Gold Mineralisation in Colombia:

production history, geologic setting - metallogeny, and exploration update

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Technical Summary

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Colombia purports an extensive and highly productive history of gold exploitation, perhaps the most historically significant in South America, dating from the pre-Colombian period and Spanish colonial era, through to modern times. This extended history can be primarily attributed to two observations. Firstly, the region geographically occupied by Colombia is underlain by a wide geologic diversity which, due to the highly active and magmatically prolific tectonic environment in which it formed, has given rise to a wealth of hydrothermal and magmatogenic mineral occurrences (not only in gold, but also in silver, copper, zinc, mercury, antimony, platinum, nickel and iron). Secondly, since at least the early Tertiary, the Northern Andes of Colombia have been subjected to a combination of a prolonged, complex, and pronounced orogenic history coupled with a climatic regime dominated by tropical to semi-tropical high-rainfall conditions. Thus in many areas the Colombian Cordilleras have undergone extensive uplift and deep erosion. This combination of processes has allowed a variety of mineralisation styles formed at depth to be exposed at the earth's surface, and hence to be "discovered". Additionally the process of tropical weathering and erosion has created extensive gold concentrations within residual, colluvial and alluvial horizons, and has greatly facilitated, from an historical through to modern artisanal perspective, the extraction and recovery of gold.

PRODUCTION HISTORY

A variety of attempts have been made to estimate historic Colombian gold production. In his classic compilation, "*Gold deposits of the World*", Emmons, 1934, estimated post-conquest Colombian production at over 48 million ounces of gold, or, according to Emmons, approaching 40% of the historic production of all of South America to that date. Production records available through the *Banco de La Republic*a document production of an additional 30 million ounces since Emmon's 1934 publication, thus a total estimate approaching 80 million ounces troy is observed. Colombian gold production since 1985 has averaged *ca.* 800,000 ounces troy *per annum*, and crested in 1986 at *ca.* 1.3 million ounces troy. Present production generally shows a growth and decline curve which parallels that of fluctuations in the price of gold, and hence production has wanned noticably since 1998.

About two-thirds of Colombian gold production comes from residual, colluvial or alluvial mines, and has been extracted via crude artisanal means utilising a minimum of expense or technology. Accordingly, the majority of present-day Colombian gold production comes from dozens of artisanal to semi-mechanised alluvial and hardrock mining camps mostly located throughout the Central and Western Colombian Cordilleras, and along the flanking intermontane and Pacific coastal valley systems. The largest present-day gold mining operations in Colombia include; 1) Mineros de Antioquia, suction dredging, Caucasia, Antioquia 2) Frontino Gold Mines Ltda., vein mining, Segovia, Antioquia, and 3) Mineros Nacionales/Mineros de Antioquia, vein mines, Marmato-Echandía, Caldas, which perhaps produce a combined 250,000 ounces troy annually. Interestingly, as with the great majority of current producing areas in Colombia, all these camps exhibit an over 150 year production history, and in the case of the areas cited above, enjoy multi-million ounce gold production histories. Figure 1 reveals many of the notable gold producing regions and deposit types of historic through modern importance in Colombia. Figure 1A depicts a number of the significant historic hardrock producing gold mines and camps. Interesting historical and modern accounts of gold production in Colombia can be found in; Restrepo, V. , *"Estudios sobre las minas de oro y plata en Colombia"*, 1883, and in the Instituto de Estudios Colombianos publication, *"El oro en Colombia"*, 1983.

GEOLOGIC SETTING – METALLOGENY

Gold mineralisation is encountered in virtually every geographic region of Colombia (Figure 2), with the exception of the Llanos Basin, which consists of a thick series of Cretaceous through Recent sedimentary strata which cover the eastern flanks of the Eastern Cordillera, and thin eastwards, lapping onto the Guiana Shield of eastern-most Colombia. From the standpoint of historic production, observed mineral occurrences and gold metallogenic/exploration potential however, the Central and Western Colombian Cordilleras and their bounding intermontane basins are by far the most important regions of the country, and this summary will focus primarily upon these areas. It is noteworthy however that isolated, and locally important gold occurrences are observed elsewhere in Colombia, including in the Eastern Cordillera (*e.g.* Vetas-California-Angostura, Paipa), the Guiana Shield (Tariera, Naquen), the Sierra Nevada de Santa Marta, and the Guajira. With the exception of Vetas-California-Angostura, these occurrences are scarcely documented and not well technically understood.

GENERAL GEOLOGY

The general geomorphologic provinces of Colombia are characterised by their marked contrasts in both physiology and underlying geology (Figure 3). Focusing geologically upon the Cordilleran region, the Andean Cordillera (*sensu lato*) of Colombia is comprised of three north-north-eastward fanning, arcuate mountain chains, the Eastern, Central, and Western Cordilleras, which are separated by the Magdalena River drainage to the east, and the Cauca River drainage in the west. The tectonic evolution of the Northern Andes of Colombia is "bewilderingly complex", primarily due to the observation that any models for the paleo-reconstruction of the Colombian Cordilleras must take into account a variety of factors atypical of the evolution of the Central Andes to the south (Livaccari et al., 1986). These factors include the placement and evolution of a triple junction geographically located under Colombia, and hence require a "three-plate-model", describing interaction between the Pacific (Farallones), South American, and Caribbean plates. Beginning in at least the Early Tertiary this has been a "trench-trench-transform"-style of triple junction, and subduction along the Pacific-South American margin is known to have been strongly oblique (right lateral). This scenario is further complicated by the Tertiary break up of the Farallones plate into the Nazca-Cocos system, and the subduction of a transverse spreading centre beneath south-central Colombia. Furthermore, the Pacific margin subduction of alternating portions of older-dense, and younger-bouyant oceanic crust has caused wide fluctuations in oceanic plate subduction angle throughout this time, strongly affecting both the style and chemistry of subduction-associated magmatism, and the high level structural - deformational regime in the ovelying plate.

The geological diversity of the three Cordilleras of the Colombian Andes is emphasised below.

Eastern Cordillera

Underlain by Proterozoic metamorphic basement, the Eastern Cordillera consists primarily of thick sequences of structurally juxtaposed low-grade Paleozoic metamorphic rocks, oxidised Mesozoic epicontinental strata, and Tertiary through Quaternary continental and transitional deposits. The northern sector of the Eastern Cordillera contains a structurally superposed igneous-metamorphic complex of Triassic-Jurassic age, the Santandar Massif, which likely represents (along with the Sierra Nevada de Santa Marta) the northern, tectonically displaced extention of the Central Cordillera. Known igneous activity, aside from the plutonic rocks observed in the Santander Massif, is rare in the Eastern Cordillera, being constrained to isolated occurrences of rhyolite dome complexes of probable Neogene age (*e.g.* Paipa). The Eastern Cordillera essentially appears to represent an autochthonous foreland thrust-and fold province recording deformation caused by the collision and accretion of arc and terrane systems along both the Pacific and Caribbean margins of Colombia.

Central Cordillera

The Central Cordillera is comprised primarily of amphibolite-grade Proterozoic and greenschist-grade Paleozoic metamorphic rocks (demarcating the western, deformed edge of the Guiana Shield, and it's Paleozoic foredeep and marginal sedimentary cover sequence) which have been intruded by three Andean-type arcs, of roughly (Triassic) Jurassic, Mid- to Late Cretaceous, and Miocene to Recent ages. These arcs are all constructed upon continental basement and record the eastward subduction of oceanic lithosphere beneath the South American continental block. Jurassic magmatism is recorded in the Segovia, Sonson, and Ibague Batholiths (Figure 4), all of which are generally of calc-alkalic, dioritic to quartz dioritic affinity. Associated intermediate volcanic and pyroclastic strata are preserved in the northern portion of the Cordillera, in the Serranía de San Lucas. The Cretaceous Antioquia, Sabanalarga, and Buga Batholiths are also of calc-alkalic affinity, however are of generally granodioritic to quartz monzonitic character. Finally, reactivated magmatic activity beginning in the Mid- to Late Miocene and continuing through to the present is first recorded in the central portion of the Central Cordillera (El Bosque Batholith), and is presently exemplified by the NNE trending chain of Andean, calc-alkalic stratovolcanic cones stretching from the central Central Cordillera (Dept. of Caldas), south through to the Colombia-Ecuador border, and southwards.

The Western Cordillera

Dominated by thick sequences of Cretaceous flyschoid volcanic and sedimentary strata, intruded by Early and Late Tertiary plutonic and hypabyssal intrusive rocks, recent interpretations of the evolution of the Western Cordillera of Colombia involve the assembly and accretion of Cretaceous oceanic terranes to the western margin of continental South America, beginning in the Late Cretaceous. The Western Cordillera may be considered in two segments; a southern segment consisting of at least three distinct accreted Cretaceous oceanic terranes, and a northern segment comprised of the Choco Segment of the Panama Arc, containing the Baudó and Cañas Gordas Terranes (GEOTEC, 2000). Magmatic activity in the north is dominated by the Eocene Mandé-Acandí, Farallones, and Mistrato Batholiths, of calc-alkalic affinity and generally tonalitic composition. They demarcate the formation of an island arc constructed upon oceanic crust prior to it's collision with northern Colombia in the Neogene (GEOTEC, 2000). Magmatism in the southern segment is volumetrically more restricted, manifesting as Eocene tonalite plutons in the southernmost Western Cordillera (Piedrancha Batholith), and widely dispersed but small andesite-dacite porphyry bodies of Neogene age.

Cauca-Patia Depression – Cauca River Drainage

This important geologic – geographic intermontane depression which separates the Central and Western Cordilleras of Colombia records clastic shallow marine and intermontane sedimentation beginning in the Eocene. It is an important feature from a metallogenic standpoint as it became the locus for eastward migrating magmatic activity beginning in the Middle Tertiary, and hosts numerous hypabyssal porphyry intrusions of andesitic to dacitic composition which intrude the generally reduced, fine-grained clastic sequences occurring along it's entire length. Recent analysis of seismic reflection profiles indicates the sedimentary sequence in the southern portion of the Depression underwent thrust-and fold-belt style deformation prior to porphyry intrusion (GEOTEC, 2000). A general three phased history for the Cauca-Patia Depression may thus be inferred – 1) as a coastal margin - intermontane basin receiving clastic sedimentation from the emerging Central and Western Cordilleras, 2) as a zone of foreland compression, responding to the collision of Cretaceous oceanic terranes along the Colombian Pacific margin, and 3) as an arc-axial grabben or zone of weak extension demarcating the thermal axis of Mid- to Late Tertiary magmatism. Such a history contains obvious metallogenetic implications.

A skeletal map of the major occurrences of plutonic and hypabyssal igneous rocks in the Colombian Andes is presented in Figure 4.

METALLOGENY

The integrated gold metallogeny of Colombia is complex, prolonged, and sparsely understood. The topic has been breached on the mine and lessor district-scale levels in various unpublished theses or governmental geological (INGEOMINAS) bulletins, however virtually no integrated approaches have been taken to assimilate the district-scale characteristics of gold mineralisation into a magmatogenic and/or metallogenetic framework (Colombian “magmatogenic” or “metallogenic” epochs) with respect to the tectonic evolution of the Colombian Cordillera *sensu lato*. In many respects this lack of conceptual integration simply reflects a paucity of modern geochemial, especially geochronologic and wide-spectrum multi-elemental data, generated purposely with repect to gold metallogeny. It is noteworthy that the great majority of radiometric age-dates produced from the Colombian Cordillera are of the K-Ar (biotite, hornblende, sericite)-type, and in this context are known to be highly susceptible to re-setting via subsequent thermal events, complicating in the process any associated time-contextual interpretations.

Regardless, in the broadest of senses, field visitation, available geochemical data, and “broad-brush” tectonic analysis all clearly indicate that the majority of the full spectrum of Colombian gold deposit-types may be viewed in terms of distinct, temporally constrained, metallogenic epochs, and in this context, exhibit petrographic, geochemical, structural, and geometric associations and charateristics unique to these gold metallogenic “pulses”. Excellent spatial correlation is observed between the plutono-volcanic (magmatogenic) units of various ages in the Colombian Cordilleras, and the varying characteristics of the gold “metallogenic pulses” in general. It is hence possible to classify Colombian gold deposits based in first principle upon the age of the magmatic event observed to be (at least) spatially associated with the mineralisation. From both a historic production as well as a geologic perspective the (Triassic) Jurassic, Late Cretaceous, and Early and Late Tertiary are clearly the ages of greatest importance with respect to Colombian gold metallogeny. The following summaries regarding these “metallogenic epochs” are presented, however it should be noted that a variety of “anomalous”, isolated yet significant, gold deposits fall outside of the simplified classifications presented below, and above all, emphasize the prolonged and complex nature of Colombian gold metallogeny, and the general lack of an integrated and coherent system for it's understanding.

Jurassic

From the standpoint of historical and modern-day production, gold mineralisation associated with Jurassic-aged rocks, and their derived colluvial-alluvial occurrences, may be considered to be of the greatest importance in Colombian gold mining. These deposits have been worked extensively over the last 200 years, by artisanal miners, and by such companies as the Choco Pacific Mining Co. (Anglo American Gold Mines), the Frontino Gold Mines, and the Pato Gold Mining Company (owned by Placer Development Inc., an early incarnation of Placer Dome Inc.). From a strictly hardrock perspective these deposits yield a variety of +1,000,000 oz. Au historical producers, including the El Silencio-Providencia Mine at Segovia, the La Bartola-Palmichela-La Castellana Mine at Remedios, and the El Limón camp near Zaragoza (Figure 2).

Jurassic-aged magmatic rocks form an ENE-striking discontinuous curvilinear belt dominating the eastern flank of the Central Cordillera, and the northern portions of the Eastern Cordillera through to the Sierra Nevada de Santa Marta (Figure 4). Viewed south to north, the geologic entities of greatest importance include the Ibague Batholith, the Segovia Batholith, the Santander Massif, and the Santa Marta Batholith. All of these units yield a rich gold metallogeny, hosted within (Triassic) Jurassic-aged plutonic and volcanic rocks as well as within the intruded Paleozoic and Precambrian metamorphic complexes. The following general characteristics are noteworthy;

Age of Plutons: (Triassic) Jurassic, 170 to 130 m.a.
Pluton Petrology: Holocrystalline, medium grained biotite +\- hornblende diorite to quartz diorite.
Pluton Petrochemistry: Intermediate, metaluminous, calc-alkalic, I-type magmatism
Style of Mineralisation: Discrete, broadly mesothermal vein structures and clusters of vein structures. Structures range from 10´s of cm to metre-plus widths. Excellent strike, down-dip and grade continuity (Note, the El Silencio vein has been worked on 44 levels). Conspicuous lack of strong post-mineral ductile deformation. Strikes and dips highly variable however many cluster N to NE, with 40 to 60° dips.
Ore Mineralogy: Mixed base-metal sulphides, pyrite (pyrrhotite)-sphalerite-chalcopyrite-galena, occasional tellurides. Generally good correlation Au (tellurides)-galena-sphalerite. Native gold common.
Gangue Mineralogy: Predominantly quartz with calcite (ankerite)
Wallrock Alteration: Pyritic sulphidation, carbonitisation, sericitisation proximal to mineralised structures, contained within a broad propylitic (epidote, lessor chlorite) halo in intrusive rocks.
Ag:Au ratio: Low, range 0.5:1 to 5:1
Geochemical Expression: Au, Ag, Zn, Pb, Cu +\- Te
Average Grades: 20 to 40 g Au\t over life of mine, multi-ounce vein segments not uncommon.
Most Active Producing Areas: Dept. of Antioquia: Segovia, Remedios, Santa Isabel, Zaragoza, El Bagre, Guamoco. Dept. of Bolívar: Simití, Santa Rosa, El Oso, Morrocoyal, San Martín de Loba. Dept. of Tolima: Ibague, San Luis.

Note that the Cerro San Carlos area in the Dept. of Bolívar (Central Cordillera), and the Vetas-California-Angostura region of the Dept. of Santander (Eastern Cordillera) both differ somewhat from the generalities outlined above. In either case mineralisation appears to be Mid- to Late-Jurassic, hosted within intrusive and/or volcanic rocks of like age. Mineralisation and alteration, dominated by silicification, argillitisation-sericitisation, and pyritic sulphidation +/- propylitisation is intensely developed, and observed on a km-scale basis. Gold-silver mineralisation is hosted within dense networks of structurally-controlled cm to 10´s-of-cm scale veinlets and sheeted veins, and phreatic breccia zones. Vein-fillings are dominated by +50% pyrite, with lessor quartz and minor base metal sulphides. In the case of Cerro San Carlos such mineralisation is volcanic-hosted, and underlain by a plutonic root zone where chalcopyrite becomes the dominant veinlet sulphide, gold grades diminish somewhat, and alteration approaches phyllic in character.

Cretaceous

Although of lessor importance to Colombian gold production history than the Jurassic-hosted occurrences, gold deposits hosted within generally Late Cretaceous plutonic rocks and their proximally located metamorphic and sedimentary cover sequences have produced significant quantities of gold. A number of historic +1,000,000 oz Au camps including the Bramadora, Anorí, the Río Nus valley, and Amalfi are documented. The geographic distribution of Cretaceous igneous rocks in Colombia is primarily restricted to the Central Cordillera, the vast majority of which are associated with a single geologic entity, the Antioquian Batholith (Figure 4), which is exposed over an area of some 8,000 sq. km in the northern portion of the Central Cordillera.

Age of Plutons: Antioquian Batholith, Late Cretaceous (+\- 70 m.a.), Sabanalarga, Buga Batoliths, Mid-Cretaceous, 110 to 90 m.a.
Pluton Petrology: Holocrystalline, medium to coarse-grained biotite +\- hornblende granodiorite to quartz monzonite, local dioritic to gabbroic phases.
Pluton Petrochemistry: Intermediate to felsic, metaluminous, calc-alkalic, I-type magmatism
Style of Mineralisation: Broadly mesothermal, syn-to post-kinematic veins and reticulate to sheeted veinlet and fracture networks cutting plutonic rocks and proximal or mantling sedimentary and metamorphic sequences.
Ore Mineralogy: Pyrite, arsenopyrite, galena, sphalerite, chalcopyrite +/- stibnite, jamisonite, pyrrhotite, native gold.
Gangue Mineralogy: Predominantly quartz with late calcite
Wallrock Alteration: Pyritic sulphidation, silicification, local potassic alteration (k-spar, biotite, sericite) and carbonitisation in batholith, regional propylitisation (epidote, lessor chlorite).
Ag:Au ratio: Low, variable 1:1 to 10:1
Geochemical Expression: Au, Ag, As, Sb, Hg, Pb,+\- Cu, Zn
Average Grades: Larger veins 10 to 30 g Au\t over life of mine, veinlet networks 3 to 4 g Au/t, local multi-ounce accumulations.
Most Active Producing Areas: Dept. of Antioquia: La Bramadora, Anorí, Amalfi, Gramalote – San José del Nus, Sonson, Gomez Plata, San Vincente. Dept. of Valle del Cauca: Buga – Ginebra.

An interesting varient on the above generalities is the Gramalote Mine, located in the Río Nus valley, central Antioquia. At Gramalote clear porphyry-related alteration and metal zonation is observed within Cretaceous biotite quartz monzonite over an area of approximately 2 sq. km. A core zone exhibiting k-spar-quartz-pyrite-biotite alteration contains auriferous molybdenite +\- chalcopyrite veining and is bordered by a well developed phyllic-sericitic zone hosting widespread auriferous quartz-pyrite veinlets. High-grade, discrete, auriferous quartz-base metal vein mineralisation is observed 2 to 5 km to the south, east, and west of Gramalote, suggesting a further regional-scale zonation.

Tertiary

Gold mineralisation hosted within Tertiary-aged plutonic, volcanic, and sedimentary rocks, and proximal intruded Cretaceous strata is widespread throughout the Western and, to a lessor degree, Central Cordilleras of Colombia. It´s occurrence spans the Tertiary, manifesting in a wide variety of styles and associations. With some notable exceptions however, it is the historically least exploited, and in many respects, least understood of the Colombian gold metallogenic pulses. Maintaining a “broad-brush” approach, mineralisation can be clustered into “Early” and “Late” classifications, and the following generalisations can be made.

Early Tertiary

Early Tertiary magmatism and related gold occurrences are primarily restricted to the northern Western Cordillera of Colombia, as exposed in the Mandé, Farallones, and Mistrato Batholiths. Regardless, additional significant gold mineralisation is observed in the southern Western Cordillera (Piedrancha Batholith), and in the Central Cordillera (El Bosque Batholith) (Figure 4). Gold metallogeny associated with the Early Tertiary may be characterised as follows;

Age of Plutons: Paleogene - Early Eocene (+/-60 to 50 m.a.)
Pluton Petrology: Holocrystalline, fine to medium grained biotite +\- hornblende tonalite, minor gabbroic phases.
Pluton Petrochemistry: Mafic to intermediate, metaluminous, calc-alkalic, I-type magmatism
Style of Mineralisation: Broadly mesothermal veins, vein swarms and sheeted veining cuttings plutons and proximal reduced Cretaceous volcano-sedimentary strata.
Ore Mineralogy: Pyrite, pyrrhotite, arsenopyrite, native gold, +/-local chalcopyrite, molybdenite.
Gangue Mineralogy: Quartz, calcite, ankerite
Wallrock Alteration: Strong, widespread carbonitisation, sulphidation (py-po-asp), silicification, minor biotite, distal epidote, chlorite (minor).
Ag:Au ratio: Low, variable 1:1 to 4:1
Geochemical Expression: Au, Ag, As, +/- Cu, Mo
Average Grades: Individual veins 15 to 40 g Au/t. Grades of +/-10 g Au/t can be sustained over 5 to 15 m vein swarm widths. Multi-ounce values locally common.
Most Active Producing Areas: Dept. of Nariño: La Llanada, Sotomayor, Cumbitará, El Diamante. Dept. of Risaralda: Puerto de Oro, Mistrato, Las Camelias. Dept. of Antioquia: Santa Inés, Andes. Dept. of Quindio: Salento.

In addition to the above characterised “gold-only” occurrences, a variety of “porphyry-related” Cu-Mo+/-Au systems of Lower Tertiary age have been documented. Associated primarily with the Mande-Acandí Batholiths of the Western Cordillera, these occurrences include Murindo, Pantanos, Acandí and Río Pito (Sillitoe et al., 1892).

Late Tertiary

A wide variety of gold occurrences, including some significant historical producing camps are associated with Late Tertiary magmatism in Colombia. The majority of these occurrences are geographically contained within or along the western margin of the roughly N-S trending Cauca-Patia Depression, and it´s northern extension along the Río Cauca valley. Gold mineralisation is related to the emplacement of numerous, generally small, often polyphase-polylithic, andesitic through dacitic stocks and plugs of hypabyssal, commonly porphyritic affinity, and is hosted within the same porphyry bodies and the intruded Tertiary and Cretaceous sedimentary and volcanic sequences. Considered from north to south, important known mineralising centres of Late Tertiary age include; Buriticá, Guintar, Titiribí, Caramanta-Valparaíso (Dept. of Antioquia), Marmato-Echandía, Supia (Dept. of Caldas), Quincha-Miraflores-Mina-Rica (Dept. of Risaralda), Buenos Aires-Suárez, El Tambo, Dominical, Altamira, Cerro Negro-La Concepción, and Cerro Bolívar (Dept. of Cauca).

In detail, characteristics of the associated gold mineralisation differ widely, given variations in pluton petrochemistry, geologic structure, and the nature of the host sedimentary and/or volcanic rocks. Regardless, the following parametres are generally valid:

Age of Plutons: Miocene-Neogene (+\-15 to 4 m.a.)

Pluton Petrology: Fine to medium grained andesite and dacite. Plagioclase, quartz, biotite, hornblende occur as phenocrysts.
Pluton Petrochemistry: Intermediate to felsic, metaluminous, calc-alkalic, I-type magmatism
Style of Mineralisation: Broadly epithermal to mesothermal. High-grade vein swarms and fracture systems cut plutons and surrounding host rocks. Disseminated and finely fracture-dispersed, sulphide-related mineralisation in host sediments seen at Buriticá, Titiribí, La Concepción. Porphyry-related Cu (Mo)-Au associations seen at Titiribí, Guintar, Valparaíso, Buenos Aires-Suárez, Cerro Negro-Dominical. Intrusive-wallrock hosted breccia zones seen at Buriticá, Quinchía-Miraflores. Porphyry-associated “gold-only” mineralisation documented at Altamira, La Concepción. Extensive fracture-controlled and veinlet-type mineralisation within porphyry and volcanic rocks at Mina Rica, Marmato-Echandía, Supia, and Buriticá.
Ore Mineralogy: Variable; pyrite +/- sphalerite (marmatite), galena, chalcopyrite, arsenopyrite, stibnite, +/- Ag-sulphosalts, pyrrhotite, native gold, electrum
Gangue Mineralogy: Predominantly quartz with late calcite, poorly documented
Wallrock Alteration: Pyritic sulphidation, silicification, sericitisation, argillitisation, propylitisation (epidote), zoning notable in intrusives, subtle biotitisation, sulphidation, (de)carbonitisation in sedimentary rocks.
Ag:Au ratio: Highly variable 5:1 to 100´s:1
Geochemical Expression: Au+/-Ag, Zn, Pb, Sb, As, Hg or Au+\- Cu, Mo, Ag
Average Grades: Highly variable, dependant upon the intensity and/or density of mineralisation, alteration, fracturing, and nature of host the rocks.
Most Active Producing Areas: Dept. of Antioquia: Buriticá, Titiribí, Guintar, Caramanta. Dept. of Caldas: Marmato-Echandía. Dept. of Risaralda: Miraflores, Mina Rica. Dept. of Cauca: Buenos Aires-Suárez, La Concepción, El Tambo, Cerro Bolívar.

Aside from the Late Tertiary mineralisation occurring along the general Cauca-Patia-Río Cauca trend, significant additional, more isolated Late Tertiary occurrences are noted in distinct areas. The most notable include:

The Lunareja-Paramo de Frontino area in the Western Cordillera of Antioquia is rather unique to Colombian metallogeny. It is hosted in a 40 km sq., partially eroded volcanic complex of Miocene age (one of the few preserved Colombian examples). Mineralisation is Ag-dominated (Ag:Au from 10 to 500:1), accompanied by sphalerite, galena, argentite, tetrahedrite, native gold and electrum, with siderite, calcite, agate, quartz, amethyst, and barite forming the gangue phases. Mineralisation occurs in mega-scale fracture zones (the Lunareja structure is 4 km long, and averages 20 m in width), phreatic poly-event breccia zones, and disseminated within hypabyssal porphyry bodies which intrude the volcanic complex.

Additionally, the nucleus of the Departments of Caldas-Quindio-Tolima, in the Central Cordillera, contains various gold occurrences associated with Late Tertiary hypabyssal porphyries and breccia zones which intrude the Paleozoic metamorphic sequences. Anomalous Au-Sb-Hg-As-Zn values are associated with these occurrences however little exploration or development has been undertaken.

In summary, it can be re-emphasised that the integrated gold metallogenic history of Colombia is not fully understood, being constructed by a clearly prolonged and complex series of tectono – magmatic events; events which have produced an ample range in the age, style, geochemistry, and structure of Colombian gold deposit-types. To a large degree, the lack of modern technical information and studies regarding gold deposits and gold metallogenesis in Colombia stems from the historic lack of *necessity* for such studies – gold occurrences in Colombia are, in general, so widespread and numerous, that it has never been necessary from a production standpoint to derive genetic or exploration models in order to actually locate more

ore. It is interesting to note that many organised Colombian mines, for lack of exploration (especially drilling) and pre-development, never carry more than a years worth of (by North American or Australian standards) “reserves” on their books. Regardless, many such mines record +100 year production histories, and will continue to produce significant quantities of gold in the future!! The traditional and modern Colombian graduate thesis or post-graduate study with respect to gold mineralisation approaches the topic from the *production* (mine planning, resource estimation) standpoint, and the subtleties of the actual metallogenesis are generally not developed to any degree. It has only been in the last decade that incipient exploration by foreign-capitalised companies has begun to address questions of Colombian gold metallogeny from a modern tectonic, metallogenic, and analytical standpoint.

EXPLORATION UPDATE, 1985 – 2000

Present-day Colombia suffers from an obvious lack of modern gold exploration. In truth, with few exceptions, the present-day producing areas in Colombia are precisely coincident with areas of historic production, the histories of the majority of which date from pre-Colombian times. This lack of internal exploration investment stems from the traditional Colombian attitude: “Why should we go look for more gold deposits, while the ones we have continue to economically produce gold?”. With respect to investment from the international community, the perceived social situation in the country has left few potential investors with the fortitude or infrastructure to initiate activities. Such exploration inactivity has placed the Colombian mineral exploration sector in a clear dichotomy: Colombia, the country which purports perhaps the largest *historic* gold production in South America, presently receives the least exploration funding, from either of the national or international sectors, of any country on the continent. Heedless of such apparent lack of interest, Colombian miners, both artisanal and semi-modernised, continue to produce significant quantities of gold, providing abundant empirical demonstration to the obvious conceptual gold metallogenic potential of this northern Andean Country.

Governmental – Institutional Studies: The Public Database

Noteworthy of modern metals exploration efforts in Colombia in general are a variety of jointly funded programs involving the Colombian governmental entity INGEOMINAS (Instituto Nacional de Investigaciones Geológico – Mineras) and various external institutions, including the United Nations, the Metallurgical Institute of Japan, and other foreign governments. These studies date primarily from the 1970’s through to the late 1980’s, and mostly addressed porphyry Cu (Mo, Au) potentials in Colombia. Some of them culminated in diamond drill programs and resource estimations. Numerous additional baseline geochemical-geological studies of value to the exploration geoscientist have been carried out by INGEOMINAS, in many regions throughout Colombia, and as with the above described joint commission studies, are available for consultation and/or purchase through the INGEOMINAS libraries in Bogotá, Medellín, Cali, Ibague, Popayan, or Pasto – look for both the INGEOMINAS “Boletín Geológico” and “Publicaciones Geológicos Especiales” series. The recent ACIGEMI project by INGEOMINAS is a digital compilation at 1:500,000 scale containing a series of geological-geochemical-mineral occurrence-mine location and topographic overlays, and is also available for purchase from INGEOMINAS.

Additionally, various good quality mine to district-scale geological, geochemical, and engineering studies are presented as Colombian university-level graduate and post-graduate theses, and are generally well archived at the respective universites. Recommended reconnaissance includes; the Universidad Nacional in Santafé de Bogotá, the Universidad de Antioquia, and the Universidad EAFIT, both in Medellín, and the Universidad del Valle, in Cali.

Private Exploration Sector

Figure 5 locates some of the most concerted gold-focussed hardrock exploration efforts in Colombia over the last 15 years, as carried out by foreign-capitalised exploration companies. To date, all of these efforts have focussed upon active areas of artisanal to semi-mechanised production, or known historic gold occurrences, and as such cannot be considered to have been *conceptually* driven, nor can they be considered to have generated *new* areas of exploration interest. Indeed, such is the case in Colombia that there remain abundant documented or producing, yet untested, gold exploration targets which merit investigation, and as such exploration to date has remained, in general, empirically driven.

Considering the 14 companies listed in Figure 5, a "ballpark" estimate of *in-ground – hard rock - gold-related* exploration expenditures for Colombia over this given 15 year time period would be on the order of U.S. $40 million. Most of this investment took place between 1993 and 1999. There are presently 4 publicly announced foreign-financed companies actively exploring for hardrock-hosted gold occurrences in Colombia.

Exploration Results

Confidentially prevents the open discussion of exploration results for all of the companies and projects outlined in Figure 5. Regardless, a brief indication of target-types and preliminary results for a number of the project areas is presented in generally chronological order below.

Greenstone Resources Ltd. – Fischer Watt Inc., El Limón Project, Zaragoza, Antioquia: The Zaragoza region is a classic high-grade mesothermal vein camp with a centuries-old, multi-million ounce production history. The El Limón Mine is one of numerous veins which fill second-order fracture zones related to movement along the Otu Fault. The mine was originally acquired by Greenstone Resources Ltd., *ca.* 1985 who proceeded to develop the vein. Fischer Watt purchased the project in 1995, and continues to operate the mine (150 tpd mill). The region is highly prospective, and numerous additional small-scale mines and undeveloped veins of similar scale are known within a 20 km radius of El Limón. Only the El Carmen structure, 15 km to the north, has undergone any degree of technical exploration.

Duel Resources Ltd., El Alacran Project, San Juan, Cordoba: This active artisanal prospect attracted the attention of Duel *ca.* 1985, and a program of mapping, trenching and diamond drilling was initiated. A series of mixed Cretaceous volcano-sedimentary strata intruded by "Tertiary porphyries", and hosting strataform and/or replacement-style mineralisation were encountered. Fifteen diamond drill holes were completed over an *ca.* 400 m strike length along the volcano-sedimentary sequence, and a "best hole" of 32 m grading 2.3 g Au/t and 4.8% Cu was returned. No further work is recorded.

Grupo de Bullet S.A., Buriticá Project, Buriticá, Antioquia: This high-level Tertiary porphyry complex set into reduced Cretaceous fine-grained clastic sedimentary strata hosts km-scale zoned intrusive-related mineralisation which has been exploited for over 500 years. Grupo de Bullet has delineated over 25 high-grade vein and breccia structures hosted within porphyritic rocks and along the margins of the intrusive complex, and has been producing Au+Ag-Pb-Zn concentrates from the area since 1994. Bullet presently produces in the Mina Yaragua zone from a series of 15 sub-parallel fault veins which average *ca.* 20 g Au, 400 g Ag and 4% Zn per tonne. No drilling has been completed. Clear sediment-hosted potential is indicated.

Gran Colombia Resources Inc., various projects:

Marmato-Echandía, Caldas: One of numerous attempts to build a bulk-mineable resource within this mega-scale porphyry-volcanic-hosted mineral system (Phelps Dodge drilled a portion of Marmato in 1985), Gran Colombia, between 1993 and 1996, compiled 1000's of chip and channel samples in the dozens of tunnels and artisanal workings at Echandía, in addition to completing at least 35 drill holes. Preliminary published calculations indicated the presence of a low-grade (+\-1.5 g Au, Au-Ag equivalent), sulphide-stable, global resource of on the order of 6 million ounces Au.

Ginebra, Buga, Valle del Cauca: This is a highly active artisanal mining region hosted within a dioritic to gabbroic phase of the Mid-Cretaceous Buga Batholith. Gran Colombia completed abundant surface sampling and various geophysical investigations, as well as *ca.* 15 diamond drill holes. Mineralisation was encountered in stacked, roughly flat-lying fracture systems within highly pyritised intrusive rock. An approximately 200,000 oz. open-pittable Au resource was reported.

Metallica Resources Inc., various projects:

Cerro San Carlos, Sur de Bolívar: This young, active artisanal area, hosted within the presently most prolific gold producing region of Colombia, was the focus of Metallica's Colombian operations in 1995. Metallica carried out 1:5,000-scale geologic and alteration mapping, collected 100´s of chip and channel samples throughout and around the intensely altered volcanic-hosted artisanal workings, and installed an *ca.* 40 line-km geochemical soil sampling grid over the entire Cerro San Carlos. A gold-in-soils anomaly measuring *ca.* 1700 m by 500 m, and averaging *ca.* 225 ppb Au was established. Fracture-style, supergene enriched, intrusive-hosted Cu-Au mineralisation was documented in deep streamcuts on the northern flank of Cerro San Carlos. No drilling was completed.

Gramalote, Providencia, Antioquia: Gramalote has been the focus of open cut gold exploitation activity in the Río Nus valley for over 100 years. Metallica's brief investigation encountered widespread fracture and joint-hosted mineralisation within altered biotite quartz monzonite, and the area was subjected to preliminary geological-structural mapping and surface chip and channel sampling. Some 150 samples were collected by Metallica. In the nucleus of Gramalote Ridge a 160 m section of continuous channel sampling averaged 1.79 g Au/t. Subsequent artisanal excavations have exposed a k-spar-quartz-pyrite-altered core zone hosting auriferous, sooty molybenite +/- chalcopyrite mineralisation some 250 m SE and 100 m topographically below the Gramalote Ridge sample profile. No drilling has been carried out.

TVX Gold Inc., various projects

Mina San Jorge, San Luis, Huila: This re-activated historic vein camp is hosted within Jurassic volcanic rocks on the southern margin of the Ibague Batholith. In 1995-1996 TVX completed extensive underground sampling at San Jorge, and surface reconnaissance on numerous artisanal operations in the area. At San Jorge the historic adits were re-opened, cleaned and sampled on one of 7 historic levels. When diluted to a width of 1.1 m, the vein returned an average grade of 128 g Au/t, sustained in 5 metre-spaced, transverse-to-vein back samples over the 70+ metres of the portion of drift cleaned and sampled. No drilling was completed.

Miraflores, Quinchía, Risaralda: The Miraflores Mine yields artisanally-produced gold from high-grade mineralised fault structures hosted within a hydrothermal mega-breccia zone within Cretaceous volcanic rocks intruded by Late Tertiary andesite and dacite porphyry. Mineralisation and alteration in the area are widespread and TVX's brief study of the area documented +1 g

Au/t with anomalous Cu values in the porphyries, as well as locally spectacular accumulations of gold with base metals in the veined and brecciated volcanic rocks. No drilling was completed.

Gold Fields Ltd., Titiribí Project, Titiribí, Antioquia: Zancudo Gold Mines production records from the 1920's to 1940's at Titiribí reveal a +3 million ounce Au-equivalent production history, primarily manifesting from dozens of manto-type, fault-vein-hosted, and disconformity-related high-grade underground ore bodies hosted within a Late Tertiary porphyry complex, it's intruded Paleozoic metamorphic basement and a diapirically-domed mantling Tertiary-aged reduced clastic sedimentary sequence. A mineralised system extending over +12 sq. km is documented at Titiribí. Based upon localised, grid-generated geophysical and geochemical results restricted to the central portion of the porphyry dome complex, Gold Fields completed *ca.* 3000 metres of drilling in 16 diamond drill holes, outlining a significant but sub-grade, zoned Au-Cu (Mo) resource.

Greystar Resources Ltd., Angostura Project, California, Santander: Since 1996 Greystar has completed *ca.* 56,000 m of drilling in this centuries-old gold producing district. Mineralisation manifests as widespread, structurally-controlled, sheeted high-pyrite + quartz veining, hosted within intensely altered Jurassic-aged "porphyritic" rocks. A 1999 independently reviewed resource estimate calculated at a 0.5 g Au/t cut-off outlined "indicated and inferred" resources totalling 96 million tonnes grading 1.6 g Au/t and 5.8 g Ag/t, for a total contained resource of 4.9 million ounces Au and 17.9 million ounces Ag. Continued exploration and preparation for completion of a full feasibility study are underway.

Sur American Gold Corporation, Mina Rica Project, Quinchía, Risaralda: This active artisanal zone is comprised of Late Tertiary veinlet and fracture-hosted Au-Ag mineralisation contained within pyritically-argillically altered agglomeratic and dacitic volcanic rocks intruded by andesite dykes. Since 1996 Sur American has carried out a variety of geochemical and geophysical studies in the area, and has completed at least 5 diamond drill holes. Published drill results include; MR-1; 18.9 m @ 3.56 g Au/t, MR-2; 22.5 m @ 4.5 g Au/t, MR-4; 12 m @ 2.51 g Au/t and MR-5; 29 m @ 2.61 g Au/t. Significant coincident IP-resistivity anomalies in the area remain untested. Exploration at the project is presently on hold.

Conquistador Mines Ltd., Marmato, Caldas; Having entered into agreements with Mineros Nacionales and Mineros de Antioquia in 1995, and more recently with MINERCOL (Colombian Ministry of Mines permit granting and management branch) Conquistador continues in the most recent attempt to legally consolidate and geologically model this mega-scale mineral system. Based upon an extensive underground sampling program (there are over 130 producing adits penetrating Marmato hill) and the completion of 44 diamond drill holes, an independent resource estimate for the combined Zona Alta and Zona Baja areas of Marmato using a 0.75 g Au/t cut-off infers a global resource consisting of some 150 million mt of sulphide-stable material grading 1.35 g Au and 5.65 g Ag/tonne, thus containing *ca.* 10,170,000 oz Au and 39,480,000 oz Ag. Conquistador has identified an additional 5 targets, including the Oro Fino and Montoya Projects, within a 5 km radius of Marmato Hill. Exploration continues. In November, 1999, Conquistador entered into a joint-venture exploration agreement with AngloGold South America.

CONCLUDING STATEMENT

It is apparent, and generally well accepted, that Colombia exhibits a rather spectacular history of gold exploitation. This history, when combined with an obvious, yet only incipiently explored metallogenic potential, appears to beckon a thorough re-evaluation of the gold exploration and development potential of the country from a modern-day viewpoint.

The decisive factors inhibiting development of the gold exploration/exploitation sector in present-day Colombia are clearly socio-political, and potentially involve security risks which most companies, both foreign and domestic, are not willing to accept. Such as the present case may be, similar situations in other regions of South America and the world have been observed to resolve relatively rapidly (Perú in fact yields a “world-class” example), and provide reasonable support to the philosophy that it is generally better to position early than to find one’s self lost in a line-up of competitors.

Colombia is a country of wide-ranging, and in many cases, contradictory and unique attributes - geographic, physiographic, cultural, historical, botanical, and geological. It is a interesting point to ponder that, comparable to Perú and her superb and ample selection of pre-Colombian ceramics and textiles, virtually all of the pre-Colombian cultures which inhabited the Andean Cordilleras and intermontane valleys of Colombia yielded a personalised, technologically advanced, and artistically profound gold craftsmanship, which is documented over a +2,500 year archaeological history (Figure 6, Note; there are 10 pre-Colombian gold museums in Colombia; the *Museo del Oro* in Bogotá is one of the most extensive historic gold museums in the world with over 33,000 articles catalogued). It may thus be considered rather poignant that, the country which exhibits the most evolved pre-Colombian history of gold working in the Western Hemisphere remains the final frontier for modern-day gold exploration and development in Latin America.

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