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GOLD FROM THE GOLFO DULCE PLACER PROVINCE, SOUTHERN COSTA RICA

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ABSTRACT: The Golfo Dulce goldfield has been mined since pre-Colombian times and during the 1980's produced at least twice as much gold as the entire Tilarán-Aguacate Gold Province in northern Costa Rica. The gold occurs in eluvial-colluvial placers overlying the Nicoya Complex basement (Late Cretaceous to early Tertiary), as alluvial placers in the unconformably overlying basal conglomerates of the Osa Group (late Pliocene) and in the gravels of the Puerto Jiménez Group (late Pleistocene-Holocene).

Studies of the geographic and stratigraphic distribution of the placer gold, its habit and composition, and the associated heavy mineral suite, demonstrate conclusively that the "source beds" form part of the underlying Nicoya Complex that is an obducted segment of ophiolitic oceanic crust characterized by E-MORB-type basalts enriched in large-ion-lithophile (LIL) elements typical of a back-arc basin setting analogous to the Mariana Trough. The gold was initially concentrated in epithermal auriferous quartz lodes in the basalts, and in interlayered pelagic sediments, by hot circulating fluids (seawater and magmatic fluids) related to one or more of the three submarine volcanic events, of Late Cretaceous to Early Tertiary age. Translative plate movement and subsequent obduction and isostatic uplift of this segment of oceanic crust during development of the Southern Central America Orogen allowed weathering and erosion of the ophiolite complex. This produced gold in solution and native gold that was concentrated during several cycles as eluvial-colluvial-alluvial placers in the late Tertiary and Quaternary sediments derived from the Nicoya Complex.

The primary gold deposits of the Southern Central America Orogen appear to include two distinct types and occur as (i) epithermal Au-Ag± (Pb-Zn-Cu) quartz veins, stockworks and disseminated deposits of late Tertiary age, associated with calc-alkaline acid-intermediate intrusives and/or volcanics in the inner-arc; or (ii) as epithermal low-Ag deposits in ophiolite terrains of the fore-arc. These originated by hydrothermal activity related to submarine basaltic volcanism, probably in an extensional environment such as a back-arc basin, and are significantly older - Late Cretaceous to early Tertiary.

Placer and/or hardrock gold is mined at numerous sites in the ophiolitic terrains of Costa Rica and Panamá, and maybe in the Serranía de Baudó of Colombia; and the Golfo Dulce Placer Province is considered to be the most westerly occurrence of an "ophiolite gold province". The recognition that virtually uncratonized oceanic crust in this region forms the "source-beds" for gold deposits, suggests that similar ophiolitic terrains in the circum-Pacific and Caribbean should be regarded as gold exploration targets.

RESUMEN: El campo aurífero de Golfo Dulce ha sido explotado desde tiempos precolombinos, y durante los años 1980 produce al menos el doble del oro que la totalidad de la provincia aurífera Tilarán-Aguacate en el norte de Costa Rica. El oro ocurre en placeres eluvio-coluviales que sobreyacen el basamento del Complejo de Nicoya (Cretácico tardío al Terciario temprano), como placeres aluviales en conglomerados basales del Grupo Osa (Pleistoceno tardío) que sobreyace en forma discordante, y en las gravas del Grupo Puerto Jiménez (Pleistoceno tardío-Holoceno).

Estudios de distribución estratigráfica y geográfica del oro de placer, su hábito y composición, y la asociación cercana de minerales pesados, demuestra concluyentemente que los "source beds" forman parte del Complejo de Nicoya subyaciente que es un segmento obducido de corteza ofiolítica caracterizados por basaltos tipo E-MORB enriquecidos en elementos litosfera-ion-grande (LIL) típicos de una cuenca trasarco análogo a la Trinchera de las Marianas. El oro estuvo concentrado inicialmente en vetas cuarzo-auríferas epitermales en los basaltos, y en sedimentos pelágicos interestratificados, debido a fluidos calientes circulantes (agua marina y fluidos magmáticos) relacionados a uno o más de tres eventos volcánicos submarinos, de edad Cretácico tardío a Terciario temprano. Movimientos de placas translativos y subsecuente obducción y levantamientos isostáticos de estos segmentos de corteza oceánica durante el desarrollo del Orógeno Sur de Centro América, permitieron la meteorización y erosión del complejo ofiolítico. Esto produjo oro en solución y oro nativo que se concentró durante varios ciclos como placeres eluvio-coluvio-aluviales en sedimentos del Terciario tardío y Cuaternario derivados del Complejo de Nicoya.

Los depósitos de oro primario del Orógeno Sur de Centro América aparentemente incluyen dos tipos distintos y ocurren como (i) vetas de cuarzo epitermal Au-Ag±(Pb-Zn-Cu), "stockworks" y depósitos diseminados de edad Terciario tardío, asociados con intrusivos ácido-intermedios calco-alcalinos y/o volcánicos en el arco interno, o (ii) depósitos epitermales pobres en plata en terrenos ofiolíticos del arco externo. Estos fueron originados por actividad hidrotermal relacionada con vulcanismo basáltico submarino, probablemente en un ambiente distensivo como una cuenca trasarco y son significativamente más viejos - Cretácico tardío al Terciario temprano.

Oro de placer y/o oro de veta es extraído en numerosos sitios en terrenos ofiolíticos de Costa Rica y Panamá y probablemente en la Serranía de Baudó en Colombia; la provincia de placer del Golfo Dulce es considerada la ocurrencia más occidental de una "provincia de oro ofiolítica". El reconocimiento de corteza oceánica virtualmente no cratonizada en esta región forma los "source beds" de los depósitos de oro, sugiere que terrenos ofiolíticos similares en el circum-Pacífico y el Caribe deberían ser considerados como prospectos para la exploración de oro.

INTRODUCTION

Gold mining in the Golfo Dulce Placer Province, that includes the Osa Peninsula, dates back 1300 years to the "gold period" of the Diquis Culture (700-1500 AD) that has yielded more gold artefacts than any other in Costa Rica. From the time of the Conquest onwards there is little record of gold working prior to the end of the 19th Century when gold was rediscovered in the area. Since then gold mining has been carried out sporadically, mainly using manual techniques and primitive recovery methods, until about 1974 when the world price of gold increased dramatically and mechanized mining methodos became more widespread on the peninsula. Ivosevic (1979) estimated that the Osa Peninsula had produced about 100,000 troy ounces of gold during and since prehistoric times up to 1974. During the eight-year period end July 1981 to September 1989 the Golfo Dulce Province produced at least 116,733 Troy ounces of 24 carat gold, ie, an average of 14,600 ounces per year. This is more than twice as much as extracted from all the mines in the Tilarán-Aguacate Gold Province in northern Costa Rica where production during the same period was only 57,475 Troy ounces. As such it constituted the country's most valuable metallic mineral resource.

In spite of the importance to Costa Rica of the Golfo Dulce placer province, its geology and mineral potential had until the mid-1980's been relatively little studied. The Osa goldfield is described superficially in articles on the Costa Rican mining industry written by Bennett (1939), Malozemoff (1942) and Cope (1985), and in a book on Costa Rica's mining industry (Anonymous, 1978). An article briefly describing the geology and mining operations in the peninsula was written by Fernández (1954), and following a visit to the goldfield Cress (1965) wrote an entertaining popular account of prospecting and mining in the area. The first serious published account of the Osa goldfield is that by Ivosevic (1979). He described all the essential features, and his article still stands as a most useful reference work. Lew (1983a, b) carried out geological mapping along the southern coast of the peninsula but paid little attention to the gold mineralization. Azuola (1985) studied the geomorphology and heavy mineral distribution (including gold) along the Rio Agujas. The Golfo Dulce Placer Province was included in a survey of the non-fuel mineral resources of Costa Rica (Los Alamos National Laboratory, et al., 1987; U.S. Geological Survey, et al., 1988), and largely on the basis of geochemical results it was concluded that the region is "still permissive for undiscovered fossil placer gold deposits", both onshore and offshore. In the mid-1980's the British Geological Survey in collaboration with the Costa Rican state mining enterprise, Minera Nacional S.A. (MINASA), made an overall survey of the geology and mineral potential of the Osa Peninsula, the results of which are included in a number of publications by Berrangé and coworkers (Barritt and Berrangé, 1987; Berrangé, 1987a, b; 1988, 1990; Berrangé et al., 1989; Berrangé & Thorpe, 1988).

Unpublished accounts of the geology and gold mining in the peninsula include those by Tremblett (1965) and Segura (1975). MINASA has carried out and commissioned studies on various aspects of the gold mineralization and mining in the area, and on techniques of gold recovery in collaboration with Sveriges Geologiska AB (Anonymous, 1987) and the Departamento de Metalurgia del Instituto Tecnológico de Costa Rica (ITCR) (Amalberto et al., 1987; Chamorro & Jiménez, 1988). It also carried out a financial modelling exercise pertaining to the investment and mining of placer deposits in the peninsula (Monge Ureña, 1985).

TECTONIC SETTING

Central America (Fig. 1) and its adjacent offshore areas include parts of five major tectonic plates: the North American, Caribbean, South

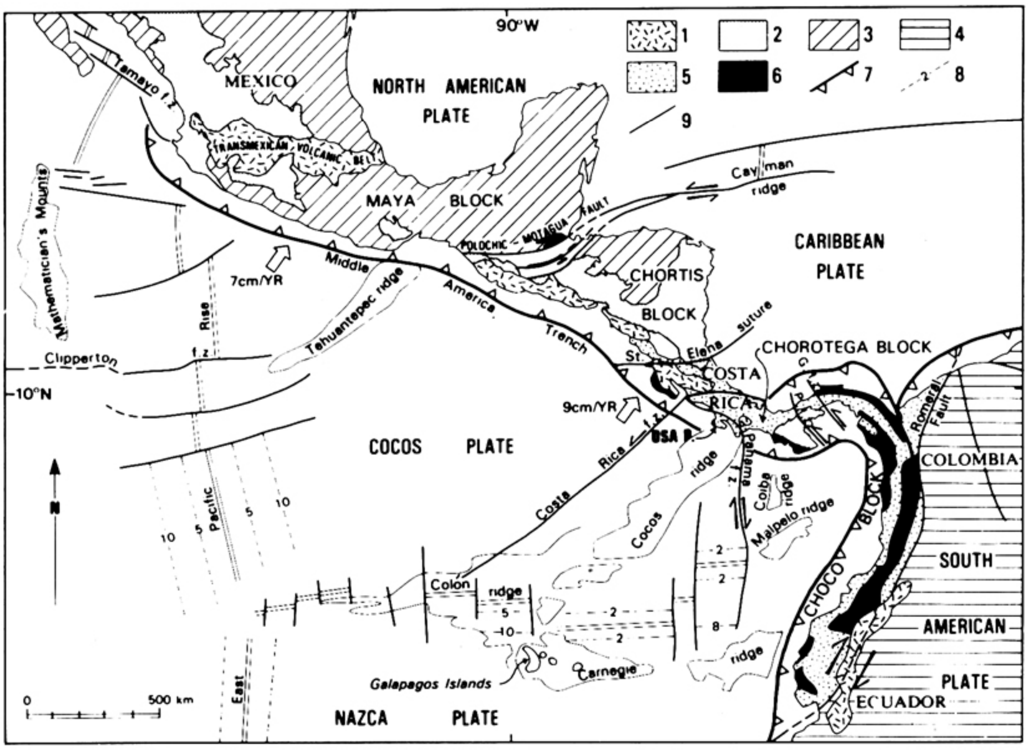

Fig. 1: Tectonic setting of the Osa Peninsula, southern Costa Rica. 1 = Holocene to Pliocene volcanic rocks; 2 = Miocene and Oligocene volcanic rocks; 3 = continental sialic rocks of the North American and Caribbean plates; 4 = continental sialic rocks of the South American plate; 5 = Cenozoic formations of the Andes and southern Central America; 6 = Cenozoic and Mesozoic ophiolite complexes (oceanic crust); 7 = subduction zones; 8 = magnetic anomalies: 9 = fault or fracture zone: G.f.z. = Gatun Fracture Zone. P.f.z. = Parrita Fracture Zone.

American, Cocos, and Nazca plates. Within these plates, smaller crustal blocks, each with its own geological history and characteristics, have been identified (Dengo, 1985). The boundaries between the plates and blocks are defined by major fault zones, spreading lineaments and/or subduction zones. This complex crustal mosaic has been divided (Weyl, 1980; Dengo, 1985) into two contrasting tectonic provinces: northern "Nuclear Central America" (including parts of the North American and Caribbean plates) that has basement of Precambrian and Palaeozoic crystalline sialic rocks overlain by younger continental and epicontinental rocks; and the "Southern Central America Orogen (including part of the South American plate) that in contrast has a basement of Mesozoic oceanic crust. Troughs of marine Tertiary deposits permeated by large quantities of volcanic and plutonic igneous rocks characterize this province. The Southern Central America Orogen extends from the Santa Elena suture (that roughly coincides with the Nicaragua-Costa Rica frontier) through Costa Rica and Panamá to include the coast ranges of Colombia and Ecuador. It can be divided (Dengo, 1985) into the Chorotega and Choco blocks by a tectonic discontinuity representated by major sinestral wrench faults, the Gatun and Parrita fracture zones.

The Chorotega block forms an arc, concave to the northeast, between the Pacific Ocean and Caribbean Sea. In general terms, it comprises a series of concentric arcs and basins (Fig. 2):

(i) The (Pacific) fore-arc ridge is formed of oceanic crust of Jurassic to lower Tertiary age comprising truncated ophiolite sequences locally overlain by Tertiary sedimentary rocks. These rocks are exposed at intervals along the Pacific coast where they form the basement of the Santa Elena, Nicoya, Osa and Burica peninsulas and the Herradura-Quepos arch. There are several intervening sedimentary basins -the Nicoya, Quepos, Dominical, Golfo Dulce and Chiriquí basins that are considered to be of pull-apart origin (Berrangé & Thorpe, 1988; Berrangé, 1990; Astorga et al., in press). The Golfo Dulce Gold Province lies in this region.

(ii) In places the fore-arc is separated from the inner arc by fore-arc basins - the Tempisque Basin and the Terraba Basin. These are grabens containing a varied sequence of shallow- to deep-water marine sedimentary rocks ranging in age from late Cretaceous to Quaternary.

(iii) The inner intrusive-volcanic arc is divided into two distinctive domains. South of the Costa Rica Fracture Zone a relatively deep crustal level is exposed where igneous plutons have intruded Tertiary marine sedimentary, volcanic and volcaniclastic rocks to produce quasi-continental crust. In the northwest the inner-arc is characterized by a chain of late Tertiary to Quaternary strato-volcanoes formed of lavas and tuffs that overlie older volcanic and sedimentary sequences of the fore-arc and back-arc basins. The Tilarán-Aguacate Gold Province is hosted by these volcanic sequences.

(iv) A complex extensional back-arc basin has developed on the Caribbean flanks of the orogen. It comprises the San Carlos, the North Limón and the South Limón basins, each containing 5,000 to 6,000 m of Cretaceous (post-Albian) to Recent sediments including pelagic facies, distal flysch and molasse.

Faulting and vertical tectonics associated with isostatic uplift characterize the fore- and inner-arc, whereas in the back-arc south of the Costa Rica Fracture Zone more flat-lying thrust and fold structures are well developed. The orogen formed in response to subduction of oceanic crust of the Cocos and Nazca plates respectively, below the oceanic Caribbean Plate and the continental South American Plate. The Middle America Trench is a neotectonic lineament that marks the surface trace of the Middle America Subduction Zone where the Cocos Plate is being subducted beneath the Caribbean Plate. This zone is still active but the trench dies out towards the Osa Peninsula in front of which it is plugged by the aseismic Cocos Ridge (van Andel et al., 1971; de Boer, 1979) (Fig. 1). The boundary between the Cocos and Nazca plates is formed by the Panamá-Coiba Fracture Zone, a north-trending series of transform faults that intersect the coast in the vicinity of the Osa and Burica peninsulas where they bend northwest to form a series of braided coast-parallel dextral wrench faults that have produced a series of pull-apart basins (Berrangé & Thorpe, 1988; Berrangé, 1990). The Costa

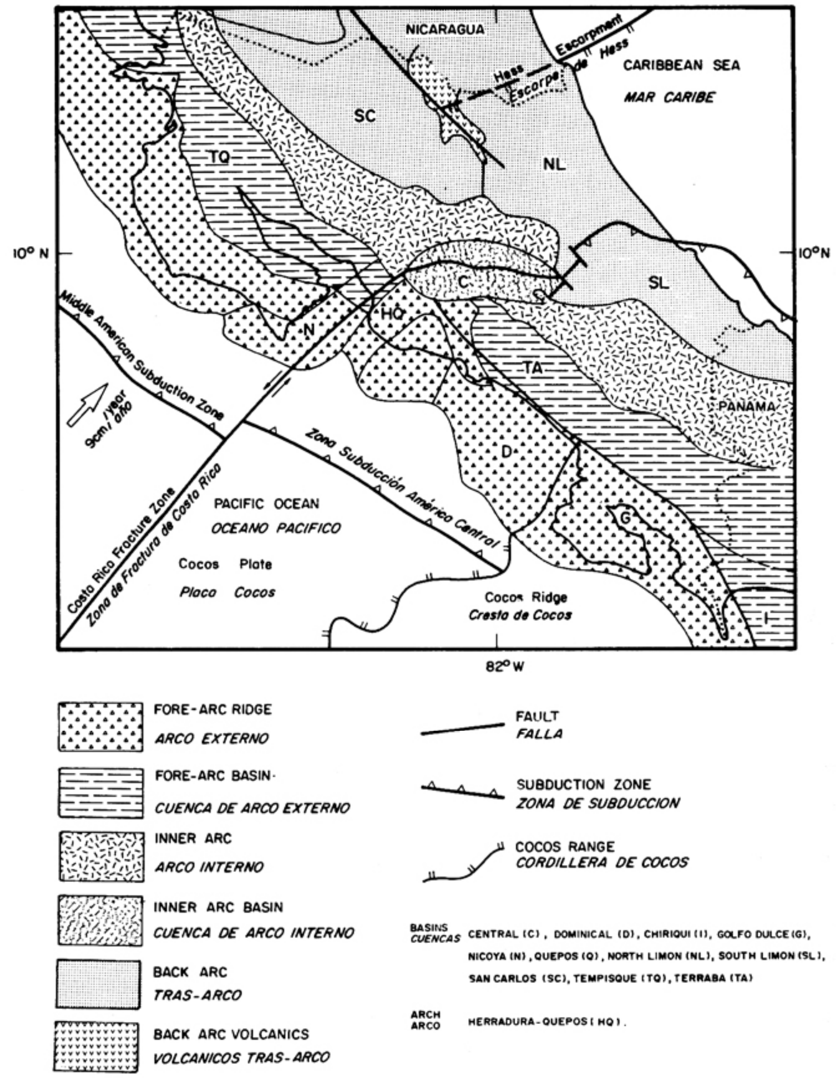

Fig. 2: Major tectonic elements of the Chorotega Block in Costa Rica.

Rica Fracture Zone is a fundamental left-lateral transform that separates the country into two distinctive tectonic domains, and has produced pull-apart basins - the Nicoya-Quepos Basin and the Central Basin (Astorga et al., in press).

GEOLOGY OF THE OSA PENINSULA

The Osa Peninsula es a parallel-sided roughly trapezoidal-shaped landmass approximately 57 km long by 26 km wide that together with its isthmus covers an area of 1100 km^2. It is elongated in a NW-SE direction and has a mountainous dorsal zone rising to 780 m above sea level. The Upper Cretaceous to lower Tertiary Nicoya Complex forms the basement that comprises a truncated ophiolite suite of basaltic lavas with associated intrusive dolerite dikes and sills, and gabro plutons, with subordinate interstratified pelagic deposits including micritic limestone, radiolarian cherts, and argillites (listed in decreasing order of abundance). The lavas are generally massive but locally are pillowed or agglomeratic. The Complex as a whole is variably deformed and altered with the resultant local development of shear and fracture zones, tectonic melanges, and vein networks filled with secondary minerals including hematite, flaky and crystalline pyrite, calcite, barite, celsian, zeolites, chlorite, talc, epidote and quartz. With the exception of an outlier of the Complex at the extreme southeast tip of the peninsula where clastic sediments occur, the sedimentary rocks lack a terrigenous clastic component and as such are inferred to have been deposited in a deep-sea environment remote from any substantial landmass. The igneous component (extrusive and intrusive) is remarkably uniform in both major and minor trace element composition and in that it has geochemical affinities to large-ion-lithophile (LIL) enriched mid-ocean ridge basalts (E-MORB) of the sort formed in an extensional back-arc basin such as the present-day Mariana Trough, the Lau Basin and/or in a setting comparable to that of the Gulf of California (Berrangé & Thorpe, 1988). One geochemically distinctive basalt is interpreted as representing a younger within-plate seamount of probable Oligocene-Miocene age. Most of the igneous rocks of the Nicoya Complex were formed episodically during three volcanic events in the Santonian-Campanian (78.0 ± 2 Ma), the Palaeocene (60.2 ± 7.6 Ma) and the middle Eocene (44.1 ± 4.4 Ma) (Berrangé et al., 1989).

In the southern two-thirds of the Osa Peninsula the basement complex is unconformably overlain by the middle to late Pliocene Osa Group comprising slightly lithified, well bedded, graded, greywacke-type conglomerates, sandstones, siltstones and claystones derived from the underlying Nicoya Complex. The Osa Group is up to at least 800 m thick and was deposited in various different environments including: fresh-water fluviatile, brackish deltaic-lagoonal-estuarine, and/or shallow shelf to deep marine basins (down to 250 m) (Berrangé, 1990).

Unconsolidated gravels, sands, silts and clays of late Pleistocene to Holocene age form the Puerto Jiménez Group that unconformably overlies the older units (Berrangé, 1988). Where not covered by the Osa Group or alluvium, the rocks of the Nicoya Complex are mantled by up to 20 m of reddish-brown laterite.

THE GOLFO DULCE PLACER PROVINCE

The Golfo Dulce Gold Province in southern Costa Rica includes the Osa and the Burica Peninsula and the Fila Golfito on the east side of Golfo Dulce (Fig. 3). It includes placer gold deposits of different types and ages (Ivosevic, 1979; Berrangé, 1987a). Although the following remarks apply strictly only to the Osa Peninsula that was investigated by the author, the gold elsewhere in the province probably has a similar setting and origin. It has been suggested that the Golfo Dulce is a pull-apart basin that in pre-Pliocene time was filled by the landmass now forming the Burica Peninsula (Berrangé, 1990). If this is true then the gold ocurrences originally formed a smaller and more unified province.

Nicoya Complex: The reddish-brown residual latosols developed from the volcanics and sediments are locally auriferous, in places so enriched as to produce bonanzas. These form in-situ eluvial placers, and colluvial placers where mass movement under the influence of gravity has moved the gold downhill by soil creep and landslides (Fig. 4). The majority of the super-large nuggets appear to have been formed in this environment.

The topmost weathered and fissured 1-2 m of the Nicoya Complex, below auriferous gravels of the Osa and Puerto Jiménez Group, may contain free gold, locally forming small bonanzas. This crevice gold is of secondary alluvial origin, ie, it has been transported and deposited at or near the unconformity and worked its way downwards into the bedrock fissures.

Osa Group: Alluvial gold occurs in conglomerate and sandstone facies in the lower and middle units of the Osa Group, but mineable concentrations are largely confined to the basal eluvial/colluvial breccia-conglomerates that grade into true alluvial conglomerates deposited in Plio-

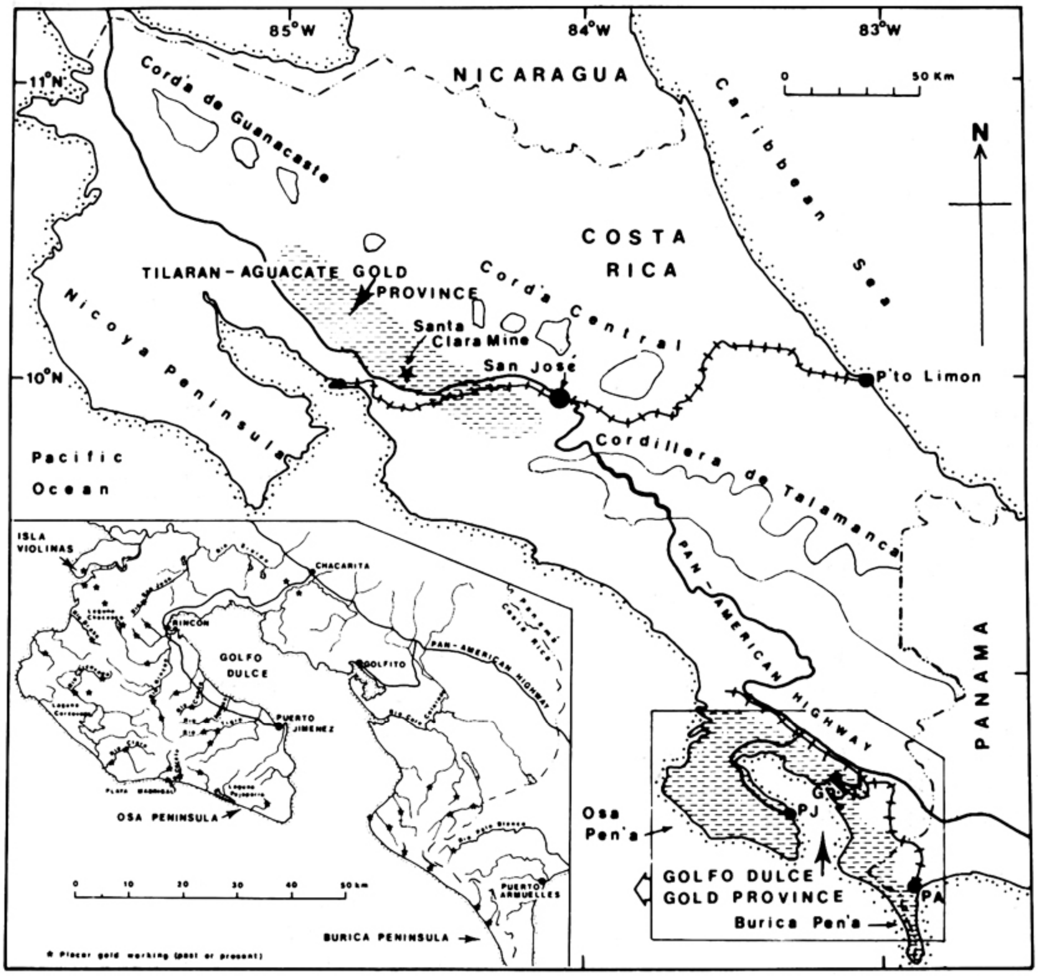

Fig. 3: Geographic setting of Costa Rican gold provinces. Inset: Main placer occurrences of the Golfo Dulce Goldfield.

cene river valleys, piedmont fans and deltas. These conglomeratic facies may have a distinctive blue-gray colour and a clayey matrix, features considered to be favourable gold indicators by the miners. Sandstones and intraformational conglomerates higher up the sequence may also contain gold, but these perched placers are not nearly as rich and their gold is finer grained than that in the basal conglomerates (Berrangé, 1990).

Puerto Jiménez Group: Alluvial placers occur in the boulder gravels forming fans, raised river terrace remnants and active sediments along the narrow valleys that penetrate the mountains. Gravels along rivers flowing over the Nicoya Complex where no Osa Group sediments occur in the catchment may be either barren or gold-bearing; those flowing over the Osa Group only are generally barren; whilst those that have cut down through the basal Osa conglomerates to expose the Osa-Nicoya unconformity are the richest producers. Gold also occurs in beach sands and gravels along Playa Carate and Madrigal, and in trace amounts at various localities offshore of the peninsula.

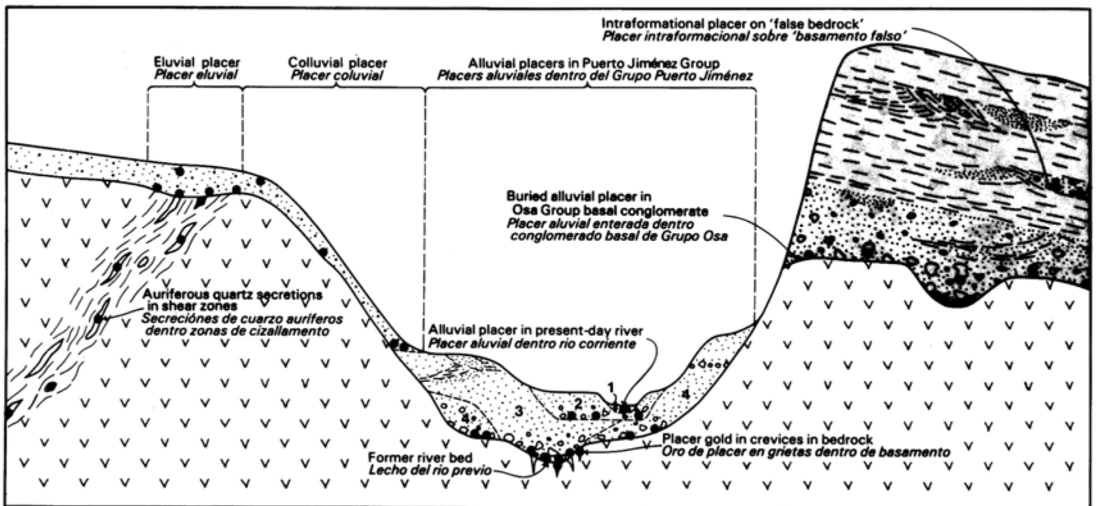

Figure 4 **Schematic representation of the main types of gold placers found in the Osa Peninsula**
Figura 4 ***Representacion esquemático de los principales tipos de placeres auríferos encontrados dentro de la Peninsula de Osa***

Holocene: Residual latosols and colluvium
Holoceno: Suelos lateríticos residuals y coluvio

Pleistocene–Holocene: Puerto Jiménez Group: alluvial boulder gravels, sands, silts and clays: **1** = youngest Unit, **4** = oldest.
Pleistoceno–Holoceno: Grupo Puerto Jiménez: Cascajo de bloques aluvial, arenas, limos y arcillas, **1** *= unidad mas joven,* **4** *= unidad mas antigua.*

● Main site of gold concentration / *sitios principales de concentración de oro*

Middle–Upper Pliocene: Osa Group: fluvial and marine greywacke-type congolmerates, sandstones, siltstones and claystones.
Plioceno medio-superior: Grupo Osa: Conglomerados, areniscas, limolitas y arcilitas fluvial y marino de tip grauvaca.

Upper Cretaceous/Lower Tertiary: Nicoya Complex: ophiolitic (meta)-basalts; intrusive dolerite-gabbro plutons; pelagic limestones, argillites and cherts.
Cretacico superior–Tertiaro inferior: Complejo Nicoya: (meta)-basaltos ofiolíticos; plutones intrusivas de dolerita-gabro; calizas, argillitas y ftanitas pelagicas.

HABIT AND COMPOSITION OF THE GOLD

Habit: The gold occurs in all sizes and shapes from flour gold barely visible to the naked eye, to flakes, grains and nuggets (Berrangé, 1987a). Nuggets weighing up to 31 g are very common, 32-100 g nuggets are quite common, whilst super-large +100 g nuggets are rare but a few are found each year. Super-large nuggets weighing respectively 166.3 g, 265 g, 243 g, 967 g, 2.8 kg and 7.7 kg have been seen by the author or are authenticated from several independent sources.

The gold generally has a bright yellow-golden lustre. The surfaces of some of the nuggets are partially tarnished black (due to MnO), brownished-red (FeO), or white ($CaCO_3$ and/or colloidal clay). The surfaces of the nuggets vary from smooth to rough and pitted, the smoothness being governed by the degree of abrasion. Most of the fine-grained gold is angular and flaky, whereas the nuggets are characteristically subrounded and flat or tabular with a shape resembling that of a broadbean, although angular, irregular and gnarled tuberose forms are also found. The morphology is typical of fluvial gold, particularly the rounded, lobate and irregular grain margins, which show evidence of abrasion, ripping and folding-over during transport.

Composite gold-quartz nuggets in which the gold occurs as disseminations, encrustations and dendritic intergrowths in the quartz are also common, and these generally have an irregular morphology. The relative proportion of gold to quartz varies from virtually pure gold flakes and nuggets, through composite gold-quartz nuggets, to quartz with sparsely disseminated gold. Even gold flakes less than 0.5 mm in diameter quite commonly have tiny quartz inclusions or attached quartz. The quartz is generally highly fractured and breaks readily into angular grains. It is either opaque or translucent, and white, grey, rose, pale to dark brown coloured. Apparently solid gold nuggets with smooth exteriors may have slightly vuggy interiors and a study of polished sections under reflected light shows them to contain inclusions of syngenetic quartz, pyrite, calcite and epidote (listed in decreasing order of abundance), together with adventitious Fe/Mg-silicate minerals, spinels and limonite grains picked up and included in the nuggets during transport and/or growth. The pyrite occurs in anhedral or euhedral forms, occasionally shows brittle fracturing and may have minute inclusions of gold - features indicating its syngenetic origin along with the gold. A combined electron microprobe and microscope study of etched polished sections shows that most of the gold grains have very thin rims relatively low in silver (ie, virtually pure gold); and silver-poor zones can also be traced along some of the internal grain boundaries and around the adventitious inclusions (Fig. 5). In many instances these silver-poor rims have a fine-grained polyhedral texture and are composed of crystals less than one tenth of the size of those forming the inner part of the gold flake or grain. The interface between the core and the rim alloys is sharp and generally exhibits an irregular scalloped texture indicating that the rim formed after the core. Occasionally nuggets are found that contain tiny blebs of a silverish mineral welded onto their exterior surfaces. X-ray study shows that these are gold-silver-copper alloys in the ratio 70-26-3.3. Minute crystals of a pale resinous green mineral, identified by scanning electron microscope as the silver chloride, cerargyrite, may occur associated with these alloys.

The silver-poor rims described above appear to be quite a common feature of placer gold worldwide and are generally considered as having formed by preferential leaching of silver from the grain surfaces (Boyle, 1979). However, in the case of the Osa gold, the sharp scalloped boundary between the core and the silver-poor rims formed of relatively fine-grained gold crystals requires a more complex mechanism. This probably involved chloride-rich solutions leaching gold and silver from the grain margins, followed by the precipitation of gold in solution onto existing grains which served as nuclei and were partially replaced by virtually pure gold. The silver-rich alloy and cerargyrite that are occasionally found on the surfaces of some nuggets were similarly formed at atmospheric temperatures but under slightly different physico-chemical conditions. The common ocurrence of gold-rich rims and occasional silver-rich blebs indicates the extreme sensitivity of reactions involving the leaching and

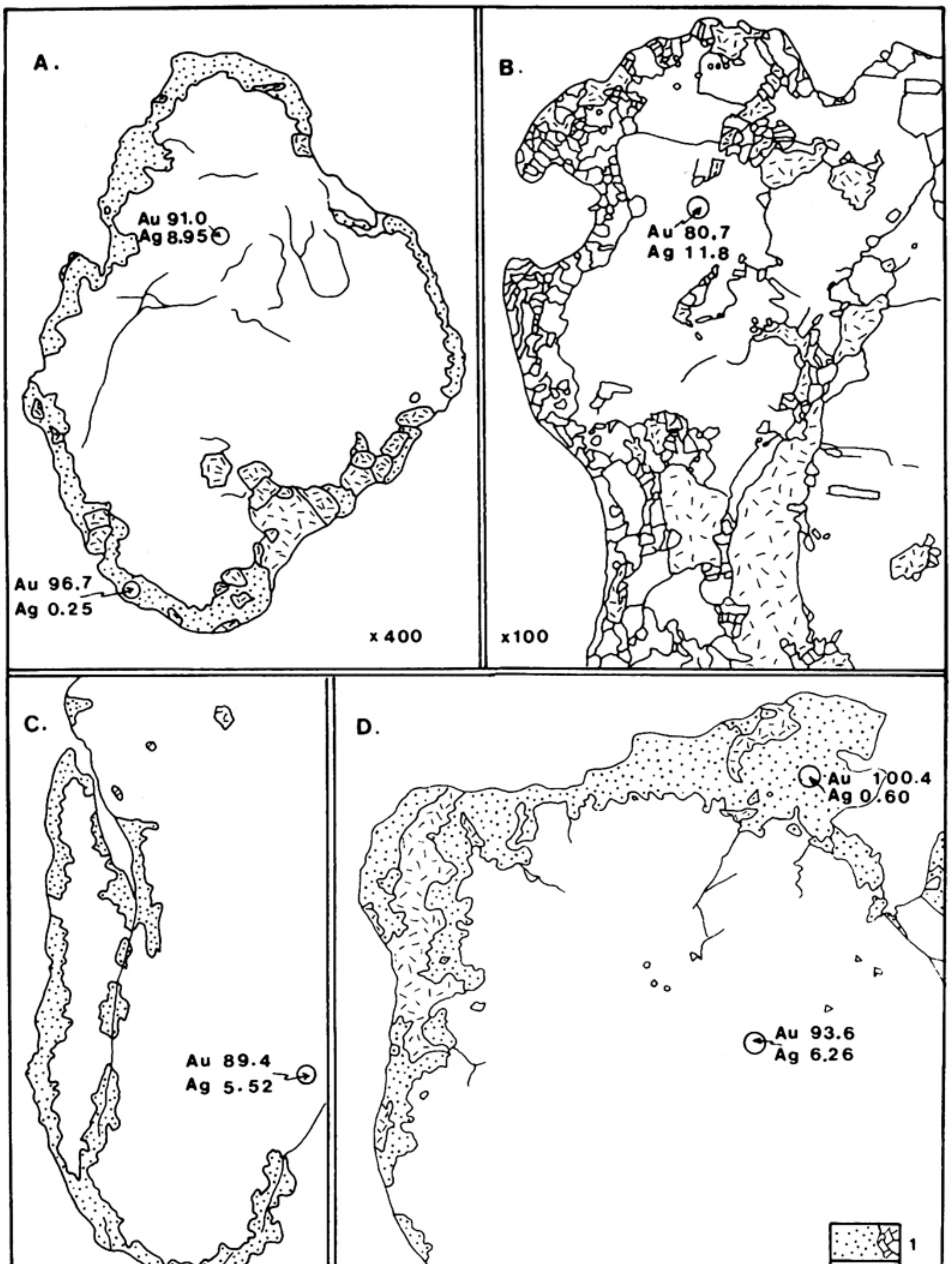

Fig. 5: Photomicrographs showing the internal structure and composition of gold grains from the Osa Peninsula. 1 = Low silver gold; 2 = Gangue and/or vug; 3 = Crystal boundaries. Percentage of gold and silver determined by electron microprobe at points indicated by circles.

precipitation of gold and silver in the exogenic cycle.

Composition: Determination of the composition of the gold is governed by factors such as differential leaching of silver and gold, the presence of inclusions, and analytical techniques. Table 1 summarizes the results of analyses of samples of the Osa gold in the laboratory of the Banco Central de Costa Rica (technique unknown), and by electron microprobe and X-ray fluorescence techniques at the British Geological Survey (Bland, 1985; 1986). There is good correspondance between the gold and silver values determined by the Banco Central and by probe of the unleached parts of the gold grains. The average gold values determined by XRF are intermediate in value between the core and the rim values determined by probe, because the XRF technique essentially measures the gold composiciton of the outer surface of the grains and hence gives slightly high gold values for the overall sample. The Osa placer gold therefore averages 93.8 % Au and 5.4 % Ag, equivalent to 22.5 carats, a fineness of 946 and an Au:Ag ratio of 17.4:1.

Table 1. Composition of placer gold from the Osa Peninsula

	Gold %			Silver %			Other Trace Elements Identified %	
Analytical Technique	**Aver.**	**Max.**	**Min.**	**Aver.**	**Max.**	**Min.**		
Banco Central	93.8	94.5	92.4	5.4	6.8	4.6	Fe, PGE, Pb, Zn, Ni, Mg	
Microprobe (core)	93.8	96.3	79.3	3.96	17.8	2.6	Cu = 0.13	Zn = 0.09
Microprobe (rim)	97.1	100.0	88.2	0.46	2.3	0.3	Cu = 0.06	Zn = 0.15
X-ray fluorescence	95.96	(sd=2.08)		3.68	(sd = 1.92)		Fe = 1.045	PGE = 0.244
							Pb = 0.163	Te = 0.127
							Hg = 0.118	Zn = 0.044
							Cu = 0.039	Bi = 0.036
							As = 0.026	Se = 0.003

The Tilarán-Aguacate Gold Province in northern Costa Rica (Figs. 2 and 3) is located within the inner arc of the Southern Central American Orogen and production is from Sado-type epithermal Au-Ag ± (Pb-Zn-Cu) quartz veins and stockworks in subaerially deposited volcanic rocks of andesitic and/or dacitic composition, associated with intrusive/extrusive rhyolites. In this province Au:Ag ratios are very variable within any given area, depending on where the samples are collected, but silver content increases with depth. "The gold to silver ratios generally range from 1:1 to 1: 10, with some rationes as low as 1: 0.1 and as high as 1: 20" (U.S. Geological Survey et al., 1987). Table 2 shows the composition of refined gold from two different mines in the province. Although the ratios quoted above and given in Tables 1 and 2 are not strictly comparable they serve to show that gold from the Tilarán-Aguacate Province and that from the Golfo Dulce Province has a very different composition which suggests that there is no genetic connection between the two goldfields.

Table 2. Composition of gold from the Tilarán-Aguacate Gold Province

Mine or mining district	Au%	Ag%	Au/Ag	Others %
Las Juntas de Abangares	73.1	24.8	2.9	2.1
Macacona	84.3	14.6	5.8	1.1

Caribbean island arcs respectively show various evolutionary stages of tectonic development or cratonization, and their mineral deposits similarly illustrate three levels of "metallogenic maturity" (Kesler, 1978). Increasing maturity is characterized, *inter alia*, by development of terrestial intermediate and silicic volcanic rocks and by the increasing Ag:Au ratio of their associated precious and base metal veins. Southern Central America is classified as showing an intermediate level (stage 2) of metallogenic maturity. As a development of this concept it is suggested that a given orogenic arc can show various stages of metallogenic maturity, especially if it has a complex polyphase origin as has been demonstrated for the Southern Central America Orogen (Berrangé & Thorpe, 1988). Although the mineral deposits of its inner arc show stage 2 characteristics; those of the outer arc, that in Costa Rica include chromite, manganese, massive sulphides and low-Ag gold, are typical of stage 1.

FLUID INCLUSION STUDY

Three quartz-gold samples and two samples of "pure" vein quartz were selected for fluid inclusion study (Shepherd, 1985). It was hoped that a knowledge of the temperature and salinity of the ore fluids would help differentiate between various theories concerning the genesis of the gold. All samples show evidence of intercrystalline deformation and are cut by myriads of microfractures carrying dense arrays of very tiny (< 1 μm) secondary inclusions. These relate to fluids circulating during tectonization and have no immediate genetic affinity with fluids responsible for the primary crystallization of the quartz. Undulose extinction and deformation lamellae are prominent. With the exception of one quartz-gold sample, the intensity of deformation has been suficient to destroy the primary inclusions. A thermometric analysis of the primary fluid inclusions in this sample gave a temperature range of 198-207°C and a salinity of 0.8 - 1.5 wt% NaCl equivalents. Many more samples would have to be analysed before a definitive statement can be made on the conditions under which the gold originated. However, it can be stated with certainty that the temperature range and salinity are not compatible with gold deposition in a Cu-Mo porphyry environment; but that they are consistent with typical epithermal Au-Ag fluids and also conform to the circulation of sea water through hot oceanic crust.

ACOCIATED HEAVY MINERAL SUITE

Thirty heavy mineral concentrates, panned from different gold-bearing rivers draining the Osa Peninsula, were studied in order to establish their provenance and to determine whether or not there are any indications of skarn-type mineralization or felsic igneous rocks associated with the gold (Basham, 1986). The samples were separated magnetically and/or by heavy liquids as appropiate for mineralogical study under a binocular microscope. Quantitiative element scans by X-ray fluorescence spectroscopy were used to assist mineral identificaction, and checks on identity performed by optical means, X-ray powder photography, or staining of feldspars as necessary. Minerals indicative of a granite-granodiorite provenance were particularly sought - zircon, rutile, monazite and sphene in the non-magnetic heavy fractions; and tourmaline, micas and K-feldspar in the intermediate density and light fractions.

All stream sediment concentrates show markedly similar qualitative mineralogical composition which is dominated by a suite derived from basic igneous rocks (Table 3). Characteristic minerals are olivine, clino-pyroxene, orthopyroxene, amphiboles, chrome spinel, magnetite and epidote. Pyrite, barite and gold occur in varying minor amounts. Associated rock fragments are mainly fine-grained and plagioclase-bearing. The only minerals noted which could relate to acid or intermediate sources are K-feldspar, apatite, zircon and some of the lighter-coloured amphiboles. Of these, the apatite and the amphibole could be derived from basic rocks. The K-feldspar is very rare; the pink zircon occurs sporadically, often only as a single grain and cannot be considered to represent any significant source; whereas the colourless zircon has a fairly uniform appearance throughout a number of samples, but zircons of this type are known to occur in gabbros and related basic rocks.

As part of a study of the distribution of heavy minerals in Holocene sediments along the Río Agujas, Azuola (1985) recorded a similar but more limited suite of heavy minerals, listed in

Table 3. "Heavy minerals" in river gravels from the Osa Peninsula

MINERAL	REMARKS
Magnetite	The principal component of the magnetic fractions. Varies from fresh euhedral crystals to rounded or pitted grains; some show surface oxidation or replacement by hematite.
Ilmenite	Difficult to quantify but probably fairly common. Black lustrous grains.
Spinel (chromite)	Common in many of the concentrates. Black lustrous octahedra. A ferro-chromite with Mg, Al and Ti.
Olivine	An important constituent in most heavy fractions. Little altered, pale green. Fayalitic variety mainly.
Pyroxene	An important constituent, generaly unaltered, includes clino- and orthopyroxenes of various compositions.
Epidote group	Occurs in many samples. Either as individual subhedral crystals or as epidotized rock fragments.
Amphibole	Present in variable amounts. Unaltered. Mainly common green hornblende, but also brown basaltic hornblende.
Rock fragmentes	Mainly fine-grained, dark-coloured, igneous-looking rocks; more feldspathic varieties occur in some samples, true leucocratic types of minor significance.
Feldspar	Mainly plagioclase, K-felspar is very rare.
Pyrite	Fairly common, mainly as partly oxidised cubes, also as platy or framboidal aggregates.
Barite	Occurs sporadically as soft, white, platy grains.
Zircon	Present in very minor amounts. Two varieties present: (a) pink, stumpy, multifaceted crystals; (b) colourless, slender, tetragonal bipyramidal crystals.
Apatite	Occasional crystals.
Garnet	Very occasional single grains of almandine-type.
Gypsum	Very occasional crystals.
Gold	Grain shape varies from rounded, flattened flakes; to delicate, dendritic or irregular forms.

decreasing order of abundance as: "titaniferous ilmenite, iron oxide complexes, leucoxene, saussurite, monoclinic pyroxene, epidote, orthorhombic pyroxene and garnets. On the basis of the textures, sizes, and shapes of gold, as well as on the freshness of the heavy minerals" she concluded that the distance of transport has been generally short, but with several cycles of concentration and reworking, and that this implies that the source can be inferred to be the Basic Osa Complex."

In conclusion, two independent studies both show that the heavy mineral suite associated with the placer gold is consistent with local derivation from the Nicoya Complex, and there is no indication of a volumetrically important granitoid provenance.

ORIGIN OF THE PLACER GOLD

The occurrence of placer gold deposits in the outer arc of the Southern Central America Orogen, apparently related to an ophiolite complex but unrelated to acid-intermediate igneous activity, may be considered to be somewhat enigmatic. A number of theories have been advocated to explain the origin of the Osa gold. These may be classified into two broad groups:

1) The gold is derived from a distant source in the Talamanca Cordillera (inner arc) and is related to either Cu-Mo porphyry deposits or to epithermal gold-quartz veins in a volcanic-subvolcanic sequence of acid-intermediate composition equivalent to the Aguacate Complex or the Monte Verde Formation of northern Costa Rica. Elsewhere in the world there are numerous examples (Boyle, 1979) of gold placers indicating the presence of various types of metalliferous deposits, particularly polymetallic lodes and Cu-Mo porhyry copper deposits of the kind found in the Talamanca Cordillera. It has been suggested (Levy, 1970; Anonymous, 1979) that the Osa gold originated by the erosion of gold-quartz veins in volcanics of Aguacate Complex-type in the Talamancas, that it was transported to the Pacific Ocean and deposited along fluvial and marine channels at the base of the Armuelles Formation (Osa Group) to be subsequently reworked and distributed in the Pleistocene-Holocene gravels. Lew (1983a) has proposed that the gold was derived from "a vegetated volcanic landmass or island chain containing hydrothermal gold deposits, flanked by a shallow marine environment" and located to the north and northeast of the Osa Pensinsula.

2) The gold is locally derived from the Nicoya Complex in which it may have occurred in highly altered peridotites; or from massive exhalative sulphide deposits; or from metalliferous pelagic sediments; and/or from quartz veins, stockworks, space fillings and replacement masses in the bedrock.

The evidence for and against these competing theories is examinded below.

(a) The Au:Ag ratios of the Osa and the Aguacate-Tilarán goldfields are dissimilar and indicate that one is dealing with two fundamentally different types of gold that have different origins, even if allowance is made for depth-related differences or modification of Au:Ag ratios due to solution and reprecipitation in the exogenic cycle. In a study of placer gold in Scotland, Naden et al. (1985) have shown that relatively "silver-rich" gold grains are associated with units containing felsic rocks, and "gold-rich" grains with basic rocks.

(b) The heavy mineral studies indicate no significant occurence of minerals diagnostic of granitoid or rhyolitic provenance associated with the gold.

(c) The evidence of fluid inclusions in gold-quartz nuggets is inconsistent with a primary origin in a Cu-Mo porphyry environment.

(d) The nearest known porphyry copper deposits are in the Talamanca Cordillera some 90 km distant, and the nearest outliers of Aguacate Complex-type volcanics are 40 km away. Furthermore, there are two major tectonic basins - the Valle del General and the Diquís/Golfo Dulce Basin - between these hypothetical source rocks and the Osa Peninsula; and there are no gulch or river placers on the western slope of the Talamancas.

(e) Ivosevic (1979) has described "hydrothermal alteration" of the "mudstone" and "basalt" of the Nicoya Complex in the Río Carate sector. On the basis of a study of both detrital material and bedrock, he recognised calcitization, silicification and metallization including "native gold filling fractures in vein quartz and in jasperized mudstone and quartz veined basalt containing 1 mm thick pyrite grains and fracture fillings." He concluded that "the predetrial source of the placer gold apparently was gold-pyrite (?)-quartz lodes in the centres of zones of silicified mudstone and maybe silicified basalt of the Nicoya Complex", although he found no lode gold in place.

(f) The present author has similarly recorded the presence of zones of brecciation, shearing and alteration in the Nicoya Complex including carbonitization, saussuritization, silicification and pyritization. Fire assays of samples from different quartz veins have given up to 510 ppb Au, compared with a background value of 5-10 ppb Au for barren veins and countryrock (Berrangé, 1987a; Berrangé & Thorpe, 1988). Narrow quartz lenses cuttingbasalt on the west side of Playa Blanca near Río Sierpe mouth have yielded free gold on crushing and panning (Colin Little, oral communication, 1989). At one locality on the upper Río Agujas "oreros" were seen winning gold by hand-mining a pocket of highly pyritized pelagic argillite interbedded with chert. [An apparently analogous gold occurrence has been described from the Palo Seco placer field of the Azuero Peninsula, Panamá (Figure 6, map i/d no. 25) where "oreros" are reported to have been seen winning gold by grinding up limestone from the ophiolite sequence that outcrops in that area (M.Ward, oral communication, 1989)].

(g) Gold is found in eluvial-colluvial latosols and gravels developed directly from the underlying Nicoya Complex. Many of the large and super-large nuggets appear to derive from this type of material including the largest nugget found in the region; this weighed 7.7 kg and came from a colluvial fan of Quebrada Bombaso on Isla Violinas.

(h) There is a general decrease in size downstream of the gold found in Holocene river gravels of the rivers draining the peninsula, indicating that the source is the Nicoya Complex that forms the basement in the central mountainous region (Azuola, 1985).

(i) The relative abundance of nuggets, including composite gold-quartz nuggets and gold flakes with attached quartz, the delicate or angular shape of some of the alluvial gold are all features indicative of recent release and a nearby source - probably less than 10 km (cf. Boyle, 1979).

(j) The habit and lustre of the gold from different rivers is different and distinctive which is not what would be expected if the gold had been derived from distant sources and spread over the area.

There can therefore be no doubt that the placer gold is locally derived from the Nicoya Complex. Some of it must come from gold-quartz veins and lenses, and some is derived from pyritiferous pelagic argillites. Exactly how and when the gold was concentrated in this segment of oceanic crust is uncertain. The various possibilities and relevant factors are discussed below.

In recent years, it has been conclusively demonstrated that submarine hot springs are the probable sources for gold enrichment in various rock types which host mineable gold deposits. These include iron formations, mixed chemical and clastic sediments, tuffaceous exhalites, and disseminated or massive sulphides in both volcanic- and sediment-dominated sequences. Submarine polymetallic sulphide deposits and their related mounds, stacks, chimneys and stockworks all associated with active hot springs have been found in a variety of geological settings on the seabed, including mid-ocean ridges, axis and off-axis seamounts, back-arc spreading centres and sedimented intercratonic rifts. Elements concentrated in these deposits include Fe, Cu, Pb, Zn, S, Si, Ba, As, Sb, Co, Se, Cd, Mo, Hg, Tl, Ag and Au. Anomalously high gold values are common; average gold contents range from 0.07 to 4.9 ppm Au, but significant gold enrichment is found in examples from each of the geological settings in which active submarine hot springs occur (Gross, 1987; Gross & McLeod, 1987; Hannington et al., 1991).

Back-arc basins related to subduction zones can be expected to be particularly favourable sites for hydrothermal metallization, including gold, because:

(a) the provide large extensional tectonic settings;

(b) they are characterized by episodic submarine volcanism active over long periods of time;

(c) they erupt bimodal (felsic and mafic) volcanics derived by partial melting and one can therefore expect enrichment in metalliferous elements contributed from contemporaneous or earlier subduction of oceanic lithosphere below the back-arc basin;

(d) they are characterized by high heat flow - Anderson (1982) has recorded hot spots on the floor of the Mariana Trough emitting more than two watts of geothermal energy per square metre or more than 50 times normal;

(e) circulation of seawater within a basin is likely to be restricted so that they form semi-closed systems and the lower anoxic water layers become enriched in metallizing elements.

Modern examples of back-arc basins are common in the western Pacific and include the Mariana Trough, the Okinawa Trough and the Lau Basin. Hydrothermal deposits enriched in gold have been located in these and other back-arc basins. For example, in the Mariana Trough hydrothermal venting at temperatures up to 287° C has precipitated numerous sulphide-sulphate chimneys and mounds consisting of barite, opaline silica, sphalerite, galena, pyrite, and rare chalcopyrite. Gold contents of samples range from 0.1 to 1.7 ppm Au and average 0.8 ppm Au, with silver contents close to 200 ppm Ag (Hannington et al., 1991).

The Nicoya Complex of the Osa Peninsula has been interpreted as an obducted segment of back-arc basin-type oceanic crust that formed episodically during three distinct events (Berrangé & Thorpe, 1988; Berrangé et al., 1989). In other words there have been at least three "golden opportunities" for hydrothermal mineralization. The following hypothesis outlines in a general manner the processes it is thought produced the gold-quartz lodes in this segment of submarine oceanic lithosphere.

Active submarine volcanic processes in a back-arc basin generated a convective hydrothermal system in hot, relatively porous oceanic lithosphere comprising interlayered basalts, pelagic limestones, argillites and cherts. The presence of abundant chert beds may be considered as evidence for siliceous exhalative hydrothermal activity. This heated seawater, that may have mixed with gold-bearing fluids derived from the ascending magma, leached gold and silica from the relatively porous gold-enriched source rocks. Depending on physico-chemical conditions such as temperature, pressure, pH and/or composition of fluids; the gold was leached and transported as cloride [$AuCl_2^-$] or sulphur [$Au(HS)_2^-$] complexes by hot, oxidising, acidic fluids. It was subsequently deposited where these fluids entered a reducing environment such as pelagic argillites rich in pyrite and/or carbonates; and/or with decrease in temperature (below ca 200°C), and/or in low-pressure zones along fractures and faults (stockworks), and/or where the fluids discharged through open vents and seepage springs on the sea floor. The fact that the Osa basalts have relatively high background values of 5-10 ppb Au lends support to the hypothesis, altough it is not dependent on the source rocks being particularly rich in gold. The temperature range and salinity determined from a study of the fluid inclusions in the gold-quartz nuggets also lends support to these ideas.

A possible alternative or additional source of the gold-quartz lodes would be the alteration of peridotites, that typically form part of ophiolite sequences, to serpentinite, talc schists and/or listwaenites (carbonitized ultramafic rocks). Numerous gold-quartz occurrences have been recognised along the carbonatized borders of ultramafic massifs associated with ophiolite complexes in various parts of the world, including Liguria in Italy, numerous deposits in the Arabian Shield and in the Bou Azzer ophiolite in Morocco (Buisson & Leblanc, 1986). These authors show that the gold deposits appear to be the result of the leaching of gold from ultramafic bodies during hydrothermal alteration at moderate temperatures (150 - 300°C) by combination of circulating seawater and mantle-derived fluids, and its deposition when the fluids entered the reducing and alkaline environment of the listwaenites. Serpentinites are considered to be the source of the Adola placer gold in Ethiopia (Clark, 1979); and in Cuba most of the gold deposits appear to have a close spatial association with the ophiolite belts, especially the tectonized and altered marginal zones of ultramafic bodies (Case, 1980). Similarly, many of the gold deposits of the Mother Lode Gold Belt in California are hosted in carbonate-altered serpentinized ultramafic plutonic rocks and resultant gold-quartz veins (Landefeld, 1986). High gold values in the parts-per-million range have been obtained in ultramafic rocks from many other parts of the world, eg, in the Urals (Borisenko et al., 1972) and in the Shetland Islands where gold is concentrated (up to 7 ppm) as discrete minerals along with platinum group elements in chromitiferous dunite lenses with harzburgite (Prichard et al., 1985). Ultramafic rocks outcrop extensively on the Santa Elena Peninsula (Azéma & Tournon, 1980; Lew, 1985); picritic "greenschists" of ultramafic composition occur in the Azuero Peninsula of western Panamá (Del Guidice & Recchi, 1969); and komatiitic volcanics have been recorded from Gorgona Island off the Pacific Coast of Colombia (Echerverria, 1980). However, no ultramafites have ever been found cropping out in the Golfo Dulce region, and in spite of a serach for ultramafic float in the rivers all that has been found is a loose boulder of fresh picrite from the Burica Peninsula (Obando, personal communication) and troctolite float in the Río Claro (Tournon, 1984). A gravity survey of the Osa Peninsula and environs (Barrit & Berrangé, 1987) has revealed the probable presence of deep-seated wedges of mantle peridotite within the ophiolite sequence. It is concluded that although an ultramafic source for the Osa gold certainly cannot be ruled out, there is little or no evidence to support this mode of origin.

The gold forming the Golfo Dulce placers may conceivably be derived from polymetallic massive sulphide deposits that in many parts of the world contain up to 2 oz Au/ton or more (cf. Boyle, 1979). These deposits are generally considered to be of submarine volcanogenic origin, and exhibit similar patterns of gold enrichment to modern seafloor polymetallic Fe-Cu-Pb-Zn sulphide deposits that are characterised by high gold contents (average 0.07 to 4.9 ppm Au) (Gross, 1987; Gross & McLeod, 1987; Hannington et al., 1991). Although massive sulphides occur in the Nicoya Peninsula where there is no placer gold, none have ever been found in the Golfo Dulce region. However, the Nicoya Complex of the Osa Peninsula should be considered to be permissive to the discovery of polymetallic sulphide deposits. In addition, pyrite is the only essential sulphide mineral found associated with gold, There is therefore no evidence to support this theory.

Another possible hypothesis is that the gold-quartz veins were deposited from gold-bearing siliceous hydrothermal solutions derived directly from a felsic calc-alkaline pluton derived by partial melting at depth along the subduction zone plunging beneath the Southern Central America Orogen; or that hot hydrothermal fluids from such a pluton scavenged gold from out of the ophiolitic country-rocks. As the Osa ophiolites are (at present) in an outer arc setting this is not where one would expect granitoid plutons, although such plutons intrude the ophiolites of Nicoya Peninsula (DGMP, 1982) where there is no gold, and in Panamá where in some cases there appear to be related gold deposits in the adjacent ophiolite terrains, eg, Cordillera San Blas and in the Azuero Peninsula (Fig. 6). However, no granitic or dioritic outcrop or float has ever been found in the Osa Peninsula and stream sediment heavy-mineral surveys have given no indication of buried granitoid rocks in the region. A gravity survey has also failed to reveal the presence at depth of a granitoid pluton to which the primary gold mineralization may be related. There is therefore no evidence to support this hypothesis.

MODEL FOR COSTA RICAN AND PANAMANIAN GOLD DEPOSITS

A tentative model is advanced to help explain some of the features of the gold deposits of the Southern Central America Orogen. These appear to occur in two distinct settings - in the inner volcanic arc and in the fore-arc (Fig. 6).

(i) **The deposits of the inner arc** are generally epithermal Au-Ag±(Pb-Zn-Cu) quartz veins, stockworks and ?disseminated deposits, of late Tertiary age, associated with subduction-related calc-alkaline acid-intermediate intrusives and/or volcanics. These quasi-continental crustal rocks and their deposits show an intermediate level of metallogenetic maturity in the sense of Kesler (1978) and are characterised by a high Ag:Au ratio relative to those of the outer arc deposits.

(ii) **The deposits of the fore-arc** occur in uplifted segments of virtually uncratonized crust - ophiolite complexes that are both the source and the host rocks. They generally show a low level of metallogenetic maturity and are characterized by a relatively low Ag:Au ratio. The gold was initially concentrated by submarine hydrothermal circulatory systems in hot rock along spreading lineaments or near submarine volcanoes. It occurs in gold-quartz lodes and disseminated in pelagic argillites or limestones. Native gold is common in these deposits which therefore tend to give rise to rich placers. The primary deposits as a whole can be expected to be relatively old and have ages similar to those of their ophiolitic

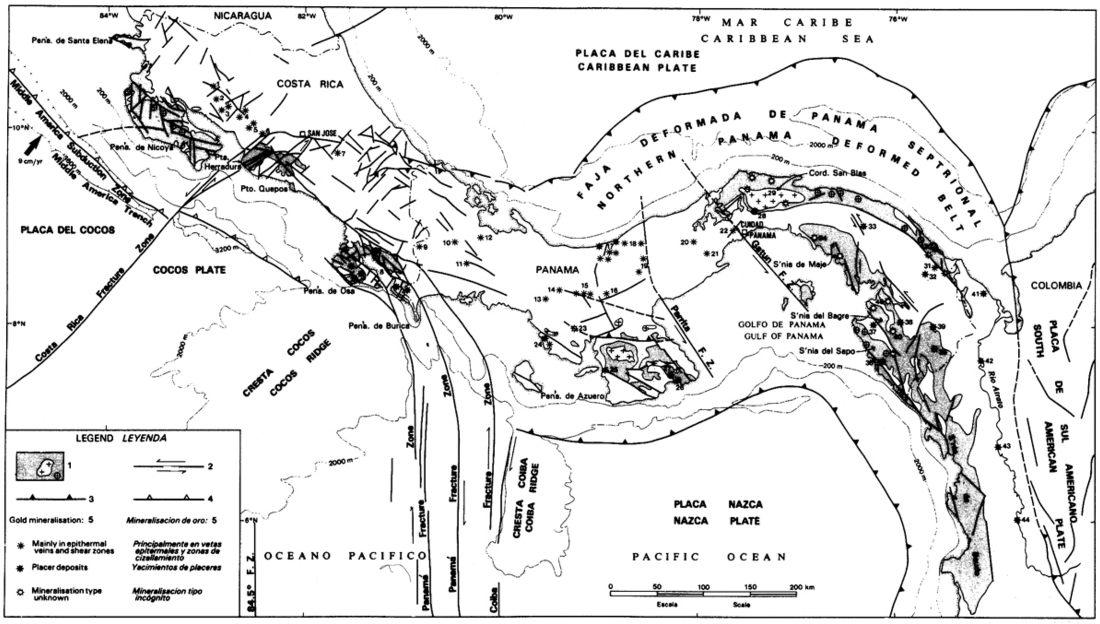
NICARAGUA
COSTA RICA
MAR CARIBE
CARIBBEAN SEA
PLACA DEL CARIBE
CARIBBEAN PLATE
FAJA DEFORMADA DE PANAMA SEPTRIONAL
NORTHERN PANAMA DEFORMED BELT
Pen'a. de Santa Elena
Pen'a. de Nicoya
SAN JOSE
Pto. Quepos
Middle America Subduction Zone
Middle America Trench
9 cm/yr
PLACA DEL COCOS
COCOS PLATE
Costa Rica Fracture Zone
Pen'a. de Osa
Pen'a. de Burica
CRESTA COCOS
COCOS RIDGE
PANAMA
Pen'a. de Azuero
Cord. San Blas
CIUDAD PANAMA
S'nia de Maje
S'nia del Bagre
GOLFO DE PANAMA
GULF OF PANAMA
S'nia del Sapo
COLOMBIA
Rio Atrato
PLACA SUL AMERICANO
SOUTH AMERICAN PLATE
Panamá Fracture Zone
Coiba Fracture Zone
CRESTA COIBA
COIBA RIDGE
84.5° F. Z.
OCEANO PACIFICO
PLACA NAZCA
NAZCA PLATE
PACIFIC OCEAN
Escala
Scale
LEGEND LEYENDA
Gold mineralisation: 5
Mineralisacion de oro: 5
Mainly in epithermal veins and shear zones
Principalmente en vetas epitermales y zonas de cizallamiento
Placer deposits
Yacimientos de placeres
Mineralisation type unknown
Mineralisacion tipo incógnito

Fig. 6

Southern Central America Orogen: plate tectonic elements, ophiolite basement outcrop and gold occurrences. 1 = Cretaceous-Tertiary oceanic crust including ophiòlite suite of peridotite, dolerite, gabbro, plagio-granitoid plutons [areas and circles with cross (+) pattern]; basaltic lavas; marine sedimentary rocks - mainly pelagic limestone, argillite and chert. 2 = Fault or fracture zone (F.Z.) defined or approximately located - arrows indicate relative movement of strike-slip or transform faults. 3 = Trace of active subduction zone - triangular symbols on upper plate. 5 = Gold mineralization - includes active and inactive mines and prospects. Numbers indentify name of the mine or district (see separate sheet for details).

Source of information: Amos & Rogers (1983), Case (1980), Case & Holcombe (1980), DGMP (1982), Dengo et al. (1969), Dengo & Levy (1970), Ferencic (1971), Ferencic et al. (1971), Kesler (1978), ICAITI (1969), Mejia et al. (1986), Utter (1982), Weyl (1980).

NAME OF DEPOSIT OR MINING DISTRICT DEPOSIT	MAP I/d No.	METALS*	CLASS OF DEPOSIT	HOST ROCKS	AGE OF DEPOSIT
COSTA RICA					
Libano District	1	Au-Ag Cu-Zn-Fe	Sado-typepithermal qtz veins and stockworks	Subaerial, altered volcanics (andesitic to rhyolitic)	Pliocene
Juntas de Abangares District	2	Au-Ag Zn-Sb-Pb-Fe	Ditto	Ditto	Pliocene
Guacimal District	3	Au-Fe	Ditto	Ditto	Pliocene
Miramar District	4	Au-Cu-Pb-Zn-Fe	Ditto	Ditto	Pliocene
Barranca-Santa Clara	5	Au-As-Fe	Ditto	Ditto	Pliocene
Montes de Aguacate	6	Au-Ag-Cu-Pb-Zn- As-Sb-Fe-Hg	Ditto	Ditto	Pliocene
Río Pejebaye	7	Au	Dissemin.replacement	Andesitic volcanics and volcaniclastics	?
Osa-Burica	8	Au-Fe	Placer	Unconsolidated seds. on ophiolite basement	Pliocene, Pleistocene Holocene
PANAMA					
Cañas Gordas	9	Au	Qtz veins, stockworks and/or shear zones	Silicic-intermediate volcanics and intrusives	Tertiary, Quaternary
Boquette	10	Au	Ditto	Ditto	Tertiary, Quaternary
Caldera 2	11	Au	Ditto	Ditto	Tertiary, Quaternary
Bocas del Toro	12	Au	Ditto	Ditto	Tertiary, Quaternary
Cerro Viejo	13	Au	Ditto	Ditto	Tertiary, Quaternary
Río Cobre	14	Au-Cu	Ditto	Ditto	Miocene, Oligocene
Cañazas, Remanse	15	Au	Ditto	Ditto	Miocene, Oligocene
Los Hatillos	16	Au-Pb	Ditto	Ditto	Miocene, Oligocene
Cocuyu, Chucú	17	Au	Ditto & placer	Ditto	Tertiary, Quaternary
Belen, Petaquilla	18	Au	Veins and shear zones	Ditto	Tertiary
Perecabé, Nuestro Amo	19	Au	Ditto	Ditto	Tertiary

NAME OF DEPOSIT OR MINING DISTRICT DEPOSIT	MAP I/d No.	METALS*	CLASS OF DEPOSIT	HOST ROCKS	AGE OF DEPOSIT
Río Indio	20	Au	Ditto	Ditto	Tertiary
Cerro Campaña	21	Au-Ag	Ditto	Ditto	Tertiary
Cerro Cabra	22	Au	Ditto	Ditto	Tertiary
Río Pable	23	Au	?	?	?
Río Lovaina	24	Au	Ditto & placer	Meta-seds and meta-igneous rocks, volcanics	Cretaceous, Tertiary and Quaternary
Palo Seco	25	Au	Placer	Unconsolidated seds. on volcanics and ultramafics	Tertiary, Quaternary
Cañas	26	Au-Cu	Veins and shear zones	Ophiolites and silicic-intermed. intrusives	Tertiary
Río de Cañas	27	Au	Placer	Unconsolidated sediments on (26)	Tertiary, Quaternary
Río Pacora	28	Au	Placer	Unconsolidated seds. on ophiolitic and silicic-intermed. intrusives	Tertiary, Quaternary
Cord. San Blas	29	Au	?	Ophiolites and silicic-intermed. intrusives	?
Sasardi	30	Au	Veins and shear zones	Ditto	?
Mina Turquesa	31	Au-Cu	Ditto Ditto	?	
Río Turquesa	32	Au	Placer	Unconsolidated seds. on (31)	Tertiary, Quaternary
Río Bayano	33	Au	Placer	Unconsolidated seds.	Tertiary, Quaternary
S'nia Majé	34	Au	?	?	?
Caña	35	Au	Veins and shear zones	Ophiolites	Cretaceous, Tertiary
Río Piña	36	Au	Ditto	Ophiolites, silicic-intermed. intrusives	Cretaceous, Tertiary
Río Sambú	37	Au	Placer	Unconsolidated seds. on ophiolite basement	Tertiary, Quaternary
Río Tucutí	38	Au	Placer	Ditto	Tertiary, Quaternary
Río Tuirá	39	Au	Placer	Ditto	Tertiary, Quaternary
S'nia del Bagre	40	Au	?	?	?
COLOMBIA					
Acandi	41	Au	Placer	Unconsolidated gravels	Quaternary
Chigorodo	42	Au	Placer	Ditto	Quaternary
Río Atrato	43	Au	Placer	Ditto	Quaternary
Jurado area	44	Au	Placer	Ditto	

* Underlining indicates metal sulphide

hostrocks, namely Cretaceous to early Tertiary. Some of these ophiolite gold deposits, such as those in the Cordillera San Blas and the Azuero Peninsula, appear to cluster around and be related to younger subduction zone-related felsic plutons (Fig. 6). The outcrop patterns are reminiscent of those typical of Precambrian granite-greenstone terrains. It is suggested that in these cases later hydrothermal activity connected to granitoid magmatism may have remobilized and reconcentrated the gold that was originally enriched in ophiolitic source rocks.

CONCLUSIONS

1. The placer gold deposits of the Osa Peninsula occur as eluvial-colluvial placers in the weathered latosols derived from the Late Cretaceous to early Tertiary Nicoya Complex; as buried fossil placers of Pliocene age in the conglomerates at the base of the Osa Group; as alluvial placers in the Pleistocene and Holocene gravels along the courses of present-day rivers where they occur in a series of raised terraces and in the active stream sediments; and as beach and offshore marine placers.

2. These placer deposits are somewhat unusual in that:

(a) they are locally derived from gold-quartz veins and from disseminated gold-pyrite mineralization in pelagic argillites and limestones in the Nicoya Complex - an obducted upper segment of an ophiolite complex that forms the basement of the outer arc of the Southern Central America Orogen;

(b) although bodies of mantle-derived ultramafic rock have been identified at depth in the region, there is no evidence to indicate that the gold-quartz veins are genetically related to altered peridotites, although this possibility cannot be ruled out.

3. The Nicoya Complex that forms the source beds for the gold mineralization comprises interlayered basalts, pelagic limestones, cherts and argillites all intruded by gabbro-dolerite plutons. Isotopic age determination studies have shown that the igneous component originated episodically during at least three igneous events over a period (Late Cretaceous - early Tertiary) of 34 Ma; and geochemical studies have shown that it is LIL-enriched (E-MORB-type) oceanic crust of the sort originating in a back-arc basin such as the Mariana Trough.

4. It is postulated that the gold mineralization probably formed in Late Cretaceous to early Tertiary time in a volcanically active submarine back-arc basin by circulation of heated seawater and magmatic fluids which leached the gold from the volcano-sedimentary sequence and deposited it where physico-chemical conditions were favourable.

5. The gold deposits of the Southern Central America Orogen occur either as epithermal Au-Ag±(Pb-Zn-Cu) quartz veins, stockworks and ?disseminated deposits of late Tertiary age, associated with calc-alkaline acid-intermediate intrusives and/or volcanics in the inner arc; or as epithermal deposits in ophiolite terrains of the outer arc and that originated by submarine hydrothermal activity related to volcanism along spreading lineaments of late Cretaceous to early Tertiary age.

6. We should direct attention to the geologically young analogues of the Precambrian greenstone belts that have yielded a very large proportion of the world's gold; and ophiolite complexes of the circum-Pacific and Caribbean should constitute a target for gold exploration. Special attention should be directed towards ultramafic bodies within the complexes, and to ophiolites in the vicinity of younger felsic plutons. Further research is necessary to determine the geochemical parameters and the original tectonic setting of those ophiolitic rocks most likely to be gold source rocks and host gold deposits: eg, back-arc basins, volcanic arcs, mid-ocean ridges or within-plate volcanoes. Ophiolite complexes are especially worthwhile targets because they can be expected to host a galaxy of other types of metalliferous deposit including platinum group elements, chrome, manganese, cobalt, nickel, copper and zinc; and non-metalallic deposits of barite, talc, asbestos, phlogopite and magnesite.

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