Rev. Geol. Amér. Central, 10: 67 - 93, 1989

THE OSA GROUP: AN AURIFEROUS PLIOCENE SEDIMENTARY UNIT FROM THE OSA PENINSULA, SOUTHERN COSTA RICA

Jevan P. Berrangé
British Geological Survey, Overseas Directorate
Keyworth, Notts. NG12 5GG
United Kingdom

ABSTRACT: Recent geological mapping in the Osa Peninsula and micropaleontological studies have led to the recognition of a new lithostratigraphic unit - the **Osa Group**. This group replaces the Charco Azul and the Armuelles Formation in the Osa Peninsula as shown on the DGMP 1:200,000 geological map, and includes the informally defined Punta La Chancha formation. It is defined as a sequence of semi-consolidated to lithified, greenish-grey, graded, graywacke-type conglomerates, sandstones, siltstones and claystones of Mid to Upper Pliocene age lying unconformably on a Nicoya Complex basement, and unconformably overlain by unconsolidated Quaternary sediments of the Puerto Jiménez Group. The Osa Group was deposited in a wide variety of sedimentary environments ranging from fresh-water fluviatile; brackish lagoonal-estuarine-deltaic; shallow shelf down to deep marine basin. Economically important placer gold is widespread and tends to be concentrated locally in the conglomeratic members, especially at the basal unconformity. It is suggested that the Osa Group sediments were deposited in intermittently subsiding pull-apart basins governed by wrench faulting in a geological setting similar to that on and around the Osa Peninsula at present. The present-day Panamá-Coiba Fracture Zone in the Gulf of Panamá can be extrapolated northwards via three submarine canyons on the continental slope, and thence into a system of braided northwest-trending transcurrent faults parallel to Costa Rica's Pacific coastline. The landforms and bathymetry of the region surrounding the Osa Peninsula are considered to be largely controlled by (intermittent) dextral strike-slip movement on the main fractures. Within this tectonic setting the Golfo Dulce basin and the Coto Colorado-Chiriquí lowlands form pull-apart or tipped-wedge basins, whereas the Osa and the Burica Peninsula, and the offshore Coiba Ridge, are tilted horst blocks.

RESUMEN: El cartografiado geológico reciente en la península de Osa y los estudios micropaleontológicos han permitido el reconocimiento de una nueva unidad litoestratigráfica el Grupo Osa. En la península de Osa este grupo reemplaza las formaciones Charco Azul y Armuelles como se muestra en el mapa geológico 1:200,000 de la DGMP, e incluye la unidad informalmente definida como "formación Punta la Chancha". El Grupo Osa se define como una secuencia de conglomerados, areniscas, limolitas y arcillitas que están semiconsolidados a litificados, de color gris-verdusco, gradados y de tipo grauvaca. El grupo es de edad Plioceno Medio a Superior. Yace discordantemente sobre el basamento del Complejo de Nicoya y es sobreyacida discordantemente por sedimentos no consolidados cuaternarios del Grupo Puerto Jiménez. El Grupo Osa fue depositado en una gran variedad de ambientes sedimentarios variando desde fluviales de agua dulce, estuarino-deltaico de agua salobre, plataforma somera, hasta de cuenca marina profunda. El oro de placer de importancia económica está difundido y localmente concentrado en los miembros conglomeráticos, especialmente cerca de la discordancia basal. Se sugiere que los sedimentos del Grupo Osa fueron depositados en cuencas del tipo "pull-apart" que se hunden a intervalos. Estas cuencas fueron formadas por fallas de desplazamiento de rumbo anastomosadas, son de dirección noroeste con rumbo paralelo a la costa pacífica, tienen un marco geológico similar a aquellas que están actualmente alrededor de la península de Osa. La zona de fractura de Panamá-Coiba en el Golfo de Panamá puede extrapolarse hacia el norte via tres cañones submarinos en la vertiente continental, y en un sistema de fallas transcurrentes de rumbo noroeste, paralela a la costa pacífica de Costa Rica. El relieve y batimetría en los alrededores de la región de la península de Osa se considera está controlada esencialmente por movimiento intermitente de desplazamiento de rumbo dextral en las fracturas principales. Dentro de este marco tectónico el Golfo Dulce y las tierras bajas de Coto Colorado-Chiriquí forman cuencas de tipo "pull-apart" o "wedge-tipped" mientras que la península de Osa y Burica y la Cresta de Coiba costa afuera, son pilares tectónicos inclinados.

INTRODUCTION

The Pacific coastline of Costa Rica and Panamá is characterized by numerous peninsulas and promontories comprising obducted segments of oceanic crust of Cretaceous to Early Tertiary age, unconformably overlain by Middle-Late Tertiary sedimentary rocks (BAUMGARTNER *et al.*, 1984). In the Osa Península of southern Costa Rica the ophiolitic basement complex comprises a basalt-dolerite-gabbro and pelagic sedimentary assemblage of Senonian to Eocene age (BERRANGE *et al.*, 1989). It is unconformably overlain successively by the Osa Group of Pliocene graywacke-type sedimentary rocks and by the Puerto Jiménez Group comprising unconsolidated sediments of Pleistocene-Holocene age. Both the Osa and the Puerto Jiménez Group contain economic deposits of alluvial gold that has been derived locally from the underlying Nicoya Complex (BERRANGE, 1987, in press).

This paper presents some of the results of a broadly defined research programme which investigated the geology and gold mineralization of the Osa Península. The work undertaken included reconnaissance geological mapping (BERRANGE, 1988) but did not include detailed studies such as measurement of sections and the construction of graphic logs of the sedimentary sequence as is standard practice in modern stratigraphic studies. However, in view of the considerable economic importance of the Late Tertiary sedimentary rocks as a source of placer gold (BERRANGE, 1987), and the fact that a substantial amount of new data on these rocks has been accumulated, a preliminary account of the group is considered worthwhile. The main purpose of this paper is to formally define the Osa Group and to present the first overall account of its geology, micropaleontology, depositional environment and age. A new tectonic-depositional model is proposed that it is hoped will be of interest from both academic and practical gold mining points of view. In order to help future workers, important selected features mentioned in this paper are identified by grid references keyed to the 1:50,000 scale topographic maps produced by the Instituto Geográfico Nacional.

TECTONIC SETTING

Costa Rica forms part of the Chorotega block, the northerly segment of the Southern Central America Orogen that extends from the Santa Elena suture through Costa Rica and Panamá to include the Coast Ranges of Colombia and Ecuador (DENGO, 1985) (Fig. 1). The Chorotega block forms an arc, concave to the northeast, 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 volcaniclastic rocks deposited in elongate basins and intruded by subvolcanic and plutonic igneous bodies; and (iii) a back-arc containing very thick

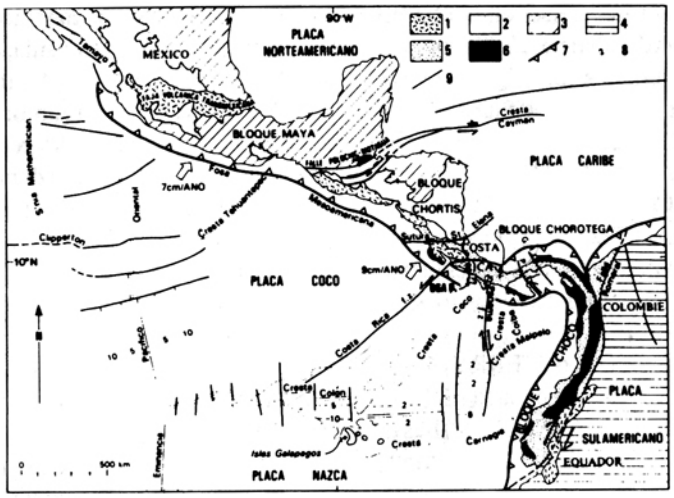


Fig. 1: Tectonic setting of the Osa Peninsula, southern Costa Rica. - 1.= Pliocene and Pleistocene volcanism; 2.= Oligocene and Miocene volcanism; 3.= continental sialic rock of the North American and the Caribbean plate; 4.= continental sialic rocks of the South American plate; 5.= Cenozoic formations 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 zoane. (Adapted from BOURGOIS et al., 1984, text figure 1).

sequences of Tertiary sediments including molasse, distal flysch and ?pelagic facies. Strike-slip faulting and vertical tectonics associated with isostatic uplift characterize the outer and inner 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 (or their ancestral equivalents) 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 actively subducted beneath the Caribbean plate. This subduction zone is still active, but dies out southwards 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 N-trending system of transform faults that if projected northwards correspond with three submarine canyons on the continental slope and intersect the coast in the vicinity of the Osa and the Burica Peninsula where they appear to bend northwest to form a system of braided, coast-parallel, dextral wrench faults giving rise to pull-apart and tipped-wedge basins with adjacent horsts (BARRITT & BERRANGE, 1987; BERRANGE & THORPE, 1988).

PREVIOUS WORK AND DEFINITION OF THE UNIT

Sequences of greenish-gray, poorly indurated, calcareous, richly fossiliferous greywacke-type conglomerates, sandstones, siltstones and claystones of Upper Tertiary age unconformably overlie the Nicoya Complex over much of the Osa Peninsula. On the 1:200,000 geological maps of Costa Rica (DGMP, 1982) these sedimentary rocks are shown as either the Pliocene Charco Azul Formation or the Pleistocene Armuelles Formation. Some previous workers (MADRIGAL, 1982; SEGURA, 1981; ACUÑA, 1983) have followed this twofold division and refer the rudaceous-arenaceous facies to the Charco Azul and the more argillaceous facies to the Armuelles Formation.

The type-area for the Charco Azul Formation is in the Burica Peninsula sector of the Chiriquí Province in Panamá (TERRY, 1941, 1956; OLSSON, 1942a, 1942b; see also HOFFSTETTER, 1960; SPRECHMANN, 1984). The basal part of the formation is conglomeratic and near Puerto Armuelles is a 180 m thick conglomerate containing almost entirely basic igneous clasts. Higher in the section the formation is a predominantly shale and siltstone sequence with plant remains and lignite seams, together with an abundant marine fauna of molluscs and foraminifera. It is strongly transgressive southwestwards onto a landmass of substantial size (?ancestral Cocos Ridge) and here it has a maximum thickness of 1220 m, a Pliocene fauna indicative of deposition in an environment characterized by variations from shallow to deep water over short distances.

The Armuelles Formation (TERRY, 1941; OLSSON, 1942a, 1942b; see also HOFFSTETTER, 1960; SPRECHMANN, 1984) has its type-area in the same region where it discordantly overlies the Charco Azul Formation. The lower part of the Armuelles Formation comprises a well-consolidated basal conglomerate with clasts of andesite and jasper up to two metres in diameter, intercalated with bluish sandstones and overlain by well-bedded, foraminifera-rich claystones containing lignite beds, leaves and wood, and intraformational conglomerates. The upper part of the formation is very arenaceous and has an abundant varied mollusc fauna. The Armuelles Formation has a maximum thickness of about 1220 m, was deposited in shallow water and is Early Pleistocene or younger in age (SPRECHMANN, 1984).

The equivalent sedimentary rocks on the Osa Peninsula are similar in lithology, fauna, depositional environment and age to the Charco Azul and the Armuelles Formation of the Burica Peninsula. However, there is no evidence to prove that the Osa sediments were deposited in the same sedimentary basin as the Burica sediments, or, that the sedimentary units in the two peninsulas are physically continuous. Furthermore, the basal disconformity separating the two formations on the Burica Peninsula, and which is marked by an indurated conglomerate, has never been recognised from the Osa Peninsula. Here the succession appears to be continuous with only minor local intraformational conglomerates, and is characterized by considerable lateral and vertical facies variations. It therefore seems inappropriate and confusing to refer the sedimentary rocks on the Osa Peninsula to either the Charco Azul or the Armuelles Formation.

On the basis of mapping the south-central sector of the Osa Peninsula, IVOSEVIC (1979) identified a sequence of lithified marine sediments derived by erosion of the nearby Nicoya Complex, and which he referred to as "Older Sediments". He identified three separate units in the sequence which he estimated to be 1150 m thick, and on the basis of dating the molluscan fauna he assigned it to the Pleistocene.

LEW (1983a, 1983b) mapped a sector of the southern Osa Peninsula that overlapped the area studied by IVOSEVIC and assigned the equivalent sequence to an informally defined "Punta La Chancha formation" of Middle Pliocene age. He estimated that the formation is +850 m thick and divided it into lower, middle and upper members comprising a sequence of calcareous graywacke turbidites characterized by graded bedding, channeling, trough and planar cross-sets, and load structures. He deduced that the sediments were derived from a distant proto-Talamanca island arc and were deposited in a WSW/ENE-trending basin as a submarine fan sequence at a minimum depth of 200 m, and probably at a depth between 700 and 800 m.

Sedimentary rocks that correlate with IVOSEVIC's (1979) Older Sediments and LEW's (1983a, 1983b) Punta La Chancha formation cover much of the Osa Peninsula and include non-marine, littoral and shallow- to deep-marine facies. A new lithostratigraphic unit of group status is needed to describe these rocks and the designation **Osa Group** is formally proposed. The Osa Group is defined as a sequence of semi-consolidated to lithified, greenish-grey, graywacke-type conglomerates, sandstones, siltstones and claystones of Pliocene age lying unconformably on the Nicoya Complex basement, and unconformably overlain by unconsolidated Quaternary sediments of the Puerto Jiménez Group. It characteristically exhitits graded bedding at various scales, contains abundant organic matter, is locally calcareous and markedly fossiliferous. It contains a rich and varied macro- and microfauna that considered together with the lithologies and structures are indicative of deposition in a variety of sedimentary environments including fresh-water fluviatile, brackish lagoonal-estuarine-deltaic, shallow shelf down to deep marine basin. Clasts in the rudaceous-arenaceous facies include basalt, dolerite, gabbro, pelagic limestone, argillite, chert, and quartz, all derived exclusively from the Nicoya Complex. Placer gold is widespread and is locally strongly concentrated in the conglomeratic members, especially at the basal unconformity. The Group is confined to the Osa Peninsula.

GEOLOGY

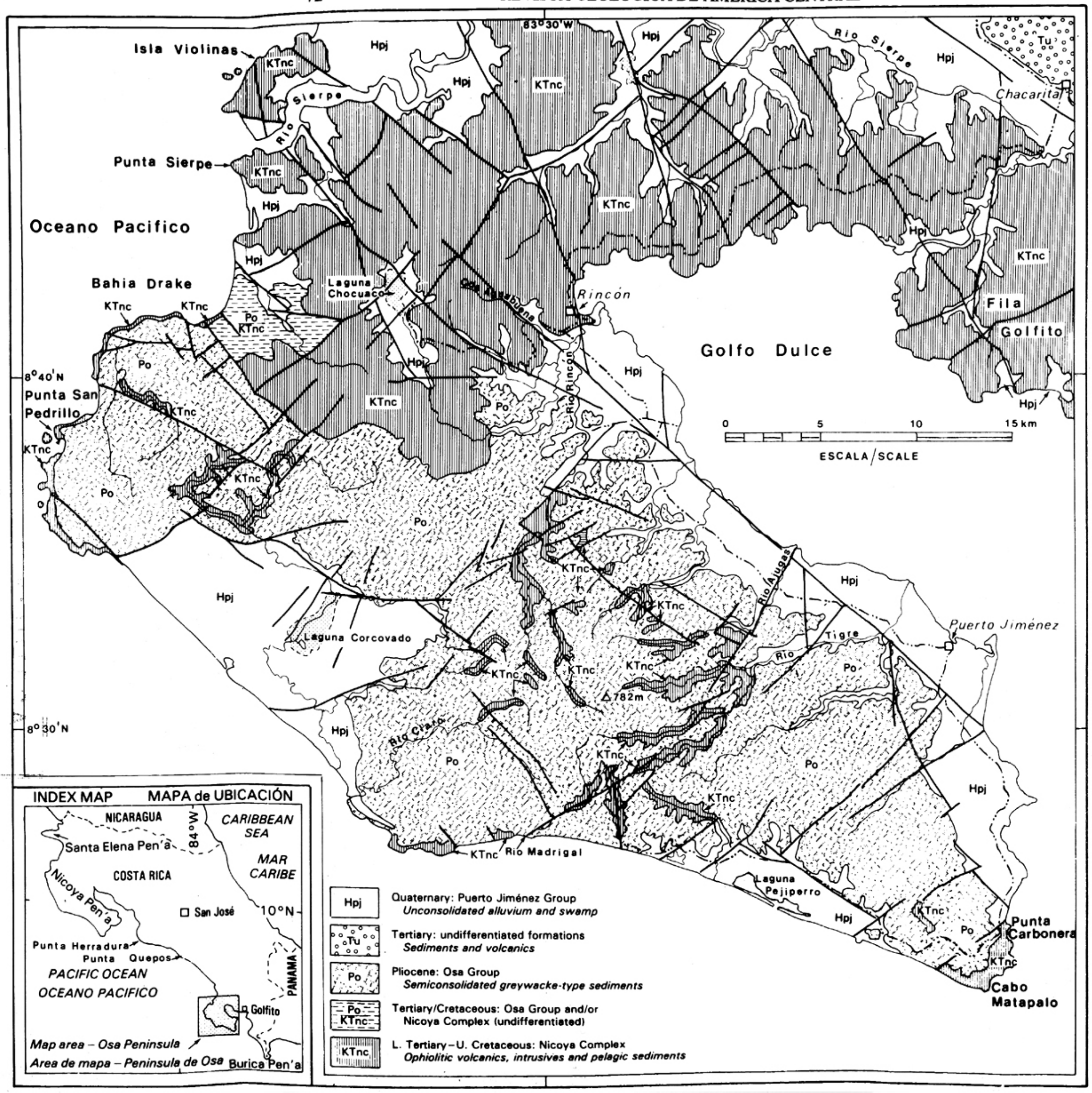
Distribution

The Osa Group is extensively exposed in the southern two-thirds of the Osa Peninsula where it forms the deeply incised mountains including the highest peak at 782 m (Fig. 2). It is also exposed locally below a cover of alluvium in the beds of the major rivers flowing across the Rincón-Puerto Jiménez lowlands, and crops out extensively along the eastern coastline of the peninsula where it is mainly exposed at low tide. This distribution shows that it underlies the Rincón-Puerto Jiménez lowlands where it is buried by generally less than 20 m of alluvium of the Puerto Jiménez Group. A gravity survey shows that there are 600-800 m of Osa Group sedimentary rocks lying below the surface at Puerto Jiménez (BARRITT & BERRANGE, 1987). The Osa Group probably also underlies the Pejeperro and Corcovado lowlands where it is deeply buried beneath alluvium. In the northern part of the peninsula the mountains are formed by the Nicoya Complex that characteristically has a thick latosol mantle and so do not appear to ever have been covered by the Osa Group. This was probably a source area for the Osa Group sediments. A gravity survey also shows that the intermontane Laguna Chocuaco basin is filled with about 100 m of sediment, but it is not known whether or not Osa Group rocks lie beneath the alluvial cover (BARRITT & BERRANGE, 1987).

The basal unconformity and rudaceous facies

The unconformable contact between the Osa Group and the Nicoya Complex is exposed at intervals along the intermontane valleys where the rivers have cut down and exposed windows of the Nicoya Complex (eg. Río Tigre, 5274/2758; Río Rincón, 5186/2785) or along the seashore (eg. Punta Chocuana, 5423/2793; Punta San Pedrillo). The unconformity varies and may be an unweathered fresh sharp contact, a highly weathered zone of rotten rock, or a regolith layer comprising angular fragments of the underlying rock forming an eluvial or colluvial deposit that is essentially in place (eg. Río Barrigones, 5223/2793; and Río Cone, 5230/2817). These deposits are commonly auriferous.

Geological mapping shows that the sediments were deposited in a region of high relief characterized by steep slopes (Fig. 6). A difference in elevation of 1.5 to 2.0 m on the unconformity can be seen on individual outcrops, whilst a relief of several tens of metres over a few hundred metres horizontal distance, or hundreds of metres over the peninsula as a whole can be demonstrated. Buried topographic highs, basins and palaeo-valleys can be all recognized locally, for example, a buried valley trends northwards on the left-hand side of the Río Brazo Izquierda from its confluence with the Río Piedras Blancas (5277/2736). Such palaeo-valleys commonly contain rich auriferous pay-streaks sought after by gold miners who tunnel along them (eg. Río Agujas, 5252/2771, 5247/2768; Río Tigre, 5274/2758; Quebrada Pizote, 5282/2749; Río Brazo Izquierda, 5288/2751, 5266/2736). The Pliocene unconformity surface was probably similar in aspect to the present-day topography of the peninsula and environs with its deeply incised mountains, lowlands, an intertidal coastal zone, and a marine shelf and basin, giving a combined subaerial-submarine relief in the order of 1000 m. This high palaeo-relief combined with subsequent differential vertical movement of fault blocks means that the sediment thicknesses vary markedly over short distances, and makes the estimate of overall thickness by field measurements or gravity modelling very difficult. A Bouguer gravity survey (BARRITT & BERRANGE, 1987) of the Osa Peninsula and environs has confirmed the existence of a significant palaeo-relief with a buried ridge separating two depositional basins containing up to 700-800 m of sedimentary fill. This thickness is consistent with field observations.


83°30'W
Isla Violinas
Punta Sierpe
Rio Sierpe
Oceano Pacifico
Bahia Drake
Laguna Chocuaco
Rincón
Golfo Dulce
Chacarita
Fila Golfito
8°40'N
Punta San Pedrillo
Laguna Corcovado
782m
Rio Rincon
Rio Agujas
Rio Tigre
Puerto Jiménez
Rio Claro
Rio Madrigal
Laguna Pejiperro
Punta Carbonera
Cabo Matapalo
8°30'N
0 5 10 15 km
ESCALA/SCALE
Hpj
Po
KTnc
Tu
INDEX MAP MAPA de UBICACIÓN
NICARAGUA
CARIBBEAN SEA
MAR CARIBE
84°W
Santa Elena Pen'a
COSTA RICA
Nicoya Pen'a
San José
10°N
Punta Herradura
Punta Quepos
PACIFIC OCEAN
OCEANO PACIFICO
PANAMA
Golfito
Map area – Osa Peninsula
Area de mapa – Peninsula de Osa
Burica Pen'a
Hpj Quaternary: Puerto Jiménez Group
Unconsolidated alluvium and swamp
Tu Tertiary: undifferentiated formations
Sediments and volcanics
Po Pliocene: Osa Group
Semiconsolidated greywacke-type sediments
Po KTnc Tertiary/Cretaceous: Osa Group and/or Nicoya Complex (undifferentiated)
KTnc L. Tertiary–U. Cretaceous: Nicoya Complex
Ophiolitic volcanics, intrusives and pelagic sediments

The lowermost members of the Osa Group are very variable. Basal conglomerate is not the rule, and siltstone-sandstone lithologies are just as common as conglomerate-sandstone lithologies. LEW (1983a) reports that at Punta San Pedrillo ten metres of sedimentary rocks are exposed unconformably overlying massive basalts of the Nicoya Complex. The contact is broadly subhorizontal and lacks incision features. The overlying sedimentary rocks are pale olive-green, calcareous, silty, medium- to fine-grained, high-rank graywackes. Sand grains are angular to subrounded. Bedding is generally poorly developed, but 5-20 cm thick lenses and stringers occur at irregular intervals in the section. These contain fragments of shallow-water molluscs, and a few articulated bivalves up to 6 cm in diameter. The articulation of these bivalves indicates that they are in place or have only undergone limited transport. Similar relationships were observed by LEW along the Río Camaronal and near Punta Chocuana.

At Punta Chocuana (5426/2615) near the southeast tip of the peninsula exposures in an elevated wave-cut platform reveal a very irregular unconformity, with a relief of about 1.5 m, between the Nicoya Complex and the Osa Group. The basement is unconformably overlain by greenish-grey bedded Osa Group claystone with lenses of sandstone and conglomerate. Bedding in the claystones is generally horizontal but is draped over basement highs. Coastal outcrops exposed at low tide along the coast between Punta Chocuana and Punta Carbonera (5423/2617) consist of greenish-grey, graded claystones containing white shell fragments and dark brown organic matter including pieces of wood. Bedding dips at 8º to the ENE. A small sea stack measuring approximately 3 x 5 x 2.5 m high rises above the claystone outcrop and is formed by a polymict clast-supported conglomerate comprising unsorted cobbles and boulders, mainly of basalt and limestone, but with a few of jasper, quartz and relatively soft rip-up clasts of (Osa Group) claystones. The boulder-sized clasts are generally more angular than the cobbles and include the rip-up Osa Group claystones. The largest clast seen was an angular pale coloured limestone boulder measuring 50 x 150 cm. The cobbles are generally rounded to subrounded. The relationships are interpreted as indicative of multiple cycles of erosion and sedimentation; and the conglomerate stack probably represents the remnants of an infilled channel cut into the claystones.

The basal member of the Osa Group is well exposed along the Río Tigre about 1.5 km above its confluence with Río Brazo Izquierda at a mining locality known as El Pergon (5274/2758). Here the unconformity surface is typically irregular with a relief of about 20 m. The basement is formed of highly fractured and locally silicified basalt that locally has a bluish-gray colour. In places this grades upwards into a 2 m thick layer of medium bluish-gray eluvial breccia comprising angular fragments of basalt and quartz set in a clayey matrix. Elsewhere there is a well lithified bluish-gray basal conglomerate formed of angular to subangular clasts up to 1 m in diameter, mainly of basalt but also including pink limestone, greenish-gray sandstone, red chert and white quartz. It is clast-supported. It contains vegetal matter including small logs of wood. Native gold is also found. The conglomerate contains siltstone-sandstone lenses up to about 2 m thick showing torrential cross-stratification, and dips at about 20º to the NE. This is interpreted as a fluvial deposit laid down under torrential flow conditions in a NE-trending valley - the proto-Río Tigre.

A rather unusual tabular cross-stratified sequence from near the basal unconformity is exposed in a river cliff on the middle Río Agujas (5268/2778). Individual cross-sets comprise bluish-gray siltstone interbedded with crumbly, pale brown, coarse sandstone and polymict pebble conglomerate layers containing clasts of Nicoya Complex lithologies. These clasts are rounded, poorly-sorted, and mainly of fine-pebble size. Many of the sandstone-conglomerate lenses are dusky red in colour due to the presence in them of abundant ochre or red iron oxide that occurs as an interstitial powder between the clasts which are also locally cemented by this material.

At many localities, especially along rivers draining the NE flanks of Osa mountains (eg. El Pergon 5274/2758; Playa Carbonera, 5423/2617; Río Piedras Blancas, 5272/2724) it is possible to observe a rough correlation between the dominant lithology of the conglomerate clasts and the local bedrock type. This indicates that the clasts forming these conglomerates were locally derived and is suggestive of a fluvial origin rather than being deposited from far-travelled submarine turbidite flows. However, in the southern part of the peninsula, southwest of the water divide, graded conglomerate-sandstone-siltstone sequences up to +200 m thick are exposed along some of the river valleys (eg. Quebrada Coyunda, Río Piro, Río Nuevo, Río Carate) and along the seashore (eg. between Quebrada Hedionda, 5159/2670, and Punta La Chancha, 5130/2660). In these sequences the clasts are generally rounded and polymict, but although they have an exclusively Nicoya Complex provenance, no obvious correlations with the local bedrock lithology is apparent; and so they could have been deposited from submarine turbidite flows.

The colour of the conglomerates is naturally governed by that of their clasts, but their finer grained matrix generally has a moderate to dark greenish-gray colour when fresh, and less commonly a bluish-gray colour indicative of weathering and diagenesis under reducing conditions. They weather to various shades of yellowish-brown, depending on the degree of oxidation. Where the basal conglomerates and sandstones have a bluish-gray colour and a large proportion of admixed clay they are called "liso" by the miners who consider this material to be a very favourable hostrock for alluvial gold.

Alluvial gold occurs in rudaceous and arenaceous facies in the lower and middle units of the Osa Group, but mineable concentrations are largely confined to the basal eluvial/colluvial breccia-conglomerates, and to true alluvial conglomerates deposited in Pliocene river valleys, piedmont fans and deltas (IVOSEVIC, 1979; BERRANGE, 1987, 1989). 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.

Arenaceous lithologies

Greywache-type sandstones are found throughout the Osa Group but appear to be relatively more abundant in the lower and upper parts of the succession. They occur as the conglomerates grade into pebbly sandstones, or as thin laminae up to 10 mm thick, and beds generally less than 1 m thick alternating with, and /or grading into, the siltstones and claystones. They quite commonly fill channels cut into the other lithologies. Trough and planar cross-stratification is also common. The sandstones are generally shades of grayish-green when fresh, many have a calcareous matrix and/or contain abundant shelly fragments, and dark brown vegetal matter is widespread.

The following petrographic account is taken from LEW (1983a) who studied medium-grained sandstones collected from different localities on the peninsula. The samples were thin sectioned, stained for plagioclase and K-feldspar and modally analysed, some 300 points being counted on each thin section. Most of the sandstones consist largely of a chloritic matrix containing large numbers of ghost grains, but some of them are grain-supported and contain relatively little matrix. The compositions of the samples analysed are presented in Table 1. These rocks are classified as calcareous high-rank graywackes. Each of the samples is at least partially cemented by calcite. Grains are mostly 0.3-0.5 mm in diameter, but a few 1-2 mm grains occur in each sample. Chert and quartz grains are angular to subrounded, and a few are well rounded. Both the altered and unaltered feldspars are angular to subangular. Almost all of the plagioclase is untwinned. A few K-feldspar grains were found in some samples, and some of the ghosts counted as altered feldspar may be K-feldspar. Angular to subrounded pyroxene grains also make up a few percent of some of the samples. Rock fragments are the major constituent of most of the samples. These are angular to subrounded, and a few are well rounded. The majority of these fragments are from mafic igneous rocks, most of which are volcanic, but a few fragments of felsic igneous rocks have been tentatively identified. A small percentage of the rock fragments were derived from sedimentary rocks and consist of limestone, graywacke sandstone and quartzitic sandstone. Coarser grained size fractions consist almost entirely of rock fragments, and finer size fractions are almost completely altered. The majority of samples contain a large amount of shelly debris that is angular to subrounded, and as a rule heavily abraded. Most samples also contain a few percent of vegetal matter.

Argillaceous lithologies

Siltstones and especially claystones are the dominant lithology of the Osa Group, especially in the middle part of the succession. They are generally calcareous and coloured shades of grayish-green when fresh and yellowish-brown when altered. Although only slightly lithified, in the mountains where rivers have cut down rapidly, they form steep-sided valleys several hundred metres deep and vertical cliffs several tens of metres high. A blocky fracture is characteristic. Many claystones outcrops appear to be massive and unbedded but careful examination generally reveals a faint lamination and/or bedding. This is well developed locally where there are rhythmic claystone-siltstone alternations or where the claystone is interbedded with conglomerate and sand-

TABLE 1
Modal analyses of medium-frained sandstones from the Osa Group including the Punta La Chancha formation

	Ped-SN1	WF-2	CH-B-1	CH-M-1	SN-CAM	PC-12	PCH-13	CL-1	CL-4	MAD-SNB	MCL	PAN
Matrix	27	32	21	24	13	23	39	23	23	34	26	18
Chert	4	4	10	2	4	3	1	6	5	6	2	19
Quartz	2	5	3	4	11	7	3	17	6	7	2	10
Plagioclase	7	9	5	8	7	19	6	16	8	7	10	16
Potassium Feldspar	<1	<1	—	—	<1	—	—	—	—	—	—	—
Altered Feldspar	10	9	11	10	13	12	10	11	8	11	15	4
Pyroxene	—	<1	<1	2	2	4	3	4	2	1	2	—
Rock Fragments	28	26	47	44	18	27	33	20	45	32	2	33
Plant Debris	—	6	3	6	2	5	4	3	3	1	6	—
Fossil Fragments	12	9	—	<1	30	—	1	—	—	1	17	—

Sample locations:

Ped-SN1: Base of Osa Group at Punta San Pedrillo, (50 cm above unconformity)
WF-2: Osa Group al waterfall on Río Claro
CH-B-1: Lower member of Punta La Chancha formation al Punta La Chancha
CH-M-1: Middle member of Punta La Chancha formation at Punta La Chancha
SN-CAM: Osa Group from outcrop un the Río Camaronal al Sirena
PC-12: Osa Group from Punta Carbonera
CL-1: Upper member of Punta La Chancha formation near Punta Río Claro
CL-4: Upper member of Punta La Chancha formation near Punta Río Claro
MAD-SNB: Upper member of Punta La Chancha formation near Quebrada Hedionda
MCL: Upper member of Punta La Chancha formation from north side of the mouth of the Río Claro
PAN: Osa Group form Punta Panamá
PCH-13: Osa Group from Punta Chocuana

stone. In these rocks there is a good bedding fissility enhanced by thin sandy partings or laminae containing abundant tiny mica flakes. These more bedded lithologies give rise to flaggy outcrops and float. Graded sequences, pebbles and rip-up clasts of claystone-siltstone within the claystone-siltstone beds are quite common and are suggestive of turbidite deposition. Low-amplitude ripple marks, soft-sediment deformation structures such as load casts and flame structures are occasionally seen, and LEW (1983a) has recorded the presence of worm burrows in beds that appear to be partially bioturbated.

Vegetal matter is commonly found in all lithologies of the Osa Group and is locally very abundant. It includes leaves, stems, twigs and logs. Perfectly preserved individual leaves and thin seams, less than a centimetre thick, formed largely of leaves are found locally (eg. Río Agujas, 5264/2777) in claystone-silstone sequences. These show that the enclosing sediments must have been deposited in a fluvial or quiet lagoonal of gulf environment. Several logs of wood, measuring up to 25 cm in diameter and more than 3 m long have been found (eg. Río Piro, 5358/2620; Río Tigre at El Pergon, 5274/2758). They are well preserved and according to M. CRAWLEY & C.R. HILL of the British Museum (Natural History) are dicotyledonous angiosperm wood.

Coastal outcrops exposed at low tide between Playa Zapote (5412/2723) and Punta Tigre (5434/2689) comprise a gently dipping sequence of greenish-gray graywacke conglomerates, sandstones, siltstones and claystones. Load structures, low-amplitude ripple marks and rip-up clasts of claystone in claystone occur locally. White shell fragments and entire bivalve fossils are common, as are remnants of dark brown vegetal matter, including leaves and logs up to three metres long. Locally, upstanding mushroom-shaped structures varying from 5-70 cm in diameter rise up to about 50 cm above the overall bedding planes. A ghost stratification is preserved in the caps of these structures the stems of which have a hollow cylindrical pipe-like core. In some cases the caps are missing so that the structures are simply upstanding pillars. They are interpreted as representing relict tree trunks that were buried in sediment which subsequently hardened outwards from the trunk. The bedding plane surfaces near these structures are in places criss-crossed by anastomosing ridges that thicken and thin and appear to represent extra-indurated sediment around a network of roots that tended to follow the bedding fissility. In some cases these "fossil root structures" radiate out from the "fossil tree trunk structures". The tentative overall interpretation is that the structures represent "fossilized" trees growing in sediments deposited in a littoral environment.

Nodules of various shapes and sizes occur locally throughout the group. Most of them are simply extra-hard spheres, up to 10 cm in diameter, of the same composition as the enclosing claystone or siltstone. Sectioning shows that some have formed by nucleation around a shelly fragment.

FAUNA, AGE AND PALAEO-ENVIRONMENT

The Osa Group contains numerous macrofossils, especially bivalves, that are very abundant in some beds. Many of them are well preserved and appear to have undergone minimal transport and abrasion after death. No systematic collection was made, but ten samples containing about 28 individual fossils were submitted to the British Museum (Natural History) for study by C.P. NUTTALL (Appendix I). He deduced that the molluscs are all "fully marine" and probably lived in the intertidal to 20-40 m depth range, and almost certainly at depths less than 100 m. He noted some similarities in the collection, with fossils from the Pleistocene Armuelles Formation in Panamá, but noted that in the absence of absolute age determinations, it is difficult to distinguish between Pliocene and Pleistocene fauna, especially in tropical regions where climatic fluctuations were less severe than in middle and high latitudes. He considered that the fauna "could be Pliocene but is most probably Early Pleistocene".

The Osa Group also contains an abundant and varied assemblage of microfossils and some 28 samples from different localities in the Peninsula were studied by J.E. WHITTAKER at the British Museum (Natural History) (Appendix II).

On the basis of the ostracod and foraminiferal assemblages, the samples were divided into three groups considered to represent distinct depositional environments.

(a) Brackish sample: This contained the foraminiferal genera *Elphidium* and *Peneroplis* and ostracods (*Cyprideis* and *Perissocytheridea*) that live in lagoons, estuaries and other low-salinity environments.

(b) Nearshore samples: These contained *Elphidium* spp., and other foraminifera belonging to the *Ammonia beccarii* group; ostracods were represented by the genera *Loxoconcha* and *Xestoleberis*. This fauna is indicative of a very shallow water littoral or sublittoral environment, and would probably have been associated with marine algae.

(c) Shelf to upper slope (150-250 m) samples: These contain abundant benthonic and planktonic foraminifera. The **benthonic fauna** is diverse and made up chiefly of the genera: *Bolivina, Uvigerina, Cibicides, Pseudononion, Nonionella, Cibicorbis, Hanzawaia* and *Cancris*. From the palaeobathymetric viewpoint the species listed below are the most significant and characterise many of the samples. All are living today on the shelf in the Caribbean and Gulf of Panamá area.

Hanzawaia concentrica (CUSHMAN) (=*Cibicides nitidula* BANDY) 35-150 m;
Cancris panamensis (NATLAND 50-150 m, sometimes deeper;
Cibicorbis hitchockae (GALLOWAY & WISSLER) = *Cibicorbis herricki* HADLEY 100 -350 m;
Valvulineria inflata (D'ORBIGNY auctt.) 100-350 m;
Nonionella stella (CUSHMAN & MOYER) 25-180 m;
Amphistegina sp. 5-50 m;
Pseudononion (= *Florilus auctt.*) and *Elphidium* spp. 0-60 m;
Bolivina interjuncta (CUSHMAN) group 100-200 m.

Foraminifera found by WHITTAKER in the Osa Group samples therefore indicate deposition in different environments: (i) brackish low-salinity lagoons and estuaries, (ii) very shallow littoral to sublittoral seas, and (iii) outer shelf to upper slope down to about 250 m. In addition, field observations indicate the presence of fluvial sediments deposited in palaeo-valleys and piedmont fans.

Other evidence suggesting a shallow nearshore depositional environment includes: (i) the relatively small number of foraminiferal species found; (ii) the widespread occurrence of vegetation-rich layers and perfectly preserved leaves, twigs and logs; (iii) the presence of alluvial gold, especially the large nuggets; (iv) the presence of thin beds containing very numerous shallow-water molluscs and barnacles (shell beds), the fact that only shallow-water and no deep-water molluscs have been found, and that articulated well preserved molluscs are relatively common.

However, on the basis of idependent micropalaontological studies on different samples, INGLE & CHOU (in LEW, 1983a) concluded respectively that the sediments of the Osa Group (Punta La Chancha formation) were deposited at a minimum depth of between 200 to 500 m and 600 to 1200 m. LEW (1983a) considered the Punta La Chancha formation to be a typical turbidite fan sequence most likely deposited at a depth between 700 to 1200 m. INGLE'S interpretations of the palaeobathymetry was based on only three selected species - *Epistominella smithi* (STEWART & STEWART), *Bolivina interjuncta bicostata* (CUSHMAN) and *Uvigerina peregrina* (CUSHMAN) which are said to be common to abundant in the samples and are considered to be the deepest-dwelling species in the faunal assemblages. Although WHITTAKER (Appendix II) has argued that the presence of these three species does not necessarily indicate a depth of deposition greater than 250 m, there remains a possibility that a part of the Osa Group sequence was deposited at an appreciably greater depth as suggested by LEW (1983a). These apparently contradictory views can be reconciled by the depositional model proposed in the next chapter.

The distribution of planktonic foraminifera in the Osa sedimentary rocks is given in Table 2, whilst Fig. 3 shows the time ranges of the critical

Table 2
Distribution chart of the planktonic foraminifera in the Osa Group, Costa Rica

SPECIES	SAMPLES																	
	R2	R6	R8	R9	R11	R26	R27	R28	R57	R68	R150	R194	R217	R229	R244	R271	R272	R281
Globigerina bulloides d' Orbigny	x	x		x			x	x	x				x	x	x		x	x
Globigerinella aequilateralis (Brady)	x			x			x			x								x
Globigerinoides bolliiblow										x								
Globigerinoides extremus Bolli																		
Globigerinoides ruber (d' Orbigny)	x			x														
Globigerinoides ruber (d" Orbigny)	x	x	x	x		x	x					x	x	x		x	x	x
Globigerinoides sacculifer (Brady)	x	x			x		x				x		x	x			x	
Globigerinoides triloba (Reuss)	x		x	x	x		x	x		x	x	x		x	x	x	x	
Globorotalia limbata/ miocenica group	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
Globorotalia menardii (Parker, Jones & Brady)	x	x	x	x	x						x	x			x	x	x	
Globorotoalia scitula (Brady)					x							x					x	
Globorotalia tumida (Brady) s.s.													x					
Globorotaloides hexagona (Natland)																	x	x
Neogloboquadrina acostaensis (Blow)	x		x					x		x			x				x	x
Neogloboquadrina dutertrei (d' Orbigny)													?			x	?	
Neogloboquadrina humerosa (Takayani & Saito)	x	x	x	x	x	x	x	x	x		x	x	x	x		x	x	x
Neogloboquadrina pachyderma (Enrenberg)												x						x
Orbulina spp.	x				x	x		x				x					x	x
Pulleniatina obliquiloculata (Parker & Jones)							x											
Pulleniatina praecursor Banner & Blow																	x	
Sphaeroidinella dehiscens (Parker & Jones)					x													
Turborotalita humilis (Brady)		x										x						
Torborotalita quinqueloba (Natland)	x	x	x									x			x	x	x	

See Appendiz II for the location of all samples

planktonic species. From the evidence presented (Appendix II) and from the overlapping ranges shown in Fig. 3, it is deduced that the Osa Group must be Mid- to Upper Pliocene in age and fall between Zones N19 (later part) and N21, equivalent to an absolute age of 3.7-2.0 Ma. From an independant micropalaeontological study of different samples, INGLE (in LEW, 1983a) determined that these sedimentary rocks have a Mid-Pliocene age of between 3.7-3.0 Ma.

STRUCTURES AND TECTONIC-DEPOSITIONAL MODEL

The Panamá-Coiba Fracture Zone in the Panamá Basin is approximately 100 km wide and consists of three principal N-trending right-lateral transform faults (CASE & HOLCOMBE, 1980) which if extrapolated north-northwestwards via three prominent submarine canyons in the continental slope (Fig. 4) merge into a braided system of curved roughly coast-parallel wrench faults documented by recent geological mapping in the Osa Peninsula and Golfito region (BERRANGE, 1988; BARRIT & BERRANGE, 1987; BERRANGE & THORPE, 1988); seismic records (WOODWARD-CLYDE CONSULTANTS, 1977) and earthquake focal plane solutions (MOLNAR & SYKES, 1969; DEAN & DRAKE, 1978; MORALES & MONTERO, 1984; MORALES, 1985).

It is suggested that the present-day configuration of the coastline (Fig. 2 & 4) and present-day landforms and bathymetry of the region are governed by a system of dextral strike-slip faults. Golfo Dulce and maybe Golfo de Chiriquí are thought to be modern pull-apart basins, whereas the adjacent Osa Peninsula, Fila Golfito and the Burica Peninsula are horsts with a gentle (2º-5º) NE tilt. Instead of becoming progressively shallower inwards as one would expect (cf. Golfo de Nicoya), Golfo Dulce deepens from about 50 m at

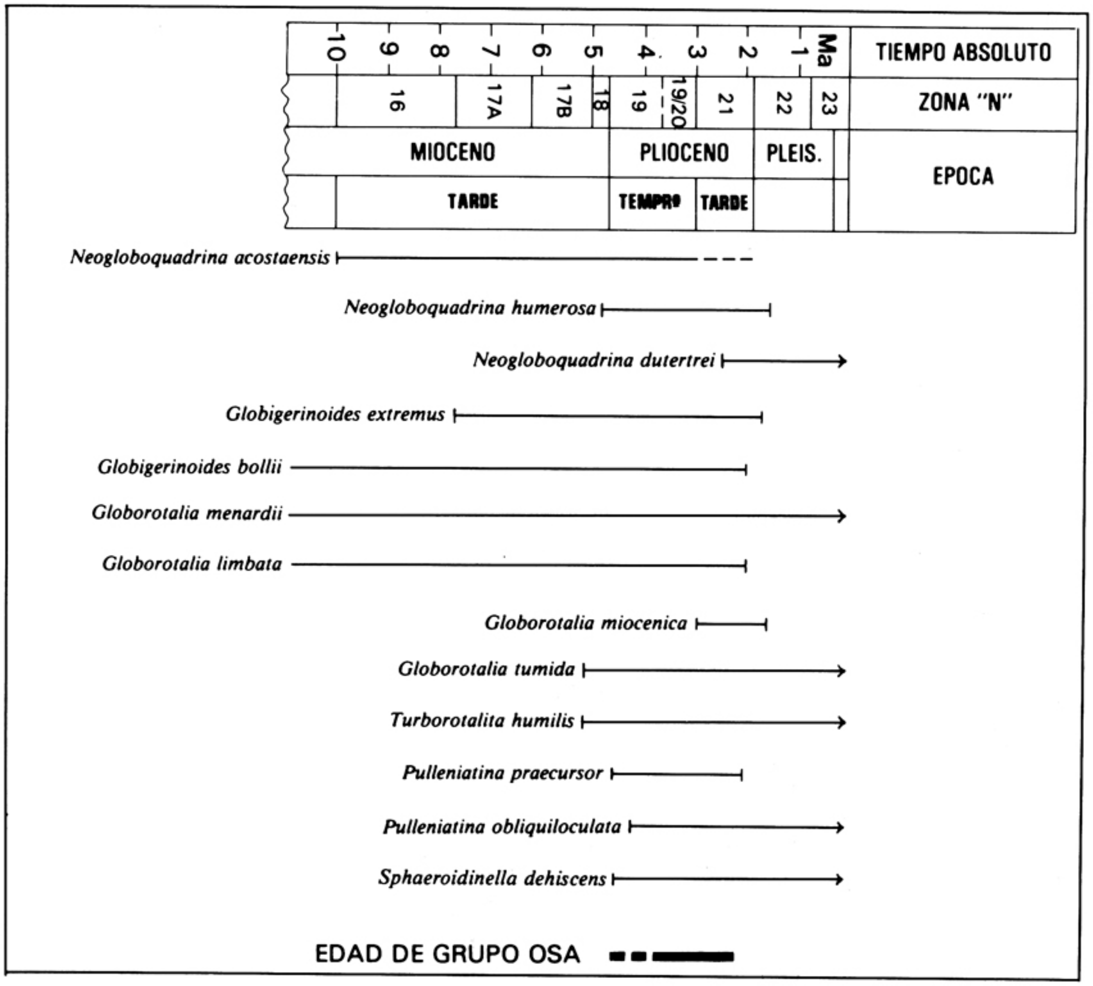


Fig. 3: Age of the Osa Group based on the ranges of critical planktonic foraminifera. Time scale and zonation taken from KENNETT & SRINIVASEN (1983, text figure 3).

its mouth to more than 200 m at its head. This suggests that it is a pull-apart basin. The fault-bounded landmass forming the Burica Peninsula fits neatly into the Golfo Dulce (Fig. 4). It is tempting to speculate that when the Osa Group was deposited (3.7-2 Ma ago) it occupied this position, and has since moved southeastwards relative to the Osa Peninsula. If separation began say 3 Ma ago, average movement at the rate of 1.5 cm/year would have brought the Burica Peninsula to its present position. LONSDALE & KLITGORD (1978) have shown that the Coiba Ridge is an uplifted, eastward-tilted slab of oceanic crust, and as such quite different to the other ridges in the eastern Panamá Basin. It is suggested here that, as in the case of the Osa and the Burica Penísula, the tectonic development of this ridge was essentially controlled by dextral strike-slip movement on a braided system of NW-trending first-order wrench faults with second- and third-order wrenches oblique to these (cf. MOODY & HILL, 1956). The tectonics are analagous to those described by CROWELL (1974a, 1974b) for development of the Gulf of California and the Baja California peninsula. The coast-parallel extensions of the Panamá Fracture

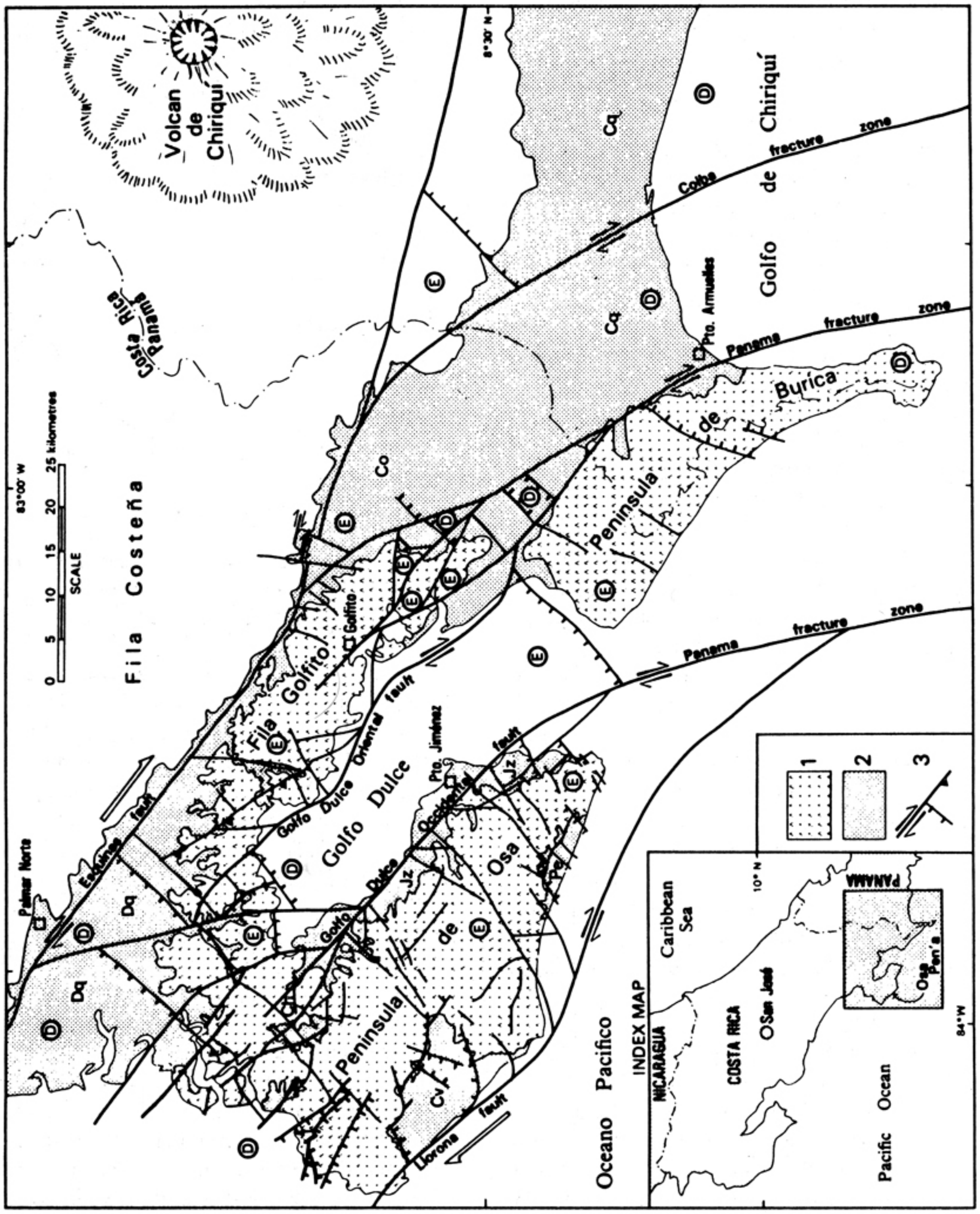


Fig. 4: Quaternary fault-bounded pull-apart and tipped-wedge basins and highlands in southern Costa Rica and western Panamá. - 1.= highland formed by exposed Mesozoic-Cenozoic rock units; 2.= lowland basin covered by Quaternary alluvium: Ch = Chocuaco basin. Co= Coto Colorado lowlands, Cq = Chiriquí lowlands, Cv = Corcovado lowlands, Dq = Diquis lowlands, Jz = Puerto Jiménez-Rincón lowlands, Pe = Pejeperro lowlands. 3.= fault or fracture zone: relative movement indicated by arrows, dip direction by solid triangle, down-throw block by ticks; E = relatively elevated segment of fault block; D = depressed segment of fault block.

Zone meet the Costa Rica Fracture Zone and the Middle America Subduction Zone at a triple junction southeast of the Nicoya Peninsula (Fig. 1).

By analogy with the present-day landforms and tectonics it is suggested that the Pliocene sediments of the Osa Group were locally derived from a nearby Nicoya Complex terrain of considerable relief forming forested islands and/or coastal ranges, and were deposited in intermittently subsiding pull-apart and/or tipped-wedge palaeobasins separated by tilted highlands. In the Osa Peninsula two palaeo-basins containing up to 800 m of sediment and separated by a buried ridge have been recognized by gravity modelling (BARRIT & BERRANGE, 1987). East of the Burica Peninsula the Coto Colorado-Chiriquí basin contains 2500 m of sediment (SPRECHMANN, 1984).

Numerous faults, including growth faults and dextral wrench faults, have been mapped (Fig. 2) cutting the Osa Group and the younger sediments of the Puerto Jiménez Group. The main trends are either NW-SE or NE-SW, although it is probable that the present-day fault pattern is radically different to that which prevailed in the Pliocene, especially as the Cocos Ridge is thought to have collided with the plate margin at around 1 Ma ago, thereby plugging the trench and promoting strong isostatic uplift (VAN ANDEL *et al.*, 1971; LONSDALE & KLITGORD, 1978; DE BOER, 1979) and modifying the direction of the stress axes.

LEW (1983a) has noted that channels in the Osa Group (Punta La Chancha formation) have SSE to SSW trends. He also recorded the presence of soft-sediment slump-folds with 15-20 cm amplitudes in three outcrops along the Río Camaronal near Sirena and at Punta Río Claro. When plotted on an equal-area stereographic projection (Fig. 5), the axes of these folds fall on a great circle which may represent the ENE-trending slope on which slumping took place. LEW interprets these structures as indicating transport of turbidites to the SSE and deposition in a fan on the ENE-trending flank of the basin. Westerly palaeocurrent directions indicated by cross-stratification are interpreted as having formed by current flowing parallel to the slope and perpendicular to the main distributary channels, thereby giving rise to "contourites".

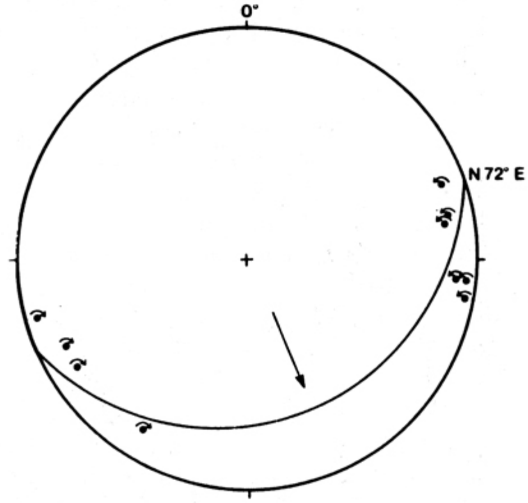


Fig. 5: Equal-area hemisphere projection of slump fold axes measured in outcrops along Río Camaronal and at Punta Río Claro. Arrows show approximate transport direction indicated by these folds (from LEW, 1983a).

Bedding measured in the field and on aerial photographs (see BERRANGE, 1988) is generally horizontal or gently dipping (less than 25º) whilst steeper dips can in many instances be shown to be due to faulting and/or tilting. For example, along the left-hand headwaters of Río Pejeperro (5299/2686) consistent dips of 8º-10º to the NE are locally turned on end where a major NNE-trending fault cuts the succession and gives rise to vertical bedding. Similarey, along the Río Riyito (5260/2793) horizontal or gentle NE-dipping bedding is locally upturned and dips 76º to the W at the intersection of NNE-, NW- and WSW-trending faults. The direction of dip varies from one sector to another but is relatively consistent within a given sector of fault block. There is generally a good correspondance between regional bedding attitudes measured in the field and those determined photogeologically. In the central part of the Osa mountains, around the headwaters of Río Pavo, Sirena, Rincón, Conte, Barrigones, Agujas and Tigre, bedding dips consistently northwards; in this sector strike-subsequent streams have cut EW-trending valleys which have relatively steep south-facing scarp slopes and more gentle north-facing dip slopes. To the

NW of Sirena, two NE-trending splays off the offshore LLorona Fault define a block composed of elongate NW-trending parallel ridges that are interpreted photogeologically as a series of cuestas formed on SW-dipping Osa Group sedimentary rocks. Adjacent to this fault block, in the Río Claro-Punta Salsipuedes sector, dips are consistently to the NNW. Around the confluence of Río Riyito and Agujas, bedding dips gently NE, but along Quebrada Gallardo it dips to the NW.

In the SE of the peninsula, regional photogeologically determined opposing dips appear to define an open anticline whose axial trace trends WNW and roughly corresponds to the water divide. It is not known to what extent this is an apparent anticline formed by primary sedimentary dips off an original basement topographic high; or a tectonic fold formed in a fault-bounded block by stresses related to a system of dextral NW-trending major wrench faults. However, it corresponds roughly to gentle asymmetric folds with EW-trending subhorizontal axes and wavelengths of 3-5 m recorded by LEW (1983a) in the Punta La Chancha sector. The major anticline mapped by IVOSEVIC (1979) as trending NE from Punta La Chancha is illusory and not substantiated by available measurements of bedding attitude.

If the pull-apart model is valid, it can be expected that the oldest sediments of the Osa Group will be those nearest basin margins and that sucessively younger stratigraphic units will lap farther and farther basinward leaving behind a record of minor unconformities. This model also accounts for many of the main features of the Osa Group, namely, the local Nicoya Complex provenance of the sediments, including the gold which is richest in the fluvial facies and apparently absent in the deep-water marine facies; the admixture of benthonic microfossils is characteristic of different bathymetric intervals, and the rapid sedimentary facies changes. Figure 6 is a schematic representation of the facies relationships in the Osa Group and illustrates how a broad range of sedimentary facies can comingle and coexist. The model illustrates abrupt vertical and lateral transitions from fluvial (gold-bearing) facies into estuarine-gulf, shallow shelf, slope and basin facies.

Alluvial gold occurs mainly in rudaceous and arenaceous facies in the lower units of the Osa Group, but mineable concentrations are largely confined to the basal boulder-conglomerates deposited in Pliocene river valleys, piedmont fans and deltas (IVOSEVIC, 1979; BERRANGE, 1987, in press). A modification of the so-called "basin-edge concept", proposed by BROCK & PRETORIUS (1964) to explain the Precambrian Witwatersrand gold deposits, may be applicable to the placers of the Osa Group. The Osa gold that is locally derived from the Nicoya Complex (BERRANGE, in press) would have been initially concentrated in eluvial-coleuvial breccia-conglomerates and subsequently in alluvial conglomerates along the floodplains of the main rivers, and in alluvial, fan-delta and beach deposits where rivers entered sheltered waters (lakes, bays and gulfs) at the edge of fault-bounded pull-apart basins. Intermittent uplift of the highland source-areas and the early alluvial deposits would have resulted in repeated downcutting by the streams, thus reworking and redistributing the gold.

CONCLUSIONS

1. The Osa Group is defined as a Mid- to Upper Pliocene sequence of graywacke-type sedimentary rocks, up to at least 800 m thick, lying unconformably on the Nicoya Complex basement forming the Osa Peninsula. The sediments were derived from a nearby Nicoya Complex terrain of considerable relief that formed forested islands and/or coastal ranges, and were probably deposited in intermittently subsiding pull-apart basins. The group is characterized by abrupt vertical and lateral facies changes: fluvial, estuarine-gulf, shallow shelf, slope and marine basin facies are all represented.

2. The Osa Group is the time-stratigraphic equivalent of the (auriferous) Charco Azul Formation that crops out on the Burica Peninsula.

3. A tentative model based on strike-slip faulting is proposed to explain the tectonic-depositional features of the Osa Group, and the present-day landforms and bathymetry of the region. It is suggested that the Golfo Dulce is a pull-apart basin and that the Burica Peninsula has been pulled out of it.

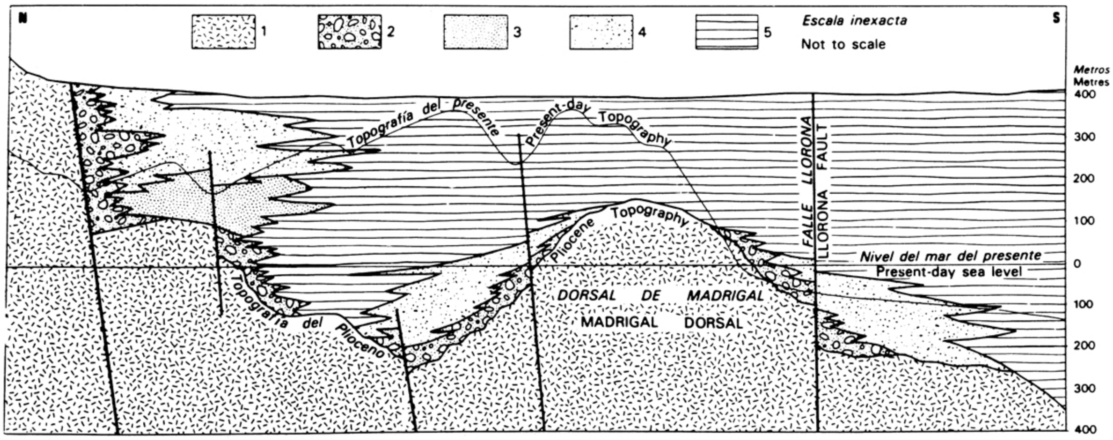


Fig. 6: Schematic N-S cross-sectional representation of facies relationships of Osa Group sediments in a Pliocene pull-apart basin, and showing vertical and lateral transition of fluvial facies into estuarine-gulf, shallow shelf and deep shelf-basin facies. - 1.= Nicoya Complex basement; 2.= fluvial facies (gold-producing); 3.= estuarine-gulf facies; 4.= shallow shelf facies; 5.= deep shelf-basin facies (including graded turbidites and contourites).

4. The Osa Group contains alluvial gold locally derived from the underlying Nicoya Complex. The gold is mainly concentrated in basal conglomerates and sandstones, representing the fluvial facies and possibly also in the estuarine-gulf facies. There are economic concentrations of gold in the basal sediments which are mined in a haphazard manner by means of blind tunnelling and excavation-caving of the hillsides in the hope of hitting a rich paystreak.

5. The Osa Group is considered to have a considerable potential for gold mining, and when the Quaternary alluvials have been worked out, the long-term future of this goldfield probably rests with exploitation of these buried palaeo-placer deposits.

6. All studies made to date (including those by the author) of the geology and mineral potential of the Osa Peninsula are of a reconnaissance nature. Detailed geological and geophysical surveys are recommended in order to provide a firm basis for underground mining of the Osa Group. These should include:

(a) Geological mapping at a scale of 1:25,000 including the measurement of numerous sections and construction of graphic logs.

(b) This should be combined with a programme of sampling and analysis for gold in order to obtain information regarding gold source areas in the basement, and to help in the recognition of gold-bearing facies.

(c) Special attention should be given to mapping the subsurface unconformity between the Nicoya Complex and the Osa Group. The application of geophysical techniques to this problem should be investigated.

ACKNOWLEDGEMENTS

This study formed part of a research and development project, which investigated the geology and gold mineralization of the Osa Peninsula and environs, sponsored by the British Government's Overseas Development Administration (Foreign and Commonwealth Office) and by the Costa Rican Government's state mining enterprise - Minera Nacional S.A. (MINASA). The support of these two organizations is gratefully acknowledged. I would like to thank Dr. C. G. Adams, Dr. J. E. Wittaker, C.P. Nuttall, M. Crawley & C. R. Hill, all of the British Museum (Natural History), for undertaking the palaeontological determinations; and S.J. Mathers of the British Geological Survey, who following a visit with the author to the Osa Peninsula read the manuscript and made a number of very useful suggestions for its improvement. This paper is published by permission of the Director of the British Geological Survey (Natural Environment Research Council).

REFERENCES

ACUÑA, J., 1983: Informe de labores de producción del 1 de Enero al 31 de Marzo 1983. Minera Dulce S.A. Expediente de exploración Nº 698, Nº 702, Río Tigre (unpublished report).

BARRITT, S. & BERRANGE, J.P., 1987: An interpretation of a gravity survey of the Osa Peninsula and environs, southern Costa Rica. - Overseas Geol. and Mineral Resources, Nº *64*, 18 pags.

BAUMGARTNER, P.O.; MORA, C.R.; BUTTERLIN, J.S.; GLACON, G.; AZEMA, J. & BOURGOIS, J., 1984: Sedimentación y paleogeografía del Cretácico y Cenozoico del litoral pacífico de Costa Rica. - Rev. geol. Am. Central, *1*: 57-136.

BERRANGE, J.P. (in press): Origin of gold from the Golfo Dulce Placer Province, southern Costa Rica. - Proceedings, Symposium Energy & Mineral Resources, San José, March 1989 (Circum Pacific Council).

BERRANGE, J.P., 1988: Mapa geológico de la península de Osa, escala 1:100,000. - Inst. Geogr. Nac., San José.

BERRANGE, J.P., 1987: Gold in Costa Rica,. - Mining Magazine, May 1987: 402-407.

BERRANGE, J.P.; BRADLEY, D.R. & SNELLING, N.J., 1989: K:Ar age dating of the ophiolitic Nicoya Complex of the Osa Peninsula, southern Costa Rica. - Jour. South Am. Earth Sci., 2(1),49-59.

BERRANGE, J.P. & THORPE, R.S., 1988: The geology, geochemistry and emplacement of the Cretaceous/Tertiary ophiolitic Nicoya Complex of the Osa Peninsula, southern Costa Rica. - Tectonophysics, *147*: 193-220.

BOURGOIS, J., AZEMA, J., BAUMGARTNER, P.O., TOURNON, J., DESMET, A. & AUBOUIN, J., 1984: The geologic history of the Caribbean-Cocos plate boundary with special reference to the Nicoya ophiolite complex (Costa Rica) and D.S.D.P. results (Legs 67 and 84 off Guatemala): A synthesis. - Tectonophysics, 108: 1-32.

BROCK, B.B. & PRETORIUS, D.A., 1964: Rand basin sedimentation and tectonics. - *IN*: HAUGHTON, S.H. (ed.): The Geology of Some Ore Deposits in Southern Africa. Geol. Soc. South Africa, 1: 549-600.

CASE, J.E. & HOLCOMBE, T.L., 1980: Geologic-tectonic Map of the Caribbean Region, scale 1:2,500,000, 3 sheets. - U.S. Geol. Surv. Miscell. Investig. Series Map *I-1100*.

CROWELL, J.C., 1974a: Sedimentation along the San Andreas Fault, California. - IN: DOTT, R.H. Jr & SHAVER, R.H. (eds.) Spec. Publ. Soc. Econ. Paleont. Miner., *19*: 292-303.

CROWELL, J.C., 1974b: Origin of late Cenozoic basins in southern California. - IN: DICKINSON, W.R. (ed.). Spec. Publ. Soc. Econ. Paleont. Miner., *22*: 190-204.

DEAN, B.W. & DRAKE, C. L., 1978: Focal mechanism solutions and the tectonics of the Middle America Arc. - J. Geol., *86*: 111-128.

DE BOER, J., 1979: The outer arc of the Costa Rican orogen (oceanic basement complexes of the Nicoya and Santa Elena Peninsulas). - Tectonophysics, *56*: 221-259.

DENGO, G., 1985: Mid America: Tectonic setting for the Pacific margin from southern Mexico to northwestern Colombia. - IN: NAIRN, A.E.M.; STEHLI, F.G. & UYEDA, S. (eds.), The Ocean Basins and Margins, Vol. 7A; The Pacific Ocean, Plenum Press, New York, pag. 123-180.

DGMP, 1982: Mapa geológico de Costa Rica, Edición preliminar, escala 1:200,000, Hoja Golfito, N º CR2CM-9. - Ministério de Industria, Energía y Minas, Dirección de Geología, Minas y Petróleo, San José.

HOFFSTETTER, R., 1960: Lexique Stratigraphique International. Amérique Latine, Fascicule IIa, Amérique Centrale. Centre National de la Recherche Scientifique, Paris, 366 pags.

IVOSEVIC, S.W., 1979: Geology and mineral deposits of Costa Rica's south-central Osa Peninsula placer gold district. - Amer. Inst. Mining Metall. & Petrol. Eng., Trans., *266*: 1876-1882.

KENNET, J.P. & SRINIVASAN, M.S., 1983: Neogene Planktonic Foraminifera, a Phylogenetic Atlas. - Hutchison Ross Publishing Co., Stroudsberg, 265 págs.

LEW, L.R., 1983a: The geology of the Osa Peninsula, Costa Rica: observations and speculations about the evolution of part of the outer arc of the Southern Central American Orogen. -128 págs., Pennsylvania State University, Dept. of Geosciences, (unpblished M.Sc. thesis).

LEW, L.R., 1983b: The geology of the Osa Peninsula, Costa Rica: Evolution of the outer arc of the Southern Central American Orogen. - Geol. Soc. Amer., Abstract Prog. *15 (6)*: 627.

LONSDALE, P. & KLITGORD, K.D., 1978: Structure and tectonic history of the eastern Panamá Basin. - Geol. Soc. Amer. Bull., *89*: 981-999.

MADRIGAL, R., 1982: Geología y fotogeología de la Península de Osa, Costa Rica. - IN: Corporación Costarricense de Desarrollo (CODESA), Proyecto Oro Aluvional, Informe Técnico de Labores 1978-82, (unpublished report).

MOLNAR, P. & SYKES, L.R., 1969: Tectonics of the Caribbean and middle America regions from focal mechanisms and seismicity. - Geol. Soc. Amer. Bull., *80*: 1639-1684.

MOODY, J.D. & HILL, M.J., 1956: Wrench-fault tectonics. - Geol. Soc. Amer. Bull., *67*: 1207-1246.

MORALES, L.D., 1985: Las zonas sísmicas de Costa Rica y alrededores. - Rev. geol. Amer. Central., *3*: 69-101.

MORALES, L.D. & MONTERO, W., 1984: Los temblores sentidos en Costa Rica durante 1973-1983, y su relación con la sismicidad del país. - Rev. geol. Amer. Central., *1*: 29-56.

OLSSON, A.A., 1942a: Tertiary deposits of northwestern South America & Panamá. - Eighth Am. Sci. Congr., Proc. *4*: 231-287.

OLSSON, A.A., 1942b: Tertiary & Quaternary Fossils from the Burica Peninsula of Panamá and Costa Rica. - Bull. Am. Paleont., *27* (106).

SEGURA, V.G., 1981: Exploración de los Ríos Conte y Rincón. - IN: Corporación Costarricense de Desarrollo (CODESA), Proyecto Oro aluvional, Informe Técnico de Labores 1978-82, (unpublished report).

SPRECHMANN, P. (ed.), 1984: Manual de Geología de Costa Rica, Vol. I: Estratigrafía. - Ed. Universidad de Costa Rica, San José, 320 pags.

TERRY, R.A., 1941: Notes on submarine valleys off the Panamanian coast. - Geogr. Rev., *31*: 377-384.

TERRY, R.A., 1956: A geological reconnaissance of Panamá. - Calif. Acad. Sci., Occas. Paper, *23*, 91 pags.

VAN ANDEL, T.H.; HEATH, G.R.; MALFAIT, B.T.; HEINRICHS, D.F. & EWING, J.I., 1971: Tectonics of the Panamá Basin, eastern equatorial Pacific. - Geol. Soc. Amer. Bull., *82*: 1489-1508.

WOODWARD-CLYDE CONSULTANTS, 1977: Geologic and seismologic investigations for the Boruca dam site, Costa Rica. - Project Nº 14417A, (unpublished report).

APPENDIX I

REPORT ON NEOGENE MOLLUSCS FROM THE OSA GROUP OF COSTA RICA, BRITISH MUSEUM (NATURAL HISTORY), DEPARTMENT OF PALAEONTOLOGY REPORT Nº BMNH OGS 1984/4 & 1985/4

C.P. Nuttall, 8 November 1985

Sample R 27 (Golfo Dulce sheet; Quebrada Gallardo near mouth)
2 valves Anadara sp. cf. concinna (SOWERBY, 1833).
1 valve juvenile *Chione (Lirophora)* aff. *subrugosa* (WOOD, 1828) also in R 51 and R 52
2 fragments *Turritella nodulosa* KING & BRODERIP (1832).
1 *Cosmioconcha* cf. *modesta* (POWYS, 1835).

Sample R 51 (Golfo Dulce sheet; Río Riyito)
Chione (Anomalocardia) aff. *subrugosa* (WOOD, 1828) (also in R 52 and R 27).

Sample R 52 (Golfo Dulce sheet; Río Riyito)
Same as R 51.

Sample R 55 (Golfo Dulce sheet; Río Riyito)
1 small Lucinid bivalve (marine) with worn surface. Not determinable.

Sample R 58 (Golfo Dulce sheet; Río Riyito)
1 *Conus* sp. indet. (same as in R 151)

Sample R 67 (Carate sheet; Playa Zapote)
1 valve *Argopecten circularis* (SOWERBY, 1835). Faint colour patterning persists (also in R 151).

Sample R 68 (Carate sheet; Playa Zapote)
1 *Soleinosteira* cf. *pallida* (BRODERIP & SOWERBY, 1829).

Sample R 150 (Golfo Dulce sheet; Río Barrigones headwaters)
1 *Costoanachis* sp.

Sample R 151 (Golfo Dulce sheet; Río Barrigones headwaters)
2 valves *Argopecten circularis* (SOWERBY, 1835) with strong colour patterning. (Also in R 67).
1 *Eucrasatella (Hybolophus)* sp. (damaged)
1 indet. heterodont bivalve.
1 *Solenosteira* (=*Hanetia* of authors) cf. *pallida* (BRODERIP & SOWERBY, 1829).
5 *Polinices uber* (VALENCIENNES, 1832).
2 *Oliva polpasta* DULCOS (1833).
1 *Cancellaria* sp. cf. *ovata* SOWERBY (1832).
1 *Conus* sp. indet. (same as in R 58).

NOTES ON SPECIES

The genus *Costoanachis* of the Pyrenidae is represented by about twenty-five species living in the region. They range from intertidal down to shallow shelf. Depth ranges are not available for many species, but few seem to be found living in sea deeper than 30 m.

Anadara concinna (SOWERBY, 1835) is a living Pacific species with 30 ribs. Our specimen has about thirty four and the Miocene species *A. henekeni* (MAURY) has a similar number. In shape, however, our shell is much more similar to *A. concinna* than to *A. henekeni*. *A. concinna* is recorded by OLSSON (1942 : 9) from the Armuelles Formation of the Burica Peninsula.

Argopecten circularis (SOWERBY, 1835) is the most common living West coast species of scallop. it has been recorded (but not figured) from the Pliocene Jama and Canoa Formations of Ecuador (PILSBRY & OLSSON, 1941: 55) under the name *Pecten (Plagictenium) ventricosus* SOWERBY. These records from Ecuador can be confirmed as being of the same species by BMNH OGS collections from both of these formations and also from the Pleistocene Tablazo. *P. ventricosus* was also listed from the Armuelles Formation for neighbouring Panama (OLSSON, 1942: 9). Slightly different scallops were described as belonging extinct subspecies of *A. circularis* from the Miocene of Venezuela by HODSON (1927): 25-27).

Eucrossatella (Hybolophus) sp. This specimen is badly damaged but could belong to the living Pacific coast type species of *Hypolophus*, *E (H.) gibbosa* (SOWERBY, 1832). Similar species are known from the Miocene onwards (Woodring, 1982: 633).

Chione (Anomalocardia) aff. *subrugosa* (WOOD, 1828). This species is often attributed to SOWERBY, and similar species are placed by many authors in *Lirophora*. Our specimen has been compared with many Recent shells (BMZD) from Mazatlan. The sculpture of our fossils falls within the range of variation of this species but all of the Recent specimens have more pointed, less truncated posteriors. The specimens figured by JUNG (1969: 381, pl. 30, figs. 4-9) from the early Pliocene of Trinidad as *Chione (Lirophora) sanctadavidis* MAURY are similar expect that their concentric ribs are more lamellate and the shell is both smaller and more elongate. JUNG'S determination cannot be substantiated as MAURY'S type illustration (1925: 161, pl. 28, fig. 12) is of a poorly preserved shell.

Our species may also be compared with *A. ebergenyii* BÖSE (1906: 28, pl. 2, figs. 4-17) from the supposedly Pliocene of Tuxtepec, Oaxaca, Mexico (18º2 'N; 96º13' W, and therefore presumably Caribbean basin). This species resembles ours in outline and has a similarly truncated posterior but it has less coarse concentric ribbing which tends to be more lamellate on its posterior area.

Turritella nodulosa KING & BRODERIP 1832 is a living Pacific species. Miocene faunas of the region (OLSSON, 1922; WOODRING, 1957) tend to be characterized by the occurence of the rather similar *T. gatunensis* CONRAD.

Polinices uber (VALENCIENNES, 1832) is a living Pacifc species and was a recorded fossil (OLSSON, 1942: 11) from the Armuelles Formation. It is very similar to fossils occurring widely in the Panamic-Pacific Province from the Miocene onwards and often identified as belonging to the living Caribbean *P. brunneus* (LINK).

Solenosteira (=*Hanetia* of authors) cf. *pallida* (BRODERIP & SOWERBY, 1829). This broken specimen has a very carinate whorl profile of a type occurring from the late Miocene Gatun Formation (*H. dalli protera*, see WOODRING, 1964: 258, pl. 47, figs. 11, 14) to the present day. The living Pacific *S. pallida* (BRODERIP and SOWERBY) is very similar to our specimen.

Cosmioconcha modesta (POWYS, 1835) was listed by OLSSON (1942:11) from the Armuelles Formation. It is widespread, living at low tide on mud flats among rocks (KEEN, 1971: 587). The determination of our specimens is not definite.

Oliva polpasta DUCLOS 1833 is living Pacific species occuring in the Pliocene Canoa Formation of Ecuador (PILSBRY & OLSSON, 1941: 26) and BMPD OGS collections. It is also listed, as *'pol y pasta'*, from the Armuelles Formation (OLSSON, 1941: 11). *Oliva* may be found at low tide.

Cancellaria obesa SOWERBY 1832 (=*C. ovata* SOWERBY, 1832) is a living species.

occuring mostly offshore in depths to 90 m (KEEN, 1971: 647-9). It occurs in the Pliocene Canoa Formation of Ecuador (BMPD OGS collections).

DISCUSSION

The *Chione (Anomalocardia)*, *Argopecten* and *Conus* occur in more than one of these small samples. This suggests that the samples are of broadly similar age and facies. Species present in the collection tend to be either referable to, or comparable with, species living off the west American coasts (KEEN, 1971) at the present day rather than with extinct species described from the prolific Neogene faunas of the region (Costa Rica, OLSSON, 1922; Panama, Gatun Formation, WOODRING, 1957-1982; Venezuela, JUNG, 1965; Trinidad, JUNG, 1969; Ecuador, PILSBRY & OLSSON, 1941, OLSSON, 1964). If the present collection was as old as Miocene, it would have been expected to contain a high proportion of extinct analogues of the living species present.

FACIES

All the molluscs are fully marine. The depth ranges of living analogues suggest that the water was comparatively shallow possibly in the 20-40 metre depth range, and almost certainly under 100 metres. Both *Cosmioconcha* and *Oliva* may be intertidal but have presumably been swept into deeper water.

AGE

The age cannot be fixed accuratley with such small samples. The Panamic-Pacific Neogene Province comprised both the Caribbean and the Pacific coast as far south as Ecuador and even northern Peru. This province was broken up by the formation of the Panama land bridge at some, as yet, unspecified post-Miocene date. This resulted in a gradual but not profound divergence of the Pacific (KEEN, 1971) and Caribbean (WARMKE & ABBOTT, 1961) molluscan faunas with the latter becoming relatively impoverished.

Our fauna, taken as a whole, is slightly different to that of the Pacific at the present day and bears no particular resemblance to the living Caribbean fauna. On the other hand it shows a marked lack of species typical of the late Miocene Panamic-Pacific faunas such as that of the Gatun Formation of Panama and its Costa Rican equivalent (OLSSON, 1922) both of which are probably of N16-N18 in age (WHITTAKER & HODGKINSON, 1977). This indicates that our fauna is post-Miocene. In the absence of absolute age determinations, it is difficult to distinguish between the Pliocene and Pleistocene, especially in tropical regions where the molluscan fauna is unaffected by the Pleistocene cooling. Our fauna is most probably early Pleistocene but could be Pliocene. It is unlikely to be late Pleistocene in spite of traces of colour patterning.

SUMMARY

The small molluscan faunules are consistent with an early Pleistocene or less likely Pliocene age. They are fully marine and indicate comparatively shallow water, probably 20-40 m in depth. Several living species also occur in the Pleistocene Armuelles Formation of the Burica Peninsula, Panamá, from which OLSSON (1942) listed a fauna of about 120 species.

REFERENCES

(*indicate useful but not quoted herein).

BOSE, E., 1906: Sobre algunas faunas Terciarias de México. - Bol. Inst. geol. México, *22*: 96, 12 pls.

*CORYELL, H.N. & MOSSMAN, R.W., 1942: Foraminifera from the Charco Azul Formation, Pliocene, of Panama. - J. Paleont., *16*: 233-246, pl. 36. (Discusses age of Armuelles Formn.).

*HASS, O., 1942: Miocene molluscs from Costa Rica. - J. Paleont., *16*: 307-316, 7 text figs.

HODSON, F. & H.K., 1927: Some Venezuelan and Caribbean molluscs. - Bull. Amer. Paleont., *13* (49) viii + 160 pags., 40 pls.

JUNG, P., 1965: Miocene Mollusca from the Paraguana peninsula, Venezuela. - Bull. Amer. Paleont. *49 (223)*: 389-651, pls. 50-79.

JUNG, P., 1969: Miocene and Pliocene molluscs from Trinidad. - Bull. Amer. Paleont., *55 (247)*: 293-657, pls. 13-60.

KEEN, MYRA, 1971: Sea Shells of Tropical West America, Ed. 2. - Stanford Univ. Press, x + 1064 págs., 22 colour plates, 3292 figs., 8 text figures, 6 maps.

MAURY, CARLOTTA J., 1917: Santo Domingo type Sections and Fossils. - Bull. Amer. Paleont., *5 (29)*, 251 pags., 39 pls.

PILSBRY, H.A. & OLSSON, A.A., 1941: A Pliocene fauna from Western Ecuador. -Proc. Acad. nat. Sci. Philad., *93*: 79 págs., 19 pls., 2 photographic figs.

*OLSSON, A.A., 1932: Contributions to the Tertiary paleontology of Northern Peru: part 5, the Peruvian Miocene. - Bull. Amer. Paleont., *19 (68)*, 264 pags., 24 pls.

OLSSON, A.A., 1942: Tertiary and Quaternary fossils from the Burica Peninsula of Panama and Costa Rica. - Bull. Amer. Paleont., *27 (105)*, 106 pags., 12 pls.

*OLSSON, A.A., 1964: Neogene molluscs from northwestern Ecuador. - Pal. Res. Inst., Ithaca NY. 256 pags., 38 pls.

WARME, G.L. & ABBOT, R.T., 1961: Caribbean Sea Shells. - x + 346 págs., 44 pls., 19 maps, 34 text figs., Narberth, Penn.

WHITTAKER, J.E. & HODGKINSON, R.L., 1977: Unpublished report on foraminifera extracted from samples from Gatun Formation extracted from molluscs in BMPD collections and from others submitted by W.P. Woodring.

*WOODRING, W.P., 1954: Caribbean land and sea. - Bull. Geol. Soc. Amer., *65*: 719-732, 3 figs., 1 pl. (all maps).

WOODRING, W.P., 1957-1982: Geology and paleontology of Canal Zone and adjoining parts of Panama. Description of Tertiary molluscs. - U.S. Geol. Surv. Prof. Pap., *306 A-F*, 759 págs., 124 pls.

APPENDIX II

MICROPALAEONTOLOGICAL REPORT ON SAMPLES FROM THE OSA GROUP, COSTA RICA. BRITISH MUSEUM (NATURAL HISTORY), DEPARTMENT OF PALAEONTOLOGY REPORT Nº BMNH OGS 1984/4 & 1985/3

J.E. Whittaker, 30 August 1985

Material: Twenty three samples submitted by Dr. J.P. Berrangé, British Geological Survey on 19 June 1985 (BMNH OGS Nº 1985/3), together with a reapprisal of the 14 samples (BMNH OGS Nº 1984/4) previously reported on by ADAMS & WHITTAKER (21 September 1984); see request by Dr. Berrangé (letter dated 10 June 1985). All the material was disaggregated and the identifications made from picked faunal slides.

Analysis: Of the total of 37 samples, 9 proved barren (R7, R10, R45, R49, R64, R193, R200, R256 and R285). R204 contained only radiolaria and although it could not be dated it was undoubtedly of marine origin. The remainder all contained foraminifera and ostracods and for the most part could be dated. On environmental grounds they can be divided into three groups.

1. Brackish sample

R0 contained small individuals of the foraminiferal genera *Elphidium* and *Peneroplis* and many ostracods belonging to *Cyprideis* and *Perissocytheridea*. The ostracods are exclusively brackish in their habitat, living in lagoons, estuaries and other low salinity marginal marine environments. The foraminifera suggest a phytal habitat.

Age: Probably late Neogene, but difficult to determine accurately in the absence of age-diagnostic planktonic foraminifera.

2. Nearshore samples

Four samples - R171, R172, R263 and R264 - contained a restricted fauna of benthonic foraminifera and ostracods. The foraminifera were characterized by *Elphidium* spp. (including the same species as in sample R0, the brackish sample) and the *Ammonia beccarii* group, the ostracods by species belonging to the genera *Loxoconcha* and *Xestoleberis*, amongst others. This fauna is indicative of a very shallow water, littoral or sublittoral environment associated with marine algae.

Age: Only a few juvenile planktonic foraminfera were found. In their absence it is difficult to date the sample precisely though there is no reason to doubt that they are coeval with the rest of the Osa Group (see below).

3. Shelf samples

Eighteen samples (Table 1) contain abundant planktonic and benthonic foraminifera and can be dated. Another 4 samples - R203, R249, R271 and R275 - contain only benthonic foraminifera (mostly broken), but from the nature of their fauna there is no doubt that they were deposited in the same environment. The ***BENTHONIC FORAMINIFERA*** are diverse and are made up chiefly of the genera: *Bolivina, Uvigerina, Cibicides, Pseudononion, Nonionella, Cibicorbis, Hanzawaia* and *Cancris*. Miliolaceans are rare, as are agglutinating foraminifera. From a palaeoecological point of view the species listed below are the most significant and characterize many of the samples; all are living today on the shelf in the Caribbean and Gulf of Panamá area, their depth distribution being taken chiefly from MURRAY (1973):

> *Hanzawaia concentrica* (CUSHMAN) (= *Cibicides nitidula* BANDY) 35-150 M (found in samples R26, R27, R68 AND R229).
> *Cancris panamensis* Natland 50-150 m (sometimes deeper) (found in sample R9).
> *Cibicorbis hitchcockae* (GALLOWAY & WISSLER) (= *Cibicorbis herricki* HADLEY), and *Valvulineria inflata* (D'ORBIGNY) *auctt.*) 100-350 m (found in samples R2, R6, R28,, R57, R68, R194, R271A and R272).
> *Nonionella stella* CUSHMAN & MOYER 25-180 m (found in sample R281).
> *Amphistegina* sp. (juveniles) 5-50 m (found in samples R27 and R68).
> *Pseudononion* (= *Florilus auctt.*) and *Elphidium* spp. 0-60 m (found in samples R11, R27, R57, R58 and R281).

Of the species of *Bolivina*, the most abundant were numbers of the *B. interjuncta* CUSHMAN group. According to SMITH (1963), this species is at its most abundant between 100 and 200 m in the Central American area. It was found in practically all the samples in Group 3.

Further indication of the relatively shallow water disposition of the Osa Group is evidenced by the size of the planktonic foraminifera. Although abundant they are all small, reaching only about half the size of their conterparts in deepwater sediments (and open ocean plankton tows).

The majority of Osa Group samples, it is concluded, indicate shelf conditions. The depth of water probably never exceeded 150-200 m.

The distribution of the ***PLANKTONIC FORAMINIFERA*** in the Osa Group material is shown in Table 2 (in this Table, the two washings from R271 are now amalgamated and R271 should read R271A). The dominant species are *Globigerinoides ruber, Neogloboquadrina humerosa* and small, keeled globorotaliids. The last named was referred to in the previous report as *Globorotalia* sp. because at that time it was found difficult to place them into any known species. Recently, two papers in the **Initial Reports of the Deep Sea Drilling Project, leg 84,** from off the west coast of Central America—STONE & KELLER (1985) and GLACON & BOURGOIS (1985)— have illustrated these forms and shown them to be characteristic of this area in the late Neogene. Following GLACON & BOURGOIS (1985), they can now be separated into a thin, compressed form referred by them to *Globorotalia menardii* (PARKER, JONES & BRADY); and a rotund form, the biconvex individuals showing a tendency towards *G. limbata* Fornasini (= *G. praemiocenica* LAMB & BEARD), other plano-convex tests being reminiscent of *G. miocenica* PALMER. In only one sample (R217) are there true (but small) examples of *G. tumida* (BRADY). These "species" appear to undergo a number of changes in coiling in the Miocene-Pleistocene time interval, but because much of the Pliocene is absent at the various sites studied by GLACON & BOURGOIS and it is the first time these globorotaliids have been studied in detail, it is perphaps premature to apply their findings to the present material. For the record, however, the predominant coiling mode in both the *menardii* and *limbata/miocenica* tendencies is sinistral in the Osa Group samples.

AGE: The ranges of the critical planktonic species are given in Fig. 3. Of the *Neogloboquadrina acostaensis-humerosa* lineage, a few specimens, particularly in sample R271, become high spired, loosely coiled and have an umbilical aperture (the supposed criteria for *N. dutertrei* (D'ORBIGNY), but definitions (and hence age-range) of this species vary from author to author. There is one specimen each of *Pulleniatina obliquiloculata* (PARKER & JONES) and *P. praecursor* BANNER & BLOW in samples R27 and R272, respectively. Previous reliance on the age range of *Globorotalia crassula* CUSHMANN & STEWART, reported formerly in R11, should be discounted as this single specimen is now interpreted as a variant of *G. scitula* (BRADY).

From the evidence presented above and from the overlapping ranges shown in Fig. 3, the age of the Osa Group must fall between Zones N19 (later part) and N21, Pliocene. As I have no means of knowing the precise stratigrpahic relationship of the samples, it is not possible to be more accurate. The samples collected from the known base of the Osa Group were unfortunately either barren or contained only benthic foraminifera; it is conceivable that they could be slightly older as indicated in Fig. 3.

REFERENCES

GLACON, G. & BOURGOIS, J., 1985: Upper Oligocene to Recent planktonic foraminiferal remains in sediments of the inner wall of the Middle America Trench with special emphasis of *Globorotalia*. - Initial Rep. Deep Sea Drilling Proj., 84: 473-513, pls. 1-4.

KENNETT, J.P. & SRINIVASAN, M.S., 1983: *Neogene Planktonic Foraminifera, a Phylogenetic Atlas*. - 265 pags. 61 pls. Hutchinson Ross Publ. Co., Stroudsburg.

MURRAY, J.W., 1973: *Distribution and Ecology of Living Benthic Foraminiferids*. - 274 págs., 12 pls. Heinemann Educational Books, London.

SMITH, P.B., 1963: Quantitative and qualitative analysis of the Family Bolivinidae Recent Foraminifera off Central America. - U.S. geol Surv. Prof. Pap., *429-A*: A1-A39, pls. 29-31.

STONE, S.M. & KELLER, G., 1985: Planktonic foraminiferal biostratigraphy of the Middle America Trench region. - Deep Sea Drilling Project Leg 84. Initial Rep. Deep Sea Drilling Proj., *84*: 419-471, pls. 1-12.

FURTHER REMARKS ON THE FORAMINIFERAL PALAEO-ECOLOGY OF THE OSA GROUP, COSTA RICA

J.E. Whittaker

The apparent conflict in interpretation of the palaeoenvironment of the Osa Group, between that given by WHITTAKER (1985) and by INGLE (in LEW, 1983), has necessitated a further investigation of the samples collected by Dr. J.P. BERRANGE, British Geological Survey, in 1984-85.

The residues of all the 27 samples were re-examined and further portions of four samples were washed and picked in detail. These were R171 and R264 from "Group 2: Nearshore samples" and R272 and R281 from "Group 3: Shelf samples" (WHITTAKER, 1985).

Of the samples considered "Nearshore" in my previous report, the two new pickings confirmed previous conclusions entirely. Apart from a slight difference in preservation (the microfossils in R264 were clean, those in R171 were rather overgrown and recrystallised), both contained identical faunas made up of a very few species which live exclusively in the littoral environment, usually associated with marine algae: the *Ammonia beccarii* group, a small *Elphidium* and *Cibicides lobatulus auctt.* This assemblage was not mentioned by INGLE in LEW (1983). There is no doubt that they indicate original deposition close to a former shore-line, further evidence for which is provided by the shallow water, partly brackish assemblage in sample R0 (WHITTAKER, 1985).

The samples referred to in my previous report (WHITTAKER, 1985) as "shelf" and deposited in depths "probably never exceeding 150-200 m" pose a problem. LEW's palaeoenvironmental interpretation (LEW, 1983, p. 64-67) is based on benthic foraminiferal identifications from three samples (INGLE in LEW, 1983, p. 120-124) and of two samples by CHOU (LEW, 1983, p. 127-128). Although as many as 28 species are identified from one sample (LEW sample WF-1), INGLE's intepretation of the palaeoenvironment is based only on three selected species, viz. *Epistominella simithi* (STEWART & STEWART), *Bolivina interjuncta bicostata* CUSHMAN, and *Uvigerina peregrina* CUSHMAN, which he says are common to abundant in the samples and "are the deepest dwelling species in this fauna .... These taxa indicate that deposition occurred at a minimum water depth between 200 and 500 m" (INGLE, in LEW, 1983, p. 64-65). It is true that *Bolivina interjuncta bicostata* is found commonly in all the samples in my "Group 3", but according to SMITH (1963, A26, Fig. 8) this species is most abundant at depths of around 150 m in the Central American region. *Epistominella smithi* has been much confused in the literature with *E. pacifica* (CUSHMAN), and LIPPS (1965) in his revision of the Pseudoparrellidae, refigures the holotypes of both species. His figures indicate that our material should be referred to *E. pacifica*, rather than to *E. smithi*; the sutures on the spiral side are angled (as in *pacifica*), rather than curved (as in *smithi*). Although *E. pacifica* can live down to depths of over 1,500 m, it is also found at around 200-250 m, in the Californian region (LIPPS, 1965, Table 3); *E. smithi* (LIPPS, 1965, Table 4) occurs at even shallower depths commonly as little as 65-150 m in the Californian and Central American regions. The third species INGLE cities as indicative of depth is *Uvigerina peregrina* . LAMB & MILLER (1984) consider the *peregrina* group to be a cline, the ornament becoming stronger and more spinose with greater depth. The forms seen in the present material are too small (usually less than 700 µm in height) and not strongly costate enough to be called *U. peregrina s.s.*; they are therefore referred to *U. subperegrina* CUSHMAN & KLEINPELL, which according to LAMB and MILLER is characteristic of depths of 100-200 m. The known bathymetric ranges of these three species do not, therefore, contradict a water depth of 150-200 m as originally postulated by WHITTAKER (1985). It must be remembered that the distribution of Recent benthic foraminfieral species is known not to be controlled solely by depth, but by a combination of physico-chemical factors, many of which are poorly understood, Many of the governing parameters cannot even be measured for Pliocene and older sediments.

The general aspect of the benthic assemblages seems to suggest outermost shelf or upper slope (150-200 m) deposition for the Osa Group. This is supported by the planktonic foraminiferal faunas which lack deeper-water species (eg. *Globorotalia crassaformis*, adult *Sphaeroidinella dihiscens*). A mixing of "shallower" (20-150 m taxa, such as *Hanzawaia concentrica*, *Nonionella* spp., *Amphistegina gibbosa*, *Pseudononion* spp., etc.) with deeper-water forms (certain *Ehrenbergina*, *Oridorsalis* and *Pullenia* spp., for example), the last two in very small numbers, suggests deposition in a zone of overlap between their ranges at the edge of the continental shelf, rather than mixing by turbidity currents. Species of all three genera are known to live on the outer shelf.

One very fine grained sample (R272) was sediment-free when disaggregated. Although this could have been deposited in deep water, it contained no exclusively deep-water taxa.

It was previously stated (WHITTAKER, 1985) that the planktonic foraminfiera were unusually small and indicative of shallow water. Examination of additional material has, however, revealed that the size range of the species concerned is fairly normal and that they are typical of depths down to about 100 m. The keeled *Globorotalia tumida* is more characteristic of deeper water, but it is rare and not accompanied by other deep-water forms; individual specimens are, in fact, rather small.

CONCLUSION

Foraminifera found in samples collected by J.P. BERRANGE from the Osa Group indicate original deposition in two different environments: (1) Nearshore, possibly brackish water; (2) Outer shelf/upper slope.

There is some evidence for mixing of shallow (ie. 100-200 m) and deeper-water (250 m or more) taxa, but this is thought to be due to an overlap of bathymetric ranges rather than to redeposition of the shelf faunas in much deeper waters. No true deep-water assemblages have been found, and individual deeper water taxa do not have the clearly demarcated upper limits implied by LEW (1983).

The possibility that the shelf faunas have been transported **en masse** to deeper water cannot be entirely discounted, but clear signs of this should be visible in the field. Mass transport on the necessary scale could hardly occur without graded bedding (not evident in our samples) being visible.

REFERENCES

LAMB, J.L. & MILLER, T.H., 1984: Stratigraphic significance of uvigerinid foraminifera in the Western Hemisphere. - Paleont. Contr. Univ. Kans., *66*: 1-98, pls. 1-40.

LEW, L.R., 1983: The geology of the Osa Peninsula, Costa Rica: Observations and spectulations about the evolution of part of the outer arc of the Southern Central American Orogen. - 128 pags., Pennysilvania State Univer., Dept. of Geosciences, (unpublished M.Sc. Thesis).

LIPPS, J.H., 1965: Revision of the foraminiferal Family Pseudoparrellidae Voloshinova. - Tulane Stud. Geol., *3*: 117-147, pls. 1-3.

SMITH, P.B., 1963: Quantitative and qualitative analysis of the Family Bolivinidae. Recent foraminifera off Central America. - U.S. geol. Surv. Prof. Pap., *429-A*: A1-A39, pls. 29-31.

WHITTAKER, J.E., 1985: Micropaleontological report on samples from the Osa Group, Costa Rica. - British Museum (Natural History), OGS Report Nº 1984/4; 1985/3. Dated 30.8.1985, 6 pags.

LOCATION OF MICROPALAEONTOLOGICAL SAMPLES

NUMBER	MAP SHEET	GENERAL LOCATION	ALTITUDE	GRID REFERENCE
R0	GOLFO DULCE	RIO AGUJAS	-	-
R2	GOLFO DULCE	RIO TIGRE	35	5307/2765
R6	GOLFO DULCE	QDA. HIGUERON	50	5348/2728
R8	GOLFO DULCE	RIO NUEVO	25	5336/2743
R9	GOLFO DULCE	RIO CONTE	55	5236/2830
R11	CARATE	PUNTA SOMBRERO	00	5430/2656
R26	GOLFO DULCE	RIO BARRIGONES	130	5234/2799
R27	GOLFO DULCE	QDA. GALLARDO	18	5336/2773
R28	GOLFO DULCE	QDA. GALLARDO	22	5334/2767
R57	GOLFO DULCE	RIO RIYITO	110	5256/2792
R68	CARATE	PLAYA ZAPOTE	00	5422/2709
R150	GOLFO DULCE	RIO BARRIGONES	200	5232/2799
R171	GOLFO DULCE	RIO RIYITO	70	5270/2786
R172	GOLFO DULCE	RIO RIYITO	70	5270/2786
R194	GOLFO DULCE	RIO RIYITO	90	5260/2793
R203	CARATE	RIO PEJEPERRO	90	5301/2684
R217	GOLFO DULCE	RIO AGUJAS	40	5293/2777
R229	GOLFO DULCE	RIO RINCON	20	5204/2884
R244	GOLFO DULCE	RIO BARRIGONES	70	5242/2801
R249	CARATE	QDA. COYUNDA	130	5382/2618
R263	LLORONA	RIO TERMO	255	5172/2780
R264	LLORONA	RIO TERMO	255	5172/2779
R271	MADRIGAL	PLAYA SIRENA	00	5078/2697
R272	MADRIGAL	RIO CLARO	5	5084/2691
R275	MADRIGAL	PUNTA RIO CLARO	10	5082/2684
R281	MADRIGAL	RIO MADRIGAL	30	5180/2675