TECTONIC EVOLUTION AND ORIGIN OF THE GOLFO DULCE GOLD PLACERS IN SOUTHERN·COSTA RICA

Stanislav J. Kriz

Consultant, Apartado 4481, 1000 San José

ABSTRACT: A new model of the geologic evolution of the Golfo Dulce gold placers is presented. It is shown that the placers were formed on or about an Early Miocene to Late Pleistocene island, prior to its tectonic break-up between Late Pleistocene and Recent times. The island had its origin in a post-Cretaceous swelling or anticlinal doming of the deep oceanic crust, from the crest of which the older pelagic sedimentary cover (Golfito Formation) was removed by submarine erosion, and was preserved only on its flanks. Younger pelagic sediments (Salsipuedes-Pavones Formation) were deposited directly over the older crust in the central part of the structure; and over the Golfito Formation on the flanks. Simultaneously, gold-bearing basaltic intrusive and extrusive activity took place in the tensionally weakened central part of the structure, giving rise to a younger Basement Complex or crust. By Early Miocene, this basement rose above sea level, and formed the island. Later it began subsiding, allowing the Charco Azul Formation to gradually encroach upon it - if not actually cover it - by Late Pliocene time. The first concentrations of gold were formed in the basal strata of this formation. Thereafter, a period of standstill or possible slight uplift followed, allowing the erosion of the Charco Azul strata in certain parts of the island, and the deposition of the Armuelles Formation in a brackish/near-shore to neritic environment. Second cycle gold concentrations were formed in its basal strata. Post-Armuelles tectonic movements caused third-cycle gold concentrations. The structurally high younger basement was thrust over the strata of its own detritic sedimentary cover by the Osa Overthrust; and the older basement was thrust over the same sediments in the area of Golfo Dulce; and over younger basement rocks in the area of the isthmus. This later faulting was brought about by the Golfo Dulce Oriental Fault and associated structures to the northwest. Therefore, no "pull-apart" Pliocene basins exist in the Golfo Dulce area, nor do certain right-lateral strike-slip faults related to the Panama Fracture Zone.

RESUMEN: Se presenta un modelo nuevo de la evolución geológica de los yacimientos auríferos del Distrito de Golfo Dulce. Se demuestra que los yacimientos se formaron alrededor o encima de una isla que existía en el área del Golfo desde el Mioceno Temprano hasta el Pleistoceno Tardío; y que se desintegró por movimientos tectónicos a fines del Pleistoceno o principios del Reciente. La isla tuvo su origen en un solevantamiento anticlinal de la corteza oceánica profunda, después de la depositación de la Formación Golfito. Esta fue removida desde la parte más alta de la estructura por erosión submarina; y fue preservada solamente en los flancos. Una formación pelágica más joven (Salsipuedes-Pavones) fue depositada directamente encima de la corteza más antigua en la parte central de la estructura; y encima de la Formación Golfito en los flancos. Conjuntamente, intrusiones y extrusiones volcánicas auríferas localizadas en el centro de la estructura formaron un complejo basal más joven en esta área. El complejo se levantó encima del mar, formando la isla. Luego empezó a hundirse, permitiendo la transgresión de la Formación Charco Azul, en cuyos sedimentos basales se formaron las primeras concentraciones de oro. A fines del Plioceno, otro levantamiento causó la erosión de los estratos Charco Azul en ciertas partes altas de la isla. Se depositó la Formación Armuelles y en sus estratos basales se formaron concentraciones auríferas del segundo ciclo. Movimientos tectónicos post-Armuelles causaron enriquecimientos auríferos del tercer ciclo. La parte alta del arqueamiento anticlinal - con corteza o complejo basal más joven - sobrecorrió su propio material detrítico a través de la Falla Inversa de Osa; y el complejo más antiguo, cubierto por la Formación Golfito, sobrecorrió los mismos sedimentos en el área del golfo; y además, sobrecorrió basamento más joven en el área del

istmo. Este movimiento se efectuó a través de la Falla Oriental de Golfo Dulce y fallas asociadas a ella. No existen cuencas pliocenas tensionales de tipo "pull-apart", ni ciertas fallas de movimiento lateral dextral relacionadas a la Zona de Fracturas de Panamá.

INTRODUCTION

In the light of recent publications concerning the geology and origin of the Golfo Dulce Gold Placers of Southern Costa Rica (BERRANGE, 1987, 1988; BARRIT & BERRANGE, 1987; BERRANGE & THORPE, 1988), I am taking the liberty of presenting my own views, formulated more than 30 years ago when I worked in the region, but brought up-to-date by later field work and an extensive review of the existing literature. The final conclusions resulted in a model diametrically opposed to the one published by the referred-to authors.

I am presenting it to be considered, analyzed and amended; as new - but factual and concrete-information becomes available. Great many structural and stratigraphic problems remain to be solved, but they may be solved only by detailed geologic field mapping, geophysical work, and exploration drilling. I trust that information obtained by these means will provide details in the form of additions, not changing fundamentally my present concept.

Data on hand today indicate that the placers were formed on - or in the perifery of - a large Miocene to Pleistocene island (the Osa-Burica Island); in a relative unity of environmental conditions; dominated by only small (200 to 250-meter) sea level fluctuations; prior to the island's tectonic break-up in Late Pleistocene to Recent times.

The tectonic movements that broke up the island were mainly vertical. They were brought about by southwest-northeast compression; and were caused most probably by active subduction and not by coast-parallel dextral wrench faults presumably related to the Panama Fracture Zone.

THE MODEL

The model that best expresses the characteristics of the Southern Costa Rica gold placers, is the gold district of Northwest California and Southwest Oregon, described by DILLER (1914),

in a work that since its publication became a classic of North American geologic literature.

In it, the author describes gold placers that originally formed as shore deposits along the perifery of an island in the Cretaceous sea (the Siskiyu Island); eroded close to sea level, if not completely covered by the sea (Fig. 1); and consisting of slates, basic intrusives, and serpentine, a bedrock series very similar to the Nicoya Complex.

The locally gold-bearing beach sands and gravels were later consolidated into the present-day sandstones and conglomerates of the Cretaceous sedimentary cover; and in two subsequent periods of uplift and erosion, they gave rise to placers of second-cycle and third-cycle gold concentrations and enrichment.

The Osa and Burica peninsulas, together with the isthmus area and probably much of the presently submerged land, were part of a similar island that existed in the Miocene to Pleistocene sea, the Osa-Burica Island.

Beach gravels and sands, locally enriched by material from river channels or deltas, were deposited about this island; were consolidated into present-day sandstones and conglomerates; and were equally reworked in at least two major periods of uplift and erosion.

STRATIGRAPHY

The stratigraphic units that have a direct bearing on the occurrence of gold in Southern Costa Rica are: (1) the Nicoya Complex, as the source of the gold; (2) the marine basal sandstones and conglomerates of the Charco Azul Formation, as the first host rock of the gold; (3) the basal, locally possibly fluviatile channels and conglomerates of the Armuelles Formation, as the second host rock of the gold; and (4) the Recent terraces and alluvials, forming the third and youngest host.

The Nicoya Complex was studied by many authors (see references in BERRANGE & THORPE, 1988); and one of the interesting con-
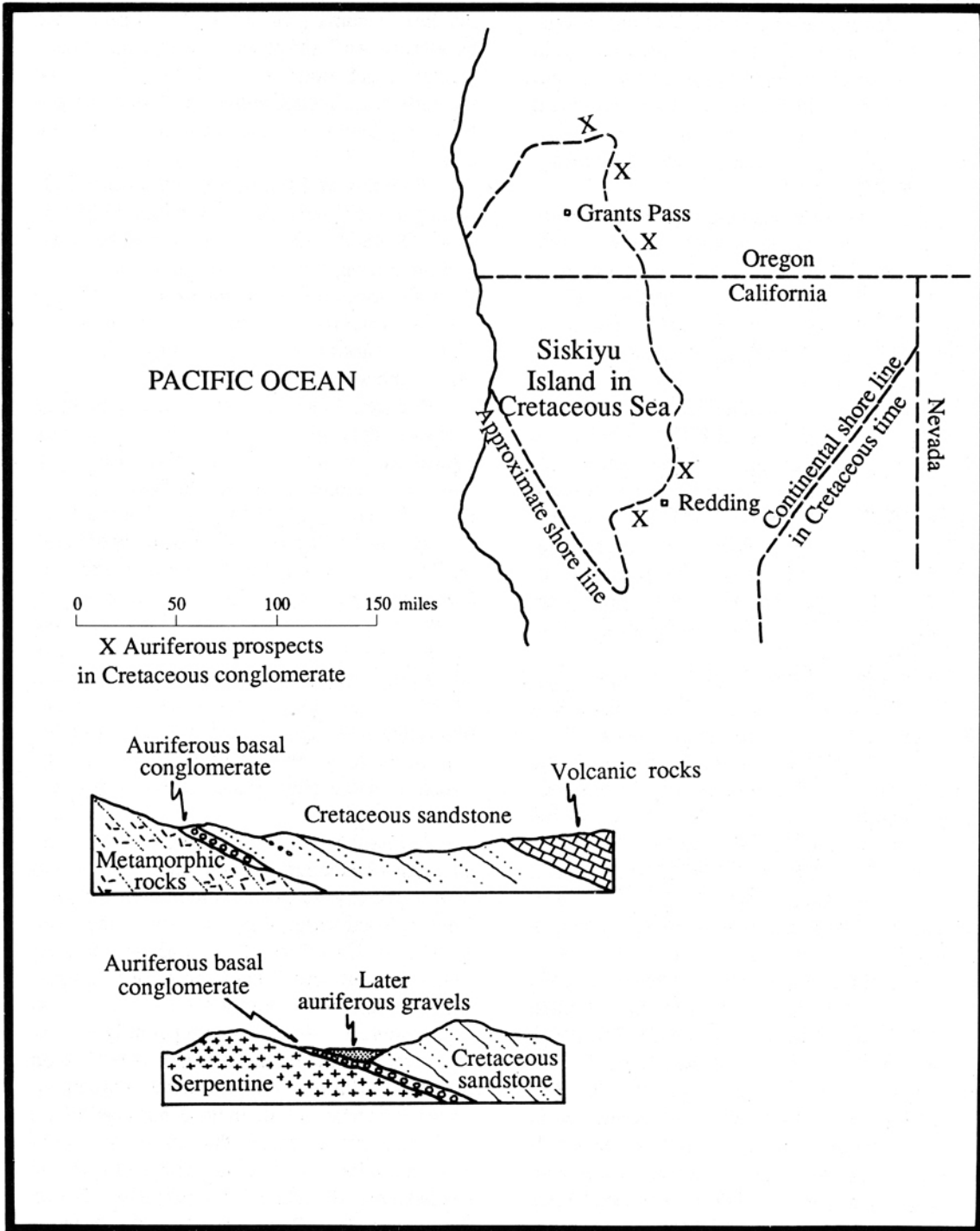
Fig. 1. The Model. Southwest Oregon and Northwest California gold district after DILLER (1914).

clusions agreed to by all authors is that the rocks are considerably older at Santa Elena and Nicoya, where there is no gold, than they are in the gold district of Golfo Dulce. In fact, even the northern portion of the gold district has older basement rocks than the southern part, as may be demonstrated by the age of their pelagic sedimentary cover (RIVIER, 1985).

In the area of the isthmus and near Golfito, the intrusive and extrusive rocks of the oceanic crust are covered by an older pelagic sedimentary cover - the Golfito Formation - that is of Campanian to Maastrichtian age (HENNINGSEN, 1966); whereas in the area of Osa and Burica, they are covered by a younger pelagic formation, called Salsipuedes in southern Osa (LEW, 1983), and Pavones at Burica (OBANDO, 1986). The limestones of the Salsipuedes Formation, coeval with intrusive and extrusive volcanism, were dated at Punta Salsipuedes and at Río Madrigal as Early Paleocene and Late Paleocene respectively (AZEMA et al., 1981a,b); while the limestones of the Pavones Formation at Pavones Bay were dated as Early Paleocene to Early Eocene (BUT-TERLIN, in OBANDO, 1986).

SCHMIDT-EFFING (1979) reports that cherts enclosed in the volcanics of the Salsipuedes Formation contain a microfauna as young as Late Paleocene to Middle Eocene; and two Middle Eocene dates were also obtained of the volcano-sedimentary series in the northwest part of the Osa Peninsula. One is radiometric (47 Ma, BEL-LON & TOURNON, in TOURNON, 1984), and one based on foraminifera (AZEMA et al., 1983). so that it would appear that the basement of Osa and Burica is definitely much younger than that of Golfito; and that the occasional Cretaceous ages obtained in the area came from down-faulted blocks, as was already suggested by OBANDO (1986); or from remnants of the older crust into which the younger volcanics were intruded. The Late Oligocene to Early Miocene sedimentation coeval with basaltic intrusive and extrusive volcanism at Cabo Matapalo is interpreted as having occurred in the perifery of the Osa-Burica Island.

The southeasternmost documented occurrence of the younger Nicoya Complex is in the Sinclair Oil Co. well Corotú No. 1, drilled in 1949 on Corotú Creek, 2.5 km southwest of Puerto Armuelles, Panama (Fig. 2). The well penetrated basalt between 2,835 m and total depth at 2,962 m (private files Union Oil Co., TERRY, 1956); and the oldest sediments above the basement and basal conglomerates were dated as Middle Miocene.

From this well southward, the surface strata belong to the Charco Azul Formation (TERRY, 1941; OLSSON, 1942); and they may be traced without interruption all the way to Burica Island. From the same well northwestward, the Charco Azul is overlain by the Armuelles Formation, and both formations may be traced without interruption all the way to Bahía Pavón on Golfo Dulce.

Between 1946 and 1959, the age of these strata was determined by two different paleontological laboratories as follows: From Burica Island to the mouth of Quebrada Bodega, Costa Rica, a thickness of 1,700 m, Late Miocene; from this point to the Corotú well, a thickness of 2,150 m, Pliocene; and on Río San Bartolo, Panama, from its confluence with Río Chiquito northeastwards, 2,700 m, marine Pleistocene. At Bahía Pavón, approximately 1,300 m of Charco Azul strata crop out along the beach; but the basal, Middle to Late Miocene sequence is missing. The overlying Armuelles Formation is badly weathered and covered by colluvium; but it may be traced on aerial photographs all the way to the bay.

Across the gulf, on Osa Peninsula, the same strata may be recognized without difficulty, and with essentially the same lithologies. From Puerto Jiménez southward, along the beach, the same 1,300 m of Charco Azul strata occur, and their base is cut out near Punta Carbonera by a fault. From the basement outcrops at Cabo Matapalo as far as Sirena, the formation is apparently equivalent to most of the Punta La Chancha Formation of LEW (1983). The Armuelles Formation, however, is present only in the central part of the peninsula, and it is here that an unconformity develops at its base, that may be traced from the headwaters of Río Madrigal, southeastward to the headwaters of Río Pejeperro. Along this distance of some 15 km, the unconformity is marked by a basal sandstone and conglomerate with boulder-
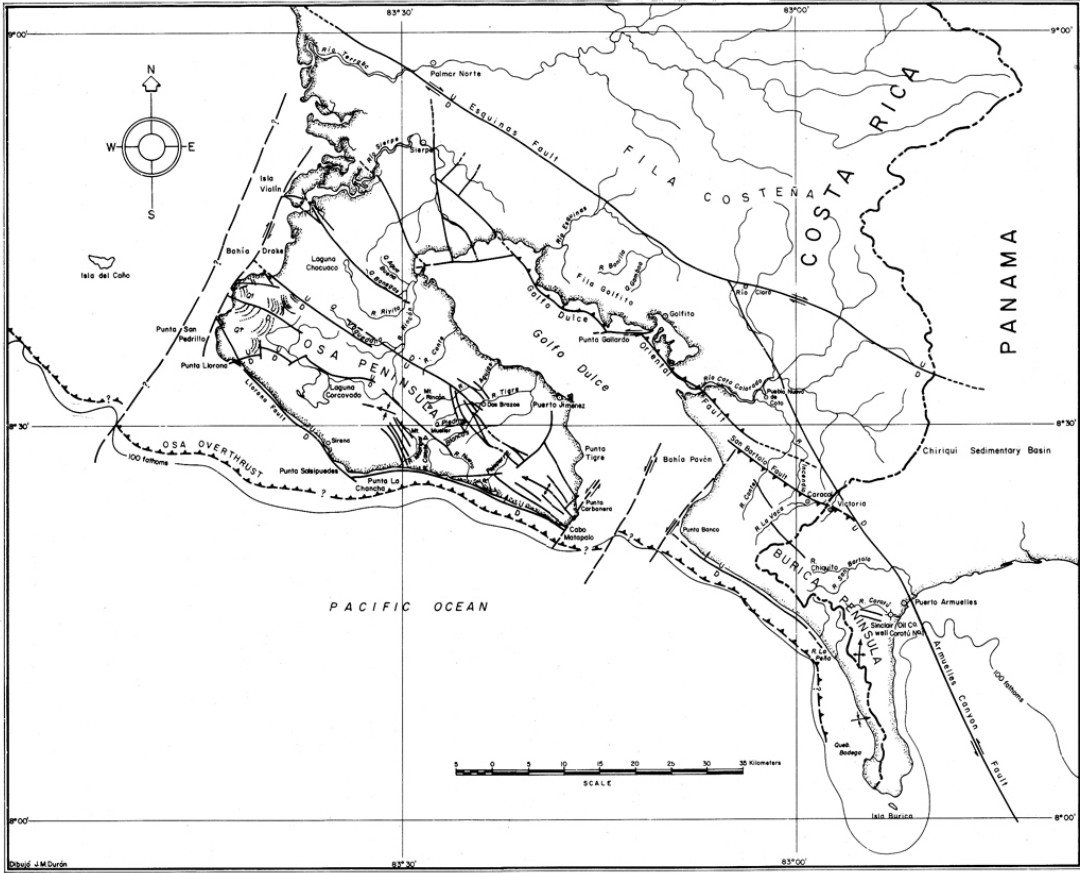
Fig. 2. Tectonic map of the structural features discussed in the present report.

filled channels, that forms the divide between the Pacific and Golfo Dulce drainages. At the head-waters of Río Pejeperro, the basal conglomerate is cut by a northwest-southeast-trending fault zone, and the unconformity may be again recognized 7 km to the northwest, near the community of Dos Brazos. By this time, most of the Charco Azul was cut out, and at El Pegón and the upper reaches of Río Tigre, the Armuelles Formation rests directly on the Basement Complex. The last possible Charco Azul outcrops were noted in Río Riyito, at the foot of Fila Sabala, below the basal Armuelles sandstones; and to the east of a fault that also brought up the Basement Complex.

To the northwest of this point, only Armuelles strata occur - about 250 m thick - and all dipping gently north, juxtaposed to a fault. On Mount Rincón and Mueller, they are subhorizontal, and molluscan as well as micropaleontological samples proved them to be Pleistocene. These are the strata that appear to overlie the basement directly in the area between the Corcovado Lagoon and Río Vaquedano.

In the headwaters of Río Sirena, the Charco Azul appears again below the unconformity; but since the discordance decreases in angularity westward and may no longer be recognized, it is possible that some of the upper conglomerates of LEW's (1983) Punta La Chancha Formation are already Armuelles. However, the 10 m of strata mentioned in his thesis as overlying the Basement Complex at Punta San Pedrillo, are not Charco Azul (Punta La Chancha), but a marine, estuarine, or deltaic terrace.

Indeed, so is the entire elevated plain of some 50 km² located to the east of Punta San Pedrillo and northwest of the Corcovado Basin, at an elevation of 150 to 200 m above sea level, that was mapped as "Osa Group" by BERRANGE (1988), and shown as such in all of his subsequent publications.

A brief photogeologic examination will reveal that what overlies the area presently is material of a terrace elevated to this position by recent uplift. The semi-circular lines covered by dense jungle vegetation, but that still reflect clearly in the topography, indicate either beach-level fluctuations similar to those present on the coastal plain south of Puerto Jiménez - where, in addition, they are perfectly parallel to the two present embayments - or a deltaic-lobate deposit.

At Cabo Matapalo, a similar terrace overlies the basement, but since it does not present the above described physiographic expression, the fact cannot be clearly demonstrated. The terrace occurs at a similar elevation, and was also mapped as "Osa Group" by BERRANGE (1988).

The only outcrops of Pliocene Charco Azul strata known to overlap the older basement complex (covered by the Golfito Formation) occur at Pueblo Nuevo de Coto, and they do not carry gold.

The above described stratigraphic relationships are presented to demonstrate the general continuity of the Charco Azul and/or Armuelles strata from the Corutú well to the central part of the Osa Peninsula. When interrupted by the waters of the gulf, offshore seismic work proves their existence.

They are presented to demonstrate, that the strata formed a continuous sedimentary cover of the gradually subsiding Osa-Burica Island, until it broke up due to tectonic movements in Late Pleistocene to Recent times.

And finally, they are presented to demonstrate that there are areas in the district, where the Charco Azul Formation was stripped from the basement, and the Armuelles was deposited directly upon it; that there are areas where the Armuelles Formation was equally stripped from the basement, and a terrace was deposited on it; and that in consequence, given the considerable thicknesses of the two formations that exist in the vicinity of major faults, most of the area of the present ophiolitic basement was originally - very probably - equally covered.

STRUCTURE

Of the many structural features introduced into recent geologic literature, the majority probably do exist. Some, however, do not exist. And a number are speculative, with a greater or lesser amount of evidence supporting them. All, with the exception of certain faults occurring in the Basement Complex, ar Late Pleistocene to Recent.

Evidently, the major ramp (Osa Overthrust) shown to underlie the Nicoya Complex of the Osa Peninsula (Fig. 3-F) is speculative. However, recent submarine seismic work carried out at the mouth of Golfo Dulce proved that the ocean floor consists of young sediments, certainly not of ophiolites. The ramp is synthetically oriented with the postulated subduction zone, and the Bouguer anomaly map prepared for the southeastern part of the Osa Peninsula by BARRIT & BERANGE (1987) supports the interpretation fully. The positive anomalies are irregular, four to five times lower than the anomalies registered by MONGES CALDERA and WEYL over the Peninsula of Nicoya (same reference, Fig. 5); and the anomalies are not increasing their values progressively seaward, into the Pacific Ocean. Invoking complicated processes of seawater entrappment in subducting oceanic crust (same reference, p. 13) so as to cause serpentinization of mantle and crustal rocks, and thus increase their volume and decrease their density, is hardly justified, if simple thrusting of the peninsula over poorly consolidated sediments equally explains the geophysical facts.

Furthermore, the 9 km long northwest-southeast-trending Cabo Matapalo Anticline can thus be easily explained as a drape fold over an overlying subsidiary thrust, or blind thrust, in the hanging wall of the ramp; which, in addition, emplaced the Basement Complex into its core. The shear zones existing in these rocks at Cabo Matapalo give evidence of considerable movement.

For the remaining features, let us refer to BERRANGE & THORPE's (1988) figure 2, beginning in the northeast, and with structures trending northwest-southeast.

The Esquinas Fault (Falla Longitudinal de Costa Rica of MORA, 1979), exists without any doubt, and is perhaps the most interesting fault of the district. It has an excellent physiographic expression. It may be traced from the vicinity of David, Panama, past Palmar Sur, and thereafter it controls the coast line as far as Dominical. Farther to the northwest and past Quepos, it separates the mountains from the coastal plain.

Along this course, the northeast block is uplifted, and since tha fault appears to dip 50° to 60° northeast like the remaining faults of the system mapped by MORA (1979), it is a high angle reverse fault. It brings Eocene to Oligocene rocks in contact with Pleistocene to Recent sediments of the Diquis and Río Coto Colorado lowlands; but also with the Nicoya Complex of the Fila de Golfito.

Thrusting older rocks over younger ones, is the normal way of thrusting. But thrusting younger rocks over older ones, is very difficult to accomplish. Hence, the fault probably also has a very pronounced strike-slip component. Its last movements are very young, perhaps Recent, but since the basement rocks apparently already acted as a foreland to the Middle Miocene folding and thrusting of the Fila Costeña (RIVIER, 1985), the fault must have already existed by Middle Miocene time.

The Golfo Dulce Oriental Fault, as drawn on FIGURE 2 (BERRANGE & THORPE, 1988), includes what may be three separate and individual structural features. The fault is obviously based on physiographic-hydrographic evidence only, because other evidence does not exist. Consequently, if this evidence was used in drawing the northwesterly segment, where it was carried along the coast so as to separate the down-thrown part of the Gulf from the up-thrown basement rocks of the Fila de Golfito, then this same evidence should be used for drawing the remainder of the fault: From Punta Gallardo, the fault should be offset along the east-west left-lateral tear fault towards the entrance to Golfito; then it should be drawn along the southwest coast line of the small peninsula separating the two gulfs, to cut the Boca del Río Coto Colorado at Punta de Cerro; and continued southwestward at the foot of the clearly exposed dissected escarpment of Pliocene (Charco Azul) strata for more than 20 km, before butting onto the landward extension of the Armuelles Canyon Fault.

Drawn in this manner, and combined with some associated faults to the northwest, the fault represents the thrust fault postulated by RIVIER (1985) to separate the two different series of basement. It also represents the northeast limit of the Osa-Burica Island of the model.

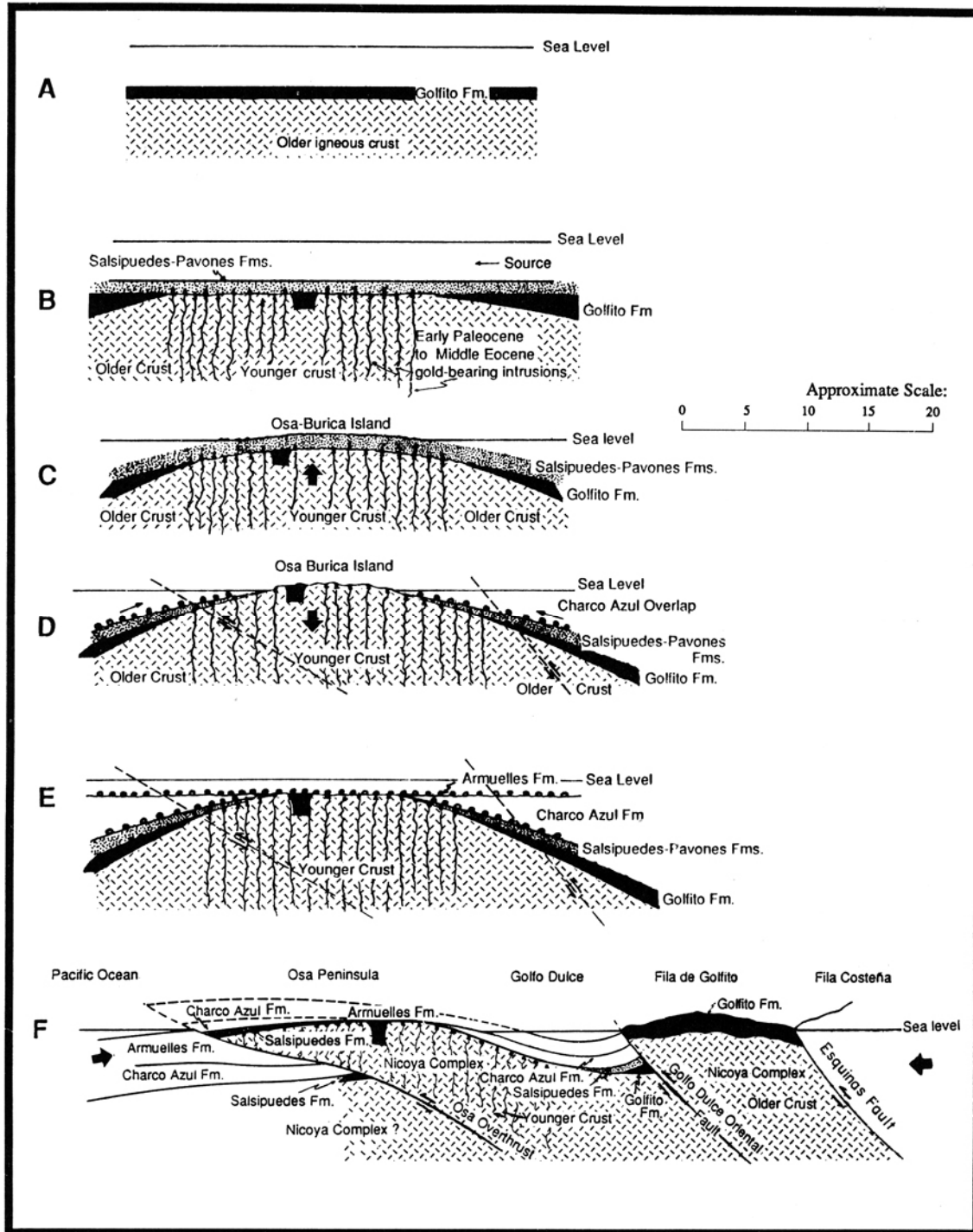Deflecting it southward from Punta Gallardo so as to follow the prominent submarine escarp-

Fig. 3. Geologic history of the Osa-Burica Island.

ment shown on hydrographic charts - and which probably is the evidence of another subparallel thrust fault - is questionable. Even more questionable, indeed even contrary to the evidence used for drawing the first two segments, is carrying the fault across Burica Peninsula towards Puerto Armuelles. Here the topographically high block lies to the southwest, not to the northeast, and thus suggests the presence of a reverse fault dipping in the opposite direction, namely to the southwest. To produce this physiographic effect with a reverse fault dipping northeast would require a new and complete geomorphic cycle; reversing the topography; and doing it only here and nowhere else, because everywhere else in the district the topographic relief always coincides with structural relief, as it should, with such young tectonic features.

This last segment is therefore a separate fault (San Bartolo Fault); a back thrust in the hanging wall of the major ramp previously described; and it ends to the northwest abutting on the northeast-southwest-trending tear faults present at the mouth of the gulf. To the southeast, it probably abuts onto the landward-projected fault of the Armuelles submarine canyon, the Armuelles Canyon Fault.

This latter fault appears to extend as far as the vicinity of Río Claro, where it joins the Esquinas fault; but it should be drawn at least one kilometer east of Puerto Armuelles, if the submarine canyon is to be regarded as its hydrographic evidence, and if the fault is not to cut the Corutú well.

What justification exists, however, to extend it 500 km to the south, to make it become part of the Panama Fracture Zone is not clear. Ostensibly, the displacement is right-lateral, presumably to make it fit the interpretation. Unfortunately, the real displacement, the 30 kilometer offset of the continental shelf across the submarine canyon shown on hydrographic charts (see TERRY's 1956 plate I), is the opposite, namely left-lateral.

The fault cuts a thick series of Teritary and Quaternary sediments, of which almost 3,000 m were drilled by the Corotú well, located only 3.5 km southwest of the canyon. Consequently, the possibility that the ocean floor should be formed by ridge basalts does not exist, and transform fault theory calling for such apparent reversals in observed displacements should not apply.

The Armuelles Canyon Fault is interpreted as an independent left-lateral feature, with the southwest wall thrown up, and of Pleistocene to Recent age.

The Golfo Dulce Occidental Fault has no physical evidence to support it. At Punta Tigre, where it presumably passes offshore, the continuity of the Charco Azul strata on the beach is not interrupted. There exists no physiographic evidence along the coast, and no gravity anomalies may be cited. The implied dextral strike-slip movement is again contradicted by the actual offset of the continental shelf, which is about 2.5 km left-lateral, as shown on hydrographic charts. And, recent offshore seismic work proves again that the ocean floor consists of young sediments, not ophiolites.

An interesting unnamed fault exists at the foot of the hills south of Puerto Jiménez. It brings the Charco Azul Formation in contact with recent alluvium of the coastal plain. Since it is offset by the Cabo Matapalo tear faults of the northeast-southwest-trending systems to be mentioned later, it is not only dated as Pleistocene to Recent, but also shown without a possibility of having a pronounced strike-slip component.

A similar fault forms the northeast border of the Pejeperro alluvial plain; of the Corcovado alluvial plain; and of the elevated terrace to the northeast of Punta San Pedrillo. In each case the contact is so straight, that it suggests a tectonic and not erosional origin.

The Llorona Fault is seen clearly in the field. It may parallel the beach all the way to Sirena. However, there is no reason for relating it with the Panama Fracture Zone.

From Punta la Chancha to Cabo Matapalo, along the coast, a similar fault may be mapped based on physiographic evidence alone. Equally, along the coast of the Burica Peninsula, to the northwest of the mouth of Río La Peña. All three faults are interpreted as high-angle faults existing in the hanging wall of the Osa Overthrust. The fault at Burica is reverse, having overturned the pillow lavas described by OBANDO (1986).

The trace of the Osa Overthrust probably falls near the edge of the continental shelf, or on the high part of the upper slope.

A considerable number of northwest-southeast-trending faults exist in the central part of the peninsula, but they do not appear on any published maps. They are of Pleistocene to Recent age and show well on aerial photographs as well as in the actual topography when flying over them in a light plane. Where they cut the Armuelles Formation overlying the Basement Complex, they may be easily recognized in the field.

Let us now consider the northeast-southwest-trending faults that could possibly represent BERRANGE & THORPE's (1988) dip-slip faults complimentary to the "braided system of curved NW-trending coast-parallel wrench faults", capable of producing "pull-apart and tipped-wedge basins with adjacent uplifted mini-horsts dating back to the Middle Pliocene". There are not any. Faults of this trend that are mapped in the Sierpe area are based on physiographic evidence only, since their presence is suggested by long straight-line contacts of basement rocks with the alluvium. They are most probably of Late Pleistocene to Recent age, and therefore did not affect the deposition of the gold attributed to Pliocene "pull-apart" basins. Some of these faults, however, appear to control the northwest coast line of the Osa Peninsula, between San Pedrillo and Isla Violín. They should have a dextral strike-slip component.

The fault shown as crossing the peninsula between Punta La Chancha and the mouth of Río Tigre does not exist. The next fault to the southeast, curved northward towards Puerto Jiménez, is real, but is Late Pleistocene to Recent again, because it offsets the previously mentioned fault existing at the foot of the hills south of Puerto Jiménez. No sedimentary basin is associated with it.

Cabo Matapalo is terminated by a northeast-southwest-trending fault that forms part of the fault zone that separated Osa from the Burica Peninsula. A similar fault exists offshore at Punta Banco and Pavón Bay; and a number of associated subparallel faults probably exist at the mouth of the gulf, giving rise to the submarine canyon

shown on hydrographic charts. The faults cut Charco Azul and Armuelles strata, are thus Pleistocene to Recent; and the net effect across them is left-lateral. They had no effect on Pliocene sedimentation.

On Burica Peninsula, no offsets may be observed in the well exposed Charco Azul strata that would justify TERRY's (1956, plate I) fault drawn between Puerto Armuelles and the submarine canyon existing off Río La Peña. Neither is there any evidence of the three northwest-southeast-trending faults shown as crossing the peninsula. The northeast-southwest-trending fault that cut the Corotú well (TERRY, 1956, p. 81) is of local extent only. So are several northwest-southeast-trending faults occurring west and northwest of the well, and the faults associated with the north-south-trending anticline show on the geologic map of Costa Rica near the Panama-Costa Rica border (D.G.M.P., 1982).

The available structural evidence thus suggests that no pull-apart basins existed during the deposition of the Charco Azul and Armuelles strata, and therefore neither during the deposition of the gold. The gold-bearing sandstones and conglomerates were deposited on an irregular surface, even against cliffs, if you will; but without pull-apart faulting that would have disrupted the physical continuity of the island. Where gold is observed in the matrix of coarse breccias or conglomerates juxtaposed to the so-called "growth faults", these are of Pleistocene age, trend northwest-southeast, and show displacements of no more than 60 m. When drawn to scale on a cross-section , the sedimentation is more similar to that taking place behind the riffles of a sluice box, than to that taking place in a bona-fide depositional basin.

All structural evidence points towards accretion caused by active subduction - not plugged and deactivated one million years ago - as maintained by some authors (BERRANGE & THORPE, 1988, p. 216).

GEOLOGIC HISTORY OF THE OSA-BURICA ISLAND

The Osa-Burica Island had its origin in a post-Cretaceous swelling or anticlinal doming of the deep oceanic crust.

From the central part of the swelling, older pelagic sediments (Golfito Formation) and parts of the underlying igneous crust were removed by submarine erosion; and were preserved only in locally-formed grabens (Fig. 3-B), as already suggested by OBANDO (1986).

Strata of the younger pelagic sedimentary cover, such as the Salsipuedes Formation (LEW, 1983) and the Pavones Formation (OBANDO, 1986), were deposited in this area mostly on the igneous part of the crust. On the flanks of the swelling, they were deposited over Golfito.

Simultaneously with the deposition of the younger pelagic cover, gold-bearing intrusive and extrusive volcanic activity took place in the anticlinally-domed and tensionally weakened central part of the swelling.

Due to the collision first postulated by RIVIER (1985), the swelling in the deep oceanic crust kept rising to sea level (Fig. 3-C), and by Late Oligocene to Early Miocene time it already formed an island that contributed detrital material to the sedimentation accompanied by basaltic volcanism in the vicinity of today's Cabo Mata-palo. The main body of the island lay to the northwest, but the area of the Corotú well was also being actively eroded.

In Middle Miocene time, the island began subsiding (Fig. 3-D), and basaltic conglomerates were deposited in the Corotú well directly above the igneous basement. The subsidence continued, allowing the Charco Azul basal conglomerates and sandstones to encroach gradually upon the island, if not completely cover it by Late Pliocene time. The surrounding waters never became deeper than outer shelf to upper slope (200 to 250 m).

The subsidence ceased towards the end of Pliocene, and was followed by a period of stand-still and possible slight uplift, that allowed the erosion of the Charco Azul strata from certain parts of the island, and the deposition of the Armuelles strata in a brakish/near-shore to neritic environment (Fig. 3-E).

In Late Pleistocene to Recent times (post-Armuelles) the island was broken up by tectonic movements that are still going on (Fig. 3-F).

The approximate boundary of the island at its maximum extent in Early Miocene time lay be-tween the present Golfo Dulce Oriental Fault, the Corotú well, and the edge of the present continental shelf, possibly up to its re-entrant at Latitude 9° North (Fig. 2 and 4). In Early Pleistocene it was probably restricted to a portion of the present isthmus, and the area to the northwest.

ORIGIN OF GOLD PLACERS

The primary gold mineralization that contributed gold to the placers, is restricted to the central part of the swelling or anticlinal doming of the oceanic crust, associated with the younger pelagic sedimentation coeval with intrusive and extrusive basaltic volcanism. The age of the primary mineralization is therefore Early Paleocene to Middle Eocene, or perhaps up to Early Miocene, if the Cabo Matapalo event also contributed gold-bearing solutions.

The basement rocks were thus the original source of the secondary gold. However, the quantities of gold present in such rocks were so small, that only upon concentration in overlying basal conglomerates, some of these may have given rise to occasional economic deposits. Most of the economic deposits - in fact, most of the major ones - were produced by two or three periods of erosion and thus second- or third-cycle enrichments, before the reworked sediments were deposited in present-day terraces and rivers.

In the entire province, from Osa to Panama, the first concentrations of gold were formed in some of the basal conglomerates of the Charco Azul Formation. To this type of occurrence belong the small deposits in the Río Nuevo (Oro) draining into the Pacific; a number of small occurrences to the southeast; and all of the deposits existing in the south-, southwest-, and northwest-flowing streams of the Burica Peninsula. All have been, in adition, reworked into recent "gulch and bench" placer accumulations.

It is to be noted that the basal sandstones and conglomerates of the Charco Azul Formation overlying the older basement rocks at Pueblo Nuevo de Coto do not carry gold.

The second-cycle concentrations were formed in the basal conglomerates and possibly fluviatile channels of the Armuelles Formation, mostly in
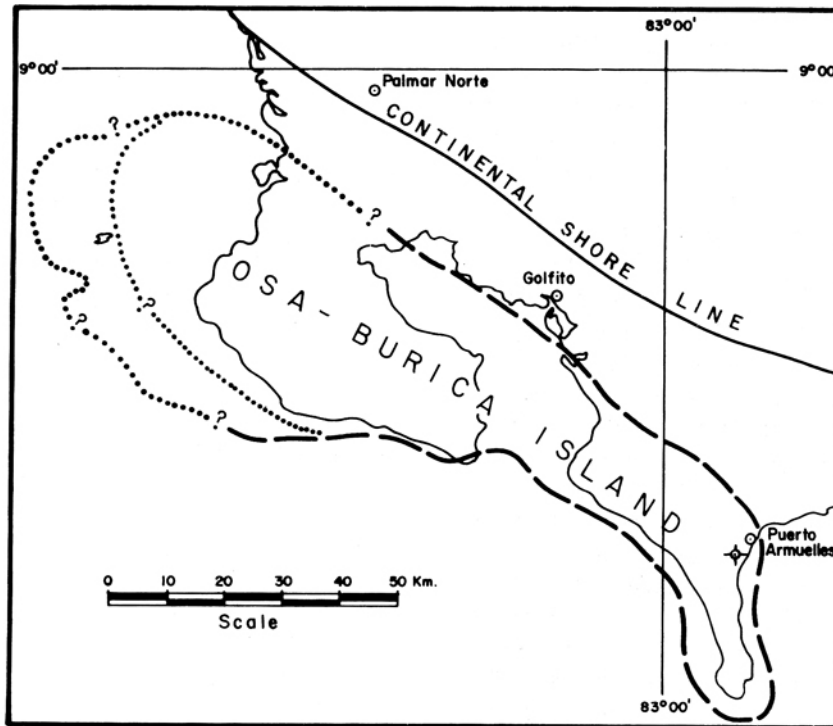
Fig. 4. The approximate outline of the Osa—Burica Island and the conntinental shore line in Early Miocene

the areas where the Charco Azul Formation was eroded away, and where these strata were deposited directly on the Basement Complex. Such is the case of the deposits occurring on the upper Río Tigre and Agujas.

Third-cycle concentrations were formed primarily by the erosion and reworking of the Armuelles Formation, and they constitute all the major gold-bearing sectors of rivers Rincón, Tigre, Carate, Agujas, Conte; and the Incendio, Conte and La Vaca of the Burica Peninsula. To this group also belong the alluvials of rivers Gamba, Bonito, Esquinas, Aguabuena, Banegas, Riyito, and the vicinity of Chocuaco , all presently located in the basement area, from which, most probably, the Armuelles sediments were stripped in the not-too-distant geologic past.

In support of this thesis, reference is made to the different periods of erosion and deposition described under stratigraphy. No recent first-cycle alluvial deposits formed by the direct erosion of the Basement Complex are known to date.

In areas, where the gold occurs occasionally in deeply weathered lateritic soils overlying the ophiolitic basement, there the occurrence is "in situ eluvial", but eluvial and residual from concentrations that once already existed in the Armuelles sedimentary cover, which has now been eroded away. Unquestionable "in situ eluvial" placer deposits developed in the ophiolites over an auriferous quartz secretion vein (BERRANGE, 1987, Fig. 2) have yet to be demonstrated.

GENERAL COMMENTS

Exception is taken to three more opinions expressed in recent geologic literature:
(1) That the streams "flowing exclusively over Osa Group are generally barren, whilst those that have cut down through the basal Osa conglomerates to expose the Osa-Nicoya unconformity are the richest gold producers" (BERRANGE, 1987: 403). The rivers are only barren when the Osa Group sediments happen to belong to the Charco Azul Formation. However, when the rivers flow over Armuelles strata, even for short distances,

then they do produce gold. All the workings in the upper reaches of the two branches of the Quebrada Piedras Blancas are of this type, since the Basement Complex does not extend as far southwest as shown on Dr. Berrangé's map. So are the deposits of Quebrada Caracol in the northern Burica Peninsula, where "perched placers" in the Armuelles Formation were being exploited during 1983, and where recent alluvials occur lower downstream. Similarly, the Quebrada Victoria in Panama. On the other hand, the already referred to Río Nuevo, for instance, is far from being a rich producer, although it cut through the Osa Group sediments and exposed the Osa-Nicoya unconformity for a long distance. This is because in this case the Osa Group sediments belong to the Charco Azul Formation, and not to the Armuelles.

(2) That most of the super-large nuggets appear to have come from the in situ eluvial placers formed in the Nicoya Complex over auriferous quartz secretion veins (ibid.). Two have not. The 237-gram nugget found by CARREZ personnel at El Pegón, on the northern branch of the Río Tigre, came from the basal unconformity of the Armuelles Formation; and the 967-gram nugget found in the headwaters of the northern branch of the Río Agujas, came from a channel developed along the same unconformity.

(3) That the size and habit "conclusively demonstrate that the gold is locally derived from the underlying ophiolitic Nicoya Complex" (ibid.:406). How far is "locally derived"? In October 1982 one of the largest gold-producing companies in Bolivia examined the possibility of placing a dredge on the Río Tigre. The company's chief geologist, their dredging expert, the manager of another consulting firm, and the author arrived on the Río Tigre, then being worked by CARREZ in the vicinity of Dos Brazos. The group watched a clean-up from 2,472 cubic yards of well-rounded gravels and sand that produced 905 g of gold (366 mgs/yd^3). The consensus of all parties present was that "well over 99% of the gold seen is exactly like the gold from Tipuani" (MATTHEWS, 1982), that is, from a well-known gold-bearing river in Bolivia, where the gold was transported over 76 km from a possible primary source, and where it was probably reworked

several times. Yet, three and a half kilometers upstream from Dos Brazos, similar gold was being produced underground from the matrix of a sedimentary breccia, associated with angular blocks of norite more than one meter in diameter. What was the distance of transport of this particular gold? Or, what deductions can one make, based on size and external form alone?

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