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NOTA CIENTIFICA

GAS SEEPS ON THE MARGINS OF THE GOLFO DULCE PULL-APART BASIN, SOUTHERN COSTA RICA

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INTRODUCTION

There are at least four localities on the Osa and Burica Peninsula, where gas is reported to escape from the ground. As the gas discharges are most readily recognised in water-covered areas, all the known localities are in areas inundated by water, but it is possible that gas seeps are much more widespread in the region. The source and composition of this gas was unknown and in view of the current interest in gas seeps world wide samples from two Costa Rican localities were collected and analysed. This note describes these gas seeps and discusses their origin in the context of their tectonic setting.

TECTONIC SETTING

The isthmus of Costa Rica and Panamá (Figure 1) is formed by the Southern Central America Orogen that is divided (Dengo, 1985) into the Chorotega block in the NW and the Choco block to the SE by an tectonic discontinuity represented by a NW-trending sinistral wrench fault through the Panamá Canal zone. The Chorotega block forms an arc, concave to the NE, between the Pacific Ocean and the Caribbean sea. In general terms it comprises three concentric zones; (i) an outer (Pacific) arc of Cretaceous to Lower Tertiary oceanic crust comprising truncated ophiolitic sequences intercalated with, and locally overlain by, Tertiary sedimentary rocks; (ii) an inner volcanic-intrusive arc of embryonic continental crust comprising sequences of Tertiary marine sedimentary, volcanic and volcano clastic rocks deposited in elongate basins and intruded by subvolcanic and plutonic rocks; and (iii) a back-arc basin containing very thick sequences of Tertiary sediments including molasse, distal flysch and pelagic facies. Faulting and vertical tectonics associated with isostatic uplift characterise the inner and outer arcs whereas folding and thrusting is more typical of the back-arc.

The orogen developed 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 American 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

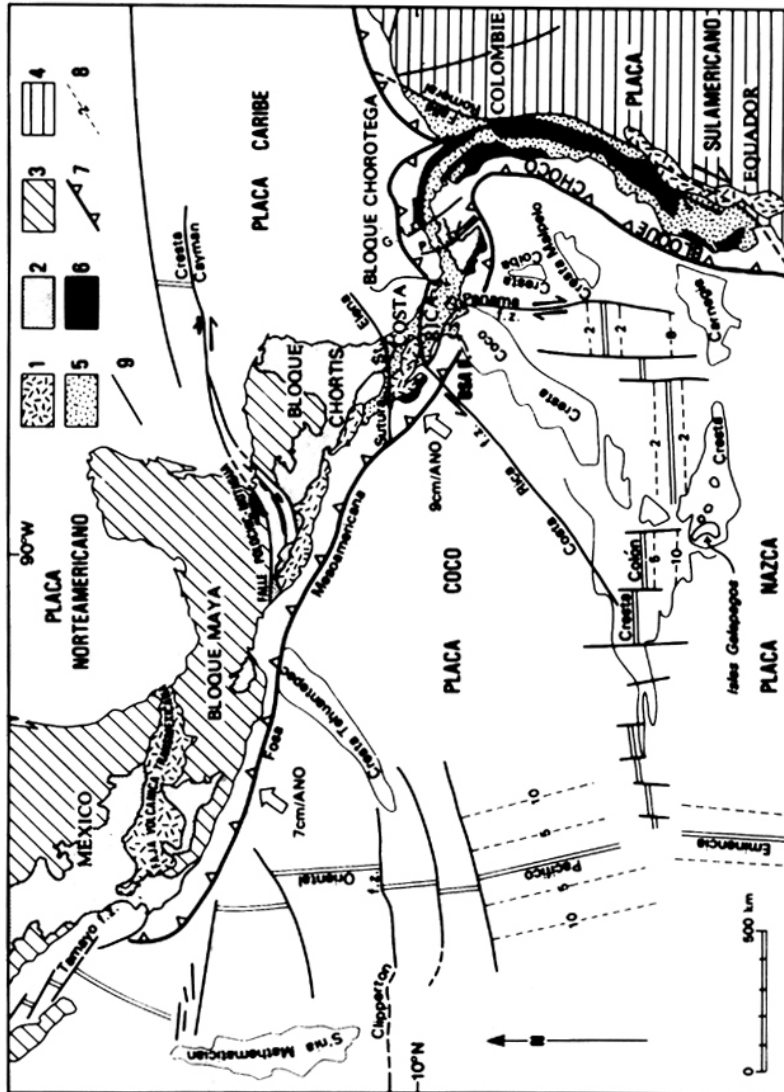


FIGURE 1

Tectonic setting of the Osa Peninsula, southern Costa Rica. 1 = Pliocene and Pleistocene volcanic rocks; 2 = Oligocene and Miocene volcanic rocks; 3 = North American plate; 4 = South American plate; 5 = Cenozoic formations of the Andes and southern Central America; 6 = Mesozoic and Cenozoic ophiolite complexes; 7 = subduction zones; 8 = magnetic anomalies; 9 = fault or fracture zone: G.f.z. = Gatun fracture zone, P.f.z. = Parrita fracture zone

active but the trench dies out towards the Osa Peninsula in front of which it is plugged by the aseismic Cocos Ridge (Figure 1). The boundary between the Cocos and Nazca plates is formed by the Panamá-Coiba Fracture Zone that is approximately 100 km wide and consists of three principal N-trending right-lateral transform faults (Case and Holcombe, 1980) which if extrapolated north-northwestwards via three prominent submarine canyons on the continental slope merge into a braided system of curved roughly coast-parallel wrench faults documented by recent geological mapping in the Osa Peninsula and Golfito region (Figure 2) (Barritt and Berrangé, in press; Berrangé, in press; Berrangé and Thorpe, in press); seismic records and earthquake focal plane solutions (Morales, 1985).

The basement in the Golfo Dulce region is formed by the Nicoya Complex comprising E/MORB-type ophiolitic lavas and intrusives intercalated with subordinate pelagic limestones, argillites and cherts of Upper Cretaceous to Middle Eocene age (Berrangé and Thorpe, in press). A number of sedimentary basins developed in the Osa-Burica region in the Middle Pliocene (3 Ma) and were filled with richly fossiliferous greywacke-type sediment derived mainly from the underlying Nicoya Complex (Berrangé and Lew, in prepn). In the Osa Peninsula the palaeo-basin contains up to 800 m of sediment (Barritt and Berrangé, in press) referred to the Osa Group. East of Golfo Dulce the Burica Peninsula the Coto Colorado - Chiriquí basin contains 2500 m of sediment referred to the Charco Azul and Armuelles Formations of Pliocene and Early Pleistocene age respectively (Sprechmann, 1984). It is proposed that these are pull-apart and tipped-wedge basins filled with sediment derived locally from adjacent mini-horst blocks of uplifted Nicoya Complex and developed as a result of the strong N-S horizontal stress field generated by the Colón spreading ridge.

The configuration of the coastline (Figure 2) and present-day landforms reflect a continuation of the process. Golfo Dulce and Golfo de Chiriquí are modern pull-apart basins, whereas the adjacent Osa Peninsula, Fila Golfito and the Burica Peninsula are mini-horsts with a gentle (2-5°) NE tilt. A similar origin is proposed for the submarine Coiba Ridge that Lonsdale and Klitgord (1978) have shown is an uplifted, eastward tilted slab of oceanic crust and as such of different origin to the other ridges in the eastern Panamá Basin. The relative relief of these features is due mainly to dextral strike-slip movement on a braided system of NW-trending first-order wrench faults with second and third order faults oblique to these. The tectonics are analagous to those described by Crowell (1974) for development of the Gulf of California and the Baja California peninsula. The coast-parallel extensions of the Panamá Fracture Zone meet the Costa Rica Fracture Zone and the Middle America Subduction Zone at a triple junction SE of the Nicoya Peninsula.

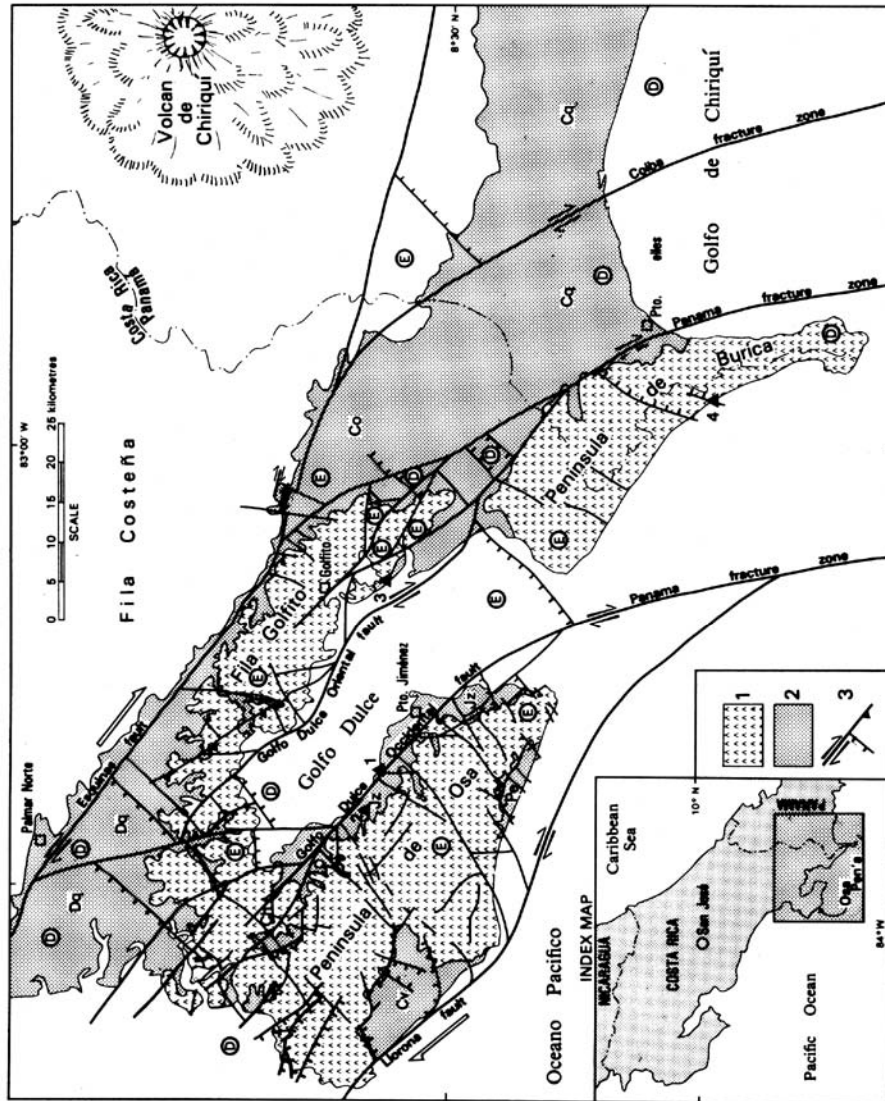


FIGURE 2: Gas seeps and Quaternary fault-bounded pull-apart and tipped wedge basins and highlands in southern Costa Rica and western Panamá. 1 = highlands formed by exposed Mesozoic-Cenozoic rock units; 2 = lowland basins covered by Quaternary alluvium: Ch = Chocuaco basin, Co = Coto Colorado lowlands, Cq = Chiriquí lowlands, Cv = Corcovado lowlands, Dq = Diquís lowlands, Jz = Jiménez-Rincón lowlands. 3 = fault or fracture zone: relative movement indicated by arrows, dip direction by solid triangles, downthrown block by ticks; E = elevated segment of fault block; D = depressed segment of fault block; ▲ = Gas seep; 1 = Playa Sándalo, 2 = Cañaza, 3 = Golfito, 4 = Río La Peña.

GAS DISCHARGES

In the Osa Peninsula one of the gas seeps is on Playa Sándalo (grid reference 3527/2813) on the farm owned by William Thompson who reports that some 25 years ago he capped the discharge area and piped the gas 270 m to his house for cooking. He says it burns with a blue flame. This seep is in the intertidal zone of the beach where at high tide the gas bubbles up through the water here and there over an area of about 15 m². Some of the discharges are continuous small bubbles, others occur as intermittent big bubbles escaping every few minutes. The adjacent bedrock outcrops are a cavernous (due to weathering out of the calcareous matrix) pebble conglomerate of the Osa Group. The discharge is located on the Golfo Dulce Occidental fault zone - a dextral coast-parallel transform (Figure 2). William Thompson reports the existence of another gas discharge nearby in the vicinity of Cañaza. This was not checked out.

There is another gas seep (grid reference 5563/2809) some 500 m south down the channel joining Golfito with Esterio Esperanza. This is also in a major transform fault zone, and local inhabitants report that the discharge increased in intensity following a recent earthquake in the region. Here, the gas discharges as continuous large bubbles at two or three localities spread over 3 m². Yet another gas discharge is reported (J. Obando, personal communication) to exist near the mouth of Rio La Peña on the west side of the Burica Peninsula.

Six samples of the gas from Playa Sándalo and Golfito have been collected by water displacement, five in McCartney glass bottles and one in a Hoke stainless steel cylinder. Gas analyses were carried out by chromatography using Porapak-Q and MS5A columns with argon and helium carrier gases and thermal conductivity and flame ionisation detectors. The cylinder sample provided sufficient gas for an isotope analysis of the methane, which was prepared by oxidation over cupric oxide at 850 °C with cryoseparation of the resulting CO₂ and H₂O, and subsequent reduction of the H₂O to H₂ by heated zinc. The carbon and hydrogen stable isotopic ratios were measured on a VG 602E mass spectrometer. All results are given in Table 1.

Table 1: Composition of gas from surface discharges at Golfito and Playa Sándalo, southern Costa Rica, (Analyses by W.G. Darling, BGS Hydrogeology Group, Wallingford, UK).

Sample	Golfito			Playa Sándalo		
	G1	G2	G3	S1	S2	S3
CH ₄ %	86.0	77.6	77.0	88.1	90.5	89.0
N ₂ %	10.6	17.3	18.3	9.3	7.2	7.1
O ₂ %	2.2	4.0	4.0	2.0	1.6	3.2
Ar %	0.17	0.33	0.20	0.11	0.08	0.10
CO ₂ %	1.03	0.78	0.47	0.47	0.60	0.59
C ₂ H ₆ vpm	37	32	37	25	24	22

$$\text{G3: } \delta^{13}\text{C}_{\text{CH}_4} = -63.3 \text{ ‰}, \quad \delta^2\text{H}_{\text{CH}_4} = -192 \text{ ‰}$$

The samples all have a similar composition and differences can be accounted for by slight contamination with air. The gas was found to be mainly methane. No H₂ was detected (detection limit < 0.01%), and although a check was made for hydrocarbons up to C₄, nothing above C₂H₆ was found (detection limit 1 vpm). The carbon isotope ratio of sample G3 is on the fringe between the 'mixed gas' and biogenic gas categories of Schoell (1980).

DISCUSSION

The Golfo Dulce gas seeps may have originated from one or more of several possible sources:

i) They could have been derived from nonbiological sources as demonstrated for seeps of gas (³He, H₂, CO₂ and CH₄) in various geological settings (Claypool and Kvenvolden, 1983; Corliss, 1980; Fritz and Frapé, 1985; Gwilliam, 1982; McDonald, 1983). For example, emanations of methane, apparently of abiogenic origin, have been recorded from deep mines in the Canadian Shield, from super-deep boreholes in the USSR, in volcanic gases from the Nyiragongo lava lake near Lake Kivu (whose bottom waters are saturated with methane) on the East African Rift, and rising from hydrothermal vents in basalt forming the East Pacific Rise. There is a worldwide occurrence of unexplained natural gas seepages in circum-Pacific regions. Such gas formation is commonly assumed to be of magmatic or hydrothermal origin, or may be derived by outgassing of primordial

nonbiological gas from the mantle or deep crustal sources. Neal and Stanger (1983) have recorded hydrogen gas emanating from ultramafic rocks of the Semail nappe in Oman, and presented evidence that it formed inorganically at relatively low temperatures by shearing and post-serpentinisation chemical degradation of ultramafites. They noted that there is a potential for the widespread development of water flow channels in ultramafic rocks under anoxic conditions along the margins of oceanic spreading centres, transform faults and subduction zones (cf, Golfo Dulce pull-apart basin); so the deep generation of abiological hydrogen and hydrocarbons is a plausible hypothesis.

ii) Methane could be derived from sheets or lenses of solid methane hydrate within marine sedimentary sequences as recorded below the continental shelves and deep ocean floors off the coasts of North and South America, Africa, Australia and the Far East, in the Pacific, Atlantic and Caribbean (MacDonald, 1983; Claypool and Kvenvolden, 1983; Hindley, 1986). For example, a huge body of white massive methane hydrate has been intersected in nine successive holes drilled offshore of Guatemala (DSDP Leg 84) ca. 1000 km NW of Golfo Dulce. Although methane hydrate bodies are generally assumed to have a biogenic source, their origin is obscure and they may in part be abiogenic.

iii) Methane emanations could be 'thermogenic' and associated with accumulations of petroleum in the sedimentary successions filling a pull-apart basin. A relatively high geothermal gradient would favour the generation of methane which would be channelled up active transform faults as reported from the Gulf of California (Lonsdale, 1985).

iv) Methane seeps could be derived from microbial degradation of marine organisms, vegetal matter and coal in the sedimentary succession, and be channelled up active transform faults.

The composition of the Golfo Dulce gas seeps, especially the absence of hydrogen, precludes any analogy with the hydrogen emanations of Oman (Neal and Stanger, 1983). There is no evidence (as yet) to indicate the presence of methane hydrate lenses in the underlying rocks, or derivation of the gas, therefrom. Petroleum is not known from the underlying Nicoya Complex or the sediments, and a petroleum source is discounted on account of the relatively light carbon isotopic ratio (-63,3) and the fact that no paraffin hydrocarbons above ethane were found. A significantly heavier isotopic ratio and the presence of higher C₂ hydrocarbons would be expected if the gas were petroleum related. The composition of the gas and its carbon isotopic ratio indicates a more-or-less biogenic origin for the gas which most probably originates mainly from microbial decay of the abundant terrestrial vegetal and marine organic

matter in the Pliocene sediments. However, contributions from a nonbiological mantle or deep crustal source cannot be ruled out in view of the tectonic setting on the margins of a pull-apart basin near active transform faults, and the carbon isotopic ratio of sample G3 which is on the border between the 'mixed gas' and biogenic gas categories of Schoell (1983).

ACKNOWLEDGEMENTS

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