite-microgranite-rhyolite).

The transformation from ultrametamorphic metasomatic low-temperature granites into high temperature « magmatic » Hercynian ones was accompanied by interesting mineralizations. In the Guajira peninsula, related with the Siapana granodioritic intrusion, gold-bearing quartz veins cutting both the micaschists and some interbedded marbles occur near Nazaret.

In the central part of the Santa Marta massif, the old migmatites are intruded by dikes-like masses of titaniferous magnetite, and titanite with very abundant apatite of Kiruna type.

In the Santander district, many mineralized dikes are connected with the « magmatic » Hercynian rocks. At California, one of them is located in the microgranites close to their contact with the old migmatites ; it belongs to a subvolcanic type and contains uraninite, marmatitic sphalerite, silver-bearing tetrahedrite, galena, enargite, pyrite, and gold disseminated in quartz (PAGNACCO, 1962 *a*). Other dikes in the same region also contain chalcopyrite, bournonite and other copper sulfides and carbonates. At Vetas, small, anastomazed quartz veins contain gold-bearing pyrites.

Near the Quetame massif, intense copper mineralization impregnate the Paleozoic strata at Cerro del Cobre with chalcopyrite.

It is very interesting to observe here, that the metallic elements concentrated by the granitic « magmatic » Hercynian bodies are those more usually found in argillaceous-calcareous rocks of sedimentary origin, of which the « magmatic », high temperature granites represent the ultimate transformation, following their transition through the metasomatic, low temperature, granitic phase.

The origin of the Hercynian mineralization of Colombia is genetically quite similar to that of Cordillera Real of Bolivia. In both countries the mineralization is derived from the metallic content of marine sedimentary rocks. In both countries those sediments were first transformed at low temperature into ultrametamorphic metasomatic granites : microcline unzoned plagioclase migmatites in Colombia ; and microcline, unzoned plagioclase sinkinematic Kutikucho granite, originated from hydrolized shales in Bolivia (LJUNGGREN and RADELLI, 1963, 1964), without associated mineralizations.

In the Hercynian paroxism, on the other hand, these granites were partly transformed at high temperatures, into magmatic bodies, which were able to mobilize and to concentrate the still-dispersed metals. The fact that tin mineralization occurs in Bolivia and gold-silver-copper-lead-zinc mineralization in Colombia is in good agreement with our knowledge of the geochemistry of these elements : in fact tin seems to be preferentialy associated with hydrolized shales, and gold-silver-copper-lead-zinc with the calcareous claystones.

After the Hercynian orogeny, the Oriente Andino of Colombia was a continental region where red beds accumulated (Giron Group) until the Cretaceous marine transgression. In the Triassic-Jurassic time flows and intrusions of basic rocks (basaltic-gabbroid magmas) accompanied sediments deposition.

A little copper mineralization occurs in the basic magmatic rocks themselves, and as impregnation in the adjacent red beds. The best known cupriferous localities are the Perija Range between Codazzi and Villanueva (PAGNACCO, 1962 *b* ; RADELLI, 1962 *b*), and the Dolores region of the Tolima Department. In the Perija Range the copper minerals are (PAGNACCO, 1962 *b*) : native copper, cuprite, chalcocite, tenorite, malachite, and azurite. Associated metallic minerals are hematite, goethite, and martite ; the gangue minerals are epidote, quartz, barite, calcite, chlorite, and tourmaline. The copper minerals occur in small dykes a few meters in length, and/or as pockets in the basic rocks.

The same copper minerals are present at Dolores, but this region has not been sufficiently studied.

Although the copper deposits are not economically workable, they appear to have contributed to the copper sulfide concentration in the Cretaceous marine strata of La Palma, Yacopí, Nocaima, Moniquirá, Gachantivá, Bolivar, Velez in the western slope of Eastern Cordillera, not yet well studied.

Occidente Andino.

1) ***The Andean Diorite and its companion mineralization.***

The Andean Diorite forms elongated bodies in the central part of both Central and Western Cordilleras.

Among the most important outcrops are : the quartz-dioritic batholith of Antioquia, and the tonalites of Anchicaya, Farallones de Cali, Manizales and Nariño. These rocks are in part Aptian-Albian in age (BÜRGL and RADELLI, 1962), in part younger.

Petrographically all these bodies are nearly identical : zoned plagioclase (usually andesine), quartz, amphibole, biotite, and sometimes microcline.

Their origin and that of the associated mineralization constitute a problem of much interest.

The country rocks older than Diorite are both ortho- (amphibolites, prasinites, saussuritic gabbros, marine diabases, basalts, andesites, and their tuffs) and parametamorphic rocks (gneiss, quartz-muscovite-biotite schists, quartz-muscovite schists, sericite-chlorite schists, and slates), and associated very thick (several hundred meters) chert beds.

As previously pointed out (RADELLI, 1965), field and laboratory studies indicate a genetic relationship between the Diorite and the basic marine volcanic rocks (and their metamorphic facies), but not between the Diorite and the schists.

Contacts between the Diorite and the schists are very well defined, but between Diorite and the basic rocks, transitional and intermediate facies are recognizable, for instance, in Cauca cañon near La Pintada, at Boquerón near Medellin, at Santa Barbara (Antioquia), and along the road between Medellin and La Ceja, east of San Francisco (Nariño). Blocks and large bodies of basic rocks are included in the Diorite, and, conversely, irregular dioritic bodies occur in the basic rocks. In both cases there are transitional contacts between the two rocks, with dioritic dikes penetrating into the basic rock. Amphibolic migmatites also occur. Consequently the Diorite seems to have formed through a intense alkali-silicic metasomatism of the basic formation. The zoned plagioclase suggests that this metasomatism was carried out by solutions that circulated easely in the basic rocks but not in the schists. The solutions originated at depth by differential tectonic movements. The cherts associated to the lavas seems to have been quite sufficient to provide the necessary supply of Si. The source of the alkali surplus was probably the marine water.

The metals associated to the Diorite are : gold, silver, lead, zinc, copper, iron, and mercury. They are metals commonly dispersed into, and associated with the basic volcanic rocks. The mineralization occurs in dykes located in the Diorite and in the schists near the contact.

The usual paragenesis includes chalcopyrite, arsenopyrite, pyrite, galena, and marmatitic sphalerite in quartz gangues. The pyrites and the sphalerite are gold-bearing, and the galena is silver-bearing.

According to the suggested origin of the Diorite, it seems possible that the associated mineralization owes its origin to the metal content of the basic metasomatized rocks being concentrated by residual solutions.

As a rule, the deposits are mined for gold and silver only. The main mine is the one at Segovia, in the northern part of Antioquia, but countless more exists in the *Departments* of Caldas and Antioquia : Remedios, Sonsón, San Roque, San Carlos, Santa Rosa, for instance.

A very interesting zone seems to be the Samanà district (West of La Dorada), where many mineralized dykes not yet exploited (massive galena, sphalerite, and pyrites, with high gold and silver contents) appear on the surface.

Mercury concentrations are known at Aranzazu and Aguadas in Caldas Department. The Aranzazu ore contains liquid mercury impregnating black metamorphic shales. The mercury was first introduced as sulfide in quartz-pyrite veins, and then reduced by the shales. At Aranzazu the Diorite is not visible, but at Aguadas (some 50 km to the north) a cinnabar-bearing quartz dyke emerges straight from the Diorite.

2) *The subvolcanic Tertiary belts and their mineralizations.*

The main Colombian zones of Tertiary subvolcanic intrusions belong to the Cauca Valley, between Quinchia and Titiribi, in the Departments of Caldas and Antioquia, and north of Popayan ; and to Patia Valley, near Mercaderes.

Here chains of rugged mountains intrude metamorphic Mesozoic schists, post-Albian marine basic lavas, and Tertiary continental sedimentary beds, with coal measures in Antioquia and Caldas.

Apart from the two little biotitic microgranitic bodies of La Pintada (Antioquia) ; these mountains, varying much in size, consist of a microdiorite, named Corcovadita by R. Scheibe, 1931. The principal bodies are : in Caldas those at Quinchia, Riosucio, Marmato ; in Antioquia those at La Pintada and Titiribi ; in Patia Valley, those of Pico de Lerma, Cerro Bolivar, Cerro de La Monja, and those at La Union. Due to development of hypidiomorphic plagioclase (1-3 cm), and sometimes of quartz, the Corcovadita is highly porphiritic.

The minerals present are : zoned plagioclase (around andesine) with albite twinning, quartz, amphibole, and biotite. The groundmass is microgranular, in part hypo- to cryptocrystalline.

The microdiorites obviously originated from molten masses, but they may represent a product of a near surface melting of parts of the Andean Diorite, followed by diapirism and magmatic crystallization, rather than primitive deep magmas. The chemical composition of the microdiorites, as revealed by microscopic examinations, is the same as that of the Diorite ; and the microdioritic bodies occur in compressed zones, which, as pointed out previously (LJUNGGREN P. and RADELLI L., 1964), are zones possible melting, and squeezing.

This hypothesis, on the other hand, seems to be proved also by the mineralization associated to the microdioritic bodies, which have quite the same mineral contents as those associated to the Diorite : silver-bearing galena, gold-bearing pyrites and marmatitic sphalerites, chalcopyrite, and arsenopyrite in quartz gangue.

Mineralizations are associated with nearly all igneous bodies, but only in Caldas and Antioquia are sufficiently known. In the Cauca Valley district, the most important mine is the Marmato one, where many dykes of subvolcanic paragenesis are minea for gold (PAGNACCO P. F., 1962 *c*).

Other mines are also worked near Riosucio, Quinchia, and Pacora. Ancient works exist at Combia, where a stockwerk with gold-bearing pyrites and sphalerite and silver-bearing tetrahedrite and galena, was exploited (GROSSE E., 1926).

In the northern part of the same district, the principal mining center is that of Titiribi, where both subvolcanic and fault dykes mineralizations are found near the contact between microdiorites and schists.

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