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The Humboldt Channel: Early Pleistocene extensional graben through eastern Venezuela and Trinidad

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ABSTRACT. **Vertical crustal movements associated with convergent and transpressional plate boundaries commonly produce small, short-lived basins which are rapidly filled by large thicknesses of sediment. In eastern Venezuela and northern Trinidad there is an E-W oriented depression, usually attributed to the El Pilar Fault system. This depression exposes thick sequences of siliciclastic sediments exposed in discontinuous outcrops. Their lithology includes conglomerates, sandstones and siltstones in massive beds, mostly of lenticular morphology. From west to east, the studied units are: Caiguire Formation, Chiguana Formation, Paria Formation (=Güiria Formation) and Talparo Formation (Compare and Caparo members). Some siltstones and thin bioclastic limestones contain molluscs, fish remains and some corals, bryozoans and barnacles. The molluscs belong to the gastropod *Turritella maiquetiana* zone and the bivalve *Larkinia patricia* zone, which indicate an Early Pleistocene age. The oligomictic faunal assemblage suggests high-salinity, marine waters, with clay in suspension, locally stratified but well circulated at the surface. These deposits occur in a 345 km wide E-W outcrop zone, suggesting a short-lived channel open at both ends to marine waters, and called the Humboldt Channel, and represents part of Molassic cycle IV. These Early Pleistocene sediments, deposited during transtensional tectonics, were subjected to NW-SE transpression along the Cumana-El Pilar segment, which caused faulting and folding during Middle-Late Pleistocene. East of El Pilar, the tectonic inversion began with the start of subduction of the Gulf of Paria sediments beneath the Paria metamorphics in the Late Pleistocene, creating the present Gulf of Paria.**

1. INTRODUCTION

Ever since Alexander Von Humboldt (1814-1824) predicted the future union of the gulfs of Cariaco and Paria, attention was drawn to an extensive east-west oriented valley separating the coastal ranges of the north, from the Serrania del Interior Oriental in the south. Liddle (1946) mapped the Araya-Paria coastal ranges as metamorphic rocks, and the Serrania to the south as sedimentary, mostly Cretaceous and Paleogene. This elongated depression was an area of frequent earthquakes, with hundreds of hydrothermal water springs, and occasional oil seeps (Urbani, 1989).

These observations led to the recognition of the El Pilar Fault zone, whose strike-slip displacement varies from 1 to more than 100 km (Schubert, 1979; Audemard and Giraldo, 1997). Thick pockets of molassic sediments on both sides of the El Pilar Fault zone were originally dated as Mio-Pliocene (Bermudez, 1966, Ascanio, 1972). Sampling of these molassic sediments, revealed the abundance of marine, brackish and non-marine molluscs, belonging mainly to Late Pliocene to Middle Pleistocene forms (Macsotay, 1976). These molluscs provided a very good correlation with the Caroní Basin in Trinidad. In this paper the sedimentary succession, lithostratigraphy and faunas of the Humboldt Channel are described.

2. MOLASSIC SEDIMENTATION

The term molasse was proposed by European geologists for an extensive, post-orogenic sedimentary formation representing the fore-deep infill and most of the foreland of an active orogenic system. According to Perriaux (1975), the molasses are sedimentary formations of rhythmic character – two sedimentary facies are represented.

a) Massive beds of ten to tens of metres thickness, of repetitive normally graded beds beginning with conglomerates, passing to sands and finally shales. Each unit is erosionally based, often lenticular, and frequently incised into the underlying unit. Fossils are rare, and when present, they are oligomictic.

b) A regular and monotonous alternation of rhythmic sandstones and shales. Both are finely bedded, up to ten metres thick and made up of regularly stacked fine laminates (or rhythmites) which are not graded.

These two facies alternate and on a basin scale, may grade into one another (Perriaux,

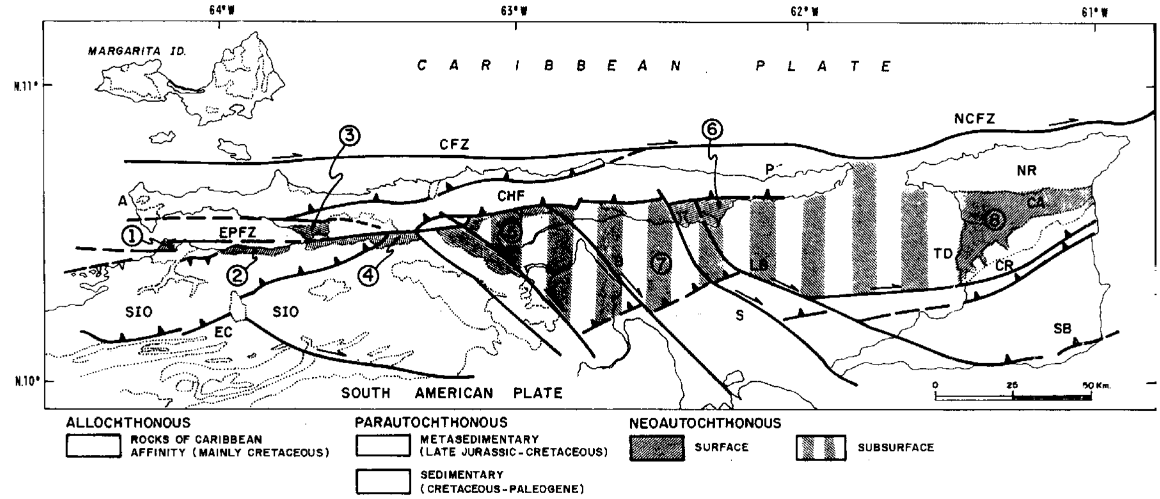

Figure 1. Geological map of NE Venezuela and Trinidad with measured sections (1-7) of late Pliocene-Pleistocene sediments. A, Araya Peninsula; B, Bohordal Fault; Ca, Caroni Basin; CHF, Chuparipal Fault; CR, Central Range Fault; CFZ, Coche Fault zone; EC, El Culon Fault; EPFZ, El Piler Fault Zone; LB, Los Bajos Fault; NCFZ, North Coast Fault Zone; NR, Northern Range; P, Paria Peninusla; S, Soldado Fault; SB, Southern Basin; SIO, Serrania del Interior Oriental; SF, San Francisco Fault; TD, Trinidad; T, Tobago.

1975). Proposed originally for alpine orogenies, similar molasses are associated with other types of orogeny, and they may be syn- or post-tectonic. The intramontane basins of mountain chains can be included in the molasse concept because they are also controlled by tectonic phases (Matter *et al.,* 1980; Vivas and Macsotay, 1989). In a review of the major Neogene sedimentary basins of Venezuela and Trinidad, Macsotay *et al.* (1998) reported five cycles of deposition, extending from the latest Eocene to Recent. Cycle IV ranged from Late Pliocene to Early Pleistocene, and cycle V, from Early Pleistocene to Recent. The boundary between cycles IV and V was placed right after the closure of the Humboldt Channel (Macsotay, 1976). A tectonostratigraphic review suggests that the tops of the Cumana and Talparo formations mark a major regional event, which can also be traced to the Tuy-Cariaco basin.

3. Stratigraphy

Seven discontinuous outcrop areas were studied in north-eastern Venezuela, located along the El Pilar Fault Zone. These areas from west to east, are: 1, The Caigüire Hills in the Cumaná area; 2, the Marigüitar area along the southern margin of the Cariaco Gulf; 3, The Chiguana area along the northeastern extreme of this gulf; 4, Muelle de Cariaco at the southeastern extreme of the same gulf; 5, El Pilar town - Cumacatal river along the western extreme of the Paria Gulf; 6, Irapa-Güiria towns along the western extreme of the same; and 7, Northern Paria Gulf called the Yaguaraparo depression (Figs 1-3).

These Venezuelan areas were compared to the information available about the Caroni Basin (8) in northern Trinidad (Figs 1, 4). Despite the variable lithostratigraphic nomenclature, the resemblance of these deposits to molassic sediments is striking. Some of the common features are:

a) The sequences vary from tens of metres to kilometres in thicknesses, despite the severe subaereal erosion along the uplifted areas.

b) The Plio-Quaternary formations cropping out along the El Pilar Fault Zone were laid down upon metamorphic or sedimentary substrates or upon both.

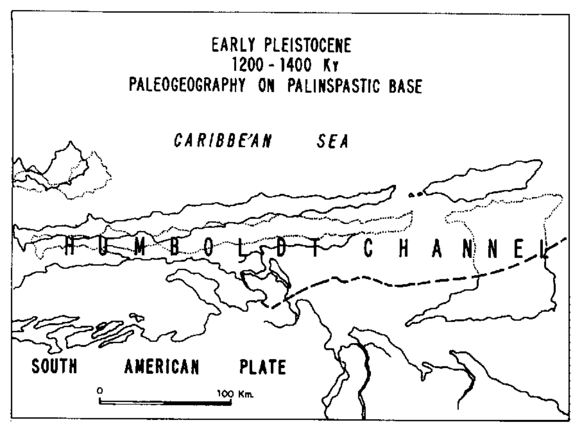

Figure 2. Palaeogeographic reconstruction of Humboldt Channel on palinspastic base.

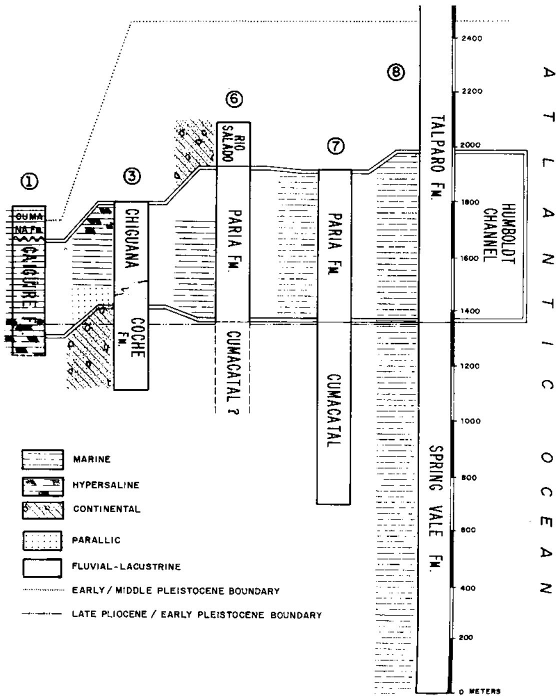

Figure 3. Correlation of the Humboldt Channel in Venezuela and Trinidad dated using molluscs.

c) They expose essentially terrigenous sedimentary sequences, with siltstones or sandstones containing local concentrations of shells and shell fragments. Part of the fauna may be *in situ*, part transported

d) The base of the fossiliferous horizons is indurated and marked by the *Thalassinoides* and *Ophiomorpha* burrows, suggesting erosional or non-depositional surfaces. The *Trypanites* ichnofacies was also locally observed, confirming the presence of some marine hardgrounds.

e) The local presence of evaporite minerals, such as gypsum, anhydrite and jarosite, suggests conditions of local evaporation in the subaqueous sediments. In contrast, evaporates are absent from the conglomerates, which were deposited in subaerial conditions.

f) Siderite occurs in highly bioturbated, fossiliferous horizons. *Thalassinoides* and *Ophiomorpha* burrow walls are replaced by limonite and goethite, possibly as late diagenetic phases, although the iron cannot be traced back to an authigenic pyrite precursor (because pyrite is absent). The iron is related to very humid tropical weathering with high rainfall that is interpreted to have affected Venezuela in the Pleistocene. Iron oxides are very important cementing agents in subaerial conglomerates such as the Coche Formation (Vivas and Macsotay, 1989). Some lenticular conglomerates within the marine sequences also exhibit iron-oxide cementation.

g) The biodiversity should reflect the palaeoecological environment within a restricted watermass. The Caparo clay (=Matura) of the Talparo Formation contains 160 different molluscs (Jung, 1969a, b), as well as bryozoans, echinoids, balanids, decapods and fish remains (Guppy, 1864). It suggests a 'marine, near-shore environment with slightly brackish water influence' (Jung, 1969b). Otherwise, the Talparo Formation, with its lignitic beds associated with sands containing possible traces of decayed mangrove roots, suggests a coastal swamp environment, whereas fossils like *Hyria* and *Hemisinus* prove the presence of fresh water. *Corbicula* (*Cyanocyclas*), whose presence was documented in most of the fresh-water Pliocene-Pleistocene sediments of northern Venezuela (Macsotay, 1969), suggests a brackish water influence.

The presence of an assemblage of *Larkinia patricia* and *Siphocypaea mus* suggests hypersaline conditions due to widespread evaporation imposed during long-lasting dry seasons. The assemblage is present in the units associated with gypsum or jarosite.

The fauna of the Paria Formation (called Güiria in the subsurface) contains 74 species of mollusc, together with some corals, bryozoans and shark teeth (Macsotay, 1969). The Chiguana Formation contains 52 molluscs, and corals, echinoids, decapod crustaeans and fish remains (Macsotay and Caraballo, 1976).

The Caigüire Formation, the westernmost of all the outcrops of this series, contained 248 taxa of mollusc, together with bryozoans, balanids, corals, shark and ray remains, and fish otoliths (Macsotay, unpublished). The biodiversity is high in the sedimentary sequence near the proposed outlets of the Humboldt channel (Cumana area and Caroni Basin) and low within the channel itself, where climatic conditions and high sedimentation rates created a stressed environmental.

h) Lignites and lignitic fragments scattered in conglomerates and sandstones are common in all the deposits. These fragments are interpreted as transported from nearby shorelines. No *in situ* roots have been observed, and all the leaf imprints observed in pelitic rocks, belong to terrestrial forms.

4. LITHOSTRATIGRAPHY

A brief description is given of the important

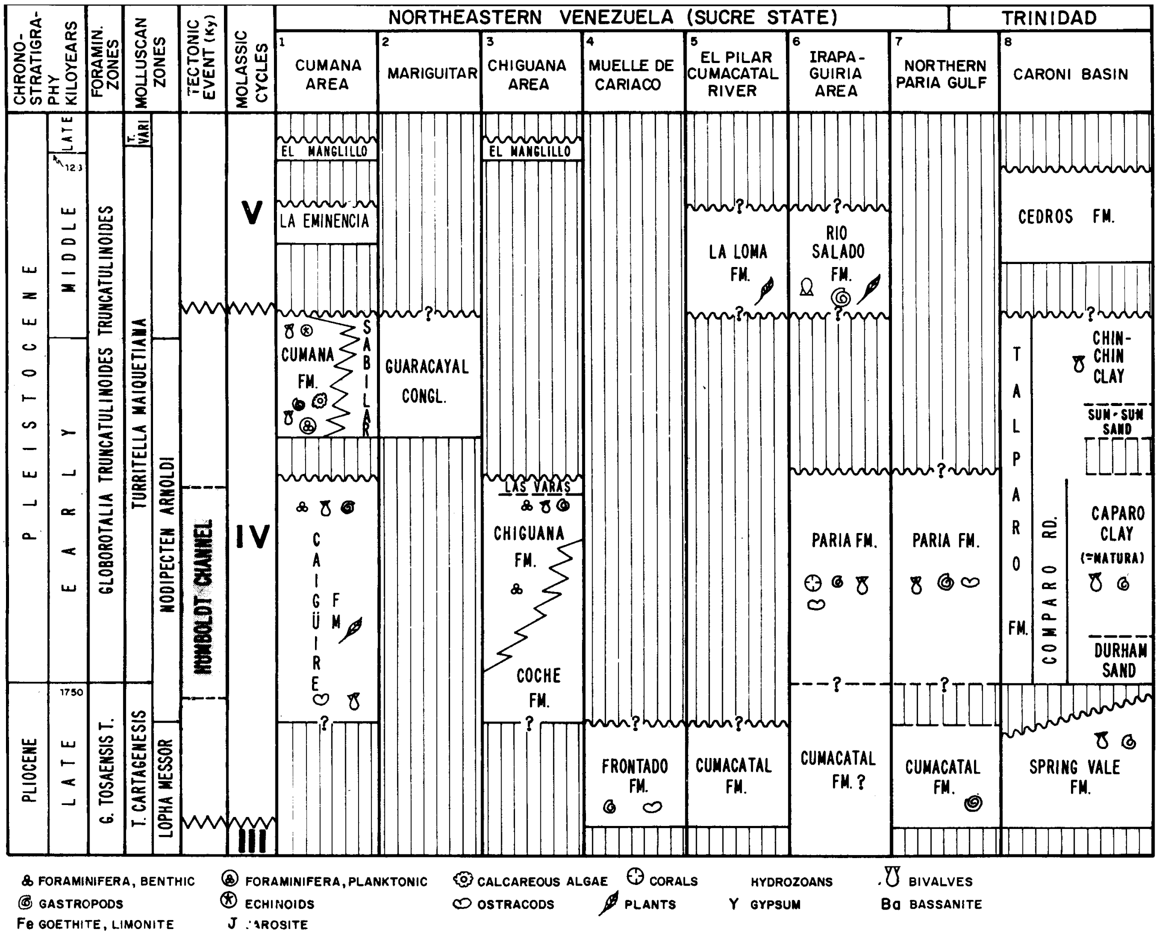

Figure 4. Correlation table of late Pliocene-Pleistocene sediments of Sucre State (Venezuela) and northern Trinidad produced with palaeontological control, Middle-Late Pleistocene units are controlled by radiometric dates.

units, especially for researchers who do not have access to the stratigraphical literature contained in the last edition of the Lexico Estratigrafico de Venezuela (1997). From west to east we are considering seven outcrop areas in Venezuela and Trinidad, and a subsurface area, in the Gulf of Paria (Fig. 4).

Caigüire Formation. Siliciclastic gypsum-bearing clays, silts and sandy gravels, which exhibits in their upper half, fossiliferous and gypsiferous marls alternating with metre-scale beds of clay, sand, and conglomerate. It is 395 m thick in its type locality (Ascanio, 1972). Originally attributed to the Miocene-Pliocene, the foraminiferal and molluscan fauna suggests it is Late Pliocene to Early Pleistocene (Bermudez and Farias, 1975; Macsotay, 1976). The lower member contains the hypersaline *Larkinia patricia – Siphocypraea mus* assemblage. The upper member carries a highly diverse assemblage with *Lopha vespertina venezuelana*, *Fasciolaria crassinoda*, *Pallacera solidula* and *P. maracibensis* suggesting a marine, infra-littoral palaeoenvironment, with a high organic input.

Cumana Formation. A heterolithic unit, starting with oligomictic conglomerates, followed by alternations of metre-scale beds of shelly limestones, marls, mudstones, calcarenites and calcareous sandstones. In the Cumana area, its thickness is 110 m, but in the Carupano basin, 686 m were drilled (Bermudez, 1966; Castro and Mederos, 1985). The fauna is dominated by the *Nodipecten arnoldi – Argopecten imitate – Lopha caboblanquensis* assemblage, containing more than 240 species of benthic mollusc, as well as corals, stromatolites, echinoids, bryozoans and hydrozoans. The assemblage is marine, infra- to circa-littoral, containing a fully marine fauna with little continental influence. Faunally, this unit has very little in common with the underlying Caigüire Formation. It was probably deposited after the closure or infill of the Humboldt Channel.

Chiguana Formation. A siliciclastic unit composed mainly of clays and silts, in rhythmic successions, and frequent beds of sub-metre-scale selenite. Gravel-conglomerates, sandstones and some fossiliferous calcareous sandstones are called the Las Varas Member (Macsotay and Caraballo, 1976). It has an estimated thickness of 400 m with the topmost 21 m being the most fossiliferous. The typical assemblage faunal is *Larkinia patricia – Lopha vespertina venezuelana – Corbula daphnia – Calliostoma laticannatum,* which is dominated by small-sized molluscs and filter-feeders. Frequent *Anomalocardia brasiliensis*, *Melongena melongena* (small varieties) and *Neritina virginea* suggest periodical variations in salinity due to the influence of creeks and small rivers. It is interpreted as a hypersaline embayment, partially isolated from the rest of the channel by conglomerates of the Coche Formation.

Frontado Formation. A siliciclastic unit, properly published by Macsotay and Caraballo (1976), but not included in the Lexico Estratigrafico de Venezuela (1997). It is mainly an alternation of claystones and clays with siliceous clays, indurated so as to resemble porcellanite or chert. The clays are varved and exhibit good lateral continuity. The siliceous clays are essentially diatomites and contain some fish remains. Towards the south, the unit becomes silty and alternates with sandstones. A bed of calcilutite contained gastropods including *Hemisinus* cf. *H. kochi* (Bernardi), Ampullariidae, Hydrobiidae, and *Styllomatophore pulmonates* together with some bivalves and ostracods, suggesting an inland aquatic habitat (Wesselingh, written communication, 2002). Abundant charophyte oogonia indicate aquatic vegetation. This unit, 240 m thick, was deposited inside an intra-montane graben, formed before the Humboldt Channel. Its age is probable Late Pliocene.

Cumacatal Formation. Another siliciclastic unit, published by Vivas and Macsotay (1995), composed of beds (from one to tens of metres thick) of fine-grained conglomerate, sandstone and siltstone, with occasional lenses of coal, clay and marl. The silts are calcareous, ferruginous and bituminous, and have lenses of fine-grained conglomerate. The upper part of the formation is an alternation of metre-scale beds of calcareous and micaceous clays with fossiliferous and bituminous marls (Furrer and Castro, 1997). The marls are rich in charophyte oogonia and gastropods [*Australorbis glabratus* (Swanson), *Sheppardiconcha* cf. *S. picardi* (Macsotay), *Hemisinus comparanus* (Maury) (also in the Talparo, Caiguire and Rio Salado formations), *Hydrobia amnicoloides* Pilsbry *Dyris* cf. *D. ortoni* (Qabb), *Neritrina virginea* (Linne)] and a bivalve [*Corbicula* (*Cyanocyclas*) *comparana* Maury (also in the Talparo, Caiguire and Las Piedras formations)].

This assemblage is definitely post-Late Miocene and pre-Pleistocene in age. In Cumacatal river (area no. 5), 350 m of this unit is exposed and was deposited in a huge fluvio-lacustrine complex close to the coastline.

A kilometre-thick sequence of siltstones, sandy shales and some beds of lignite was drilled in oil wells in the Gulf of Paria. This has been called the ‘Formacion Las Piedras’ by Perez de Mejia and Tarache (1985). They reported frequent shell fragments, ostracods and benthic foraminifers, such as, *Florilus* sp. and *Hanzawaia* sp. Lithologically, the succession in this well is comparable to the Cumacatal Formation, rather than the typical ‘Formacion Las Piedras’. This unit underlies the Paria Formation, and is older that the Humboldt channel.

Paria Formation (=Güiria Formation of Bermudez, 1966). A siliciclastic unit composed of laminar clays, siltstones, carbonaceous shales and sandstones, with locally beds of limestone or lignite (Hedberg *in* De Sisto, 1961, fig. 4). The type section, well Paria no. 1, exposes 374 m, but towards the north (area no. 7), it could reach a kilometre in thickness (Perez de Mejia and Tarache, 1985). From this area, frequent bivalve and gastropod shells, and benthic foraminifers such as *Cibicides* sp. and *Miliammina* sp. were reported. In the upper part, charophyte oogonia are frequent. Furrer (*in* Perez de Mejia and Tarache, 1985) suggests a shallow marine environment in the lower part, and a fluvial one in the upper part. The molluscs examined by the author, are identical to the small-sized fauna of the Caigilire, Chiguana and Talparo (Caparo clay member) formations. The similarity with the Guiria Formation is so high (Bermudez, 1966; Macsotay, 1969), that this unit is considered a junior synonym of the Paria Formation. The age is definitely Early Pleistocene, and the Paria Formation was an important part of the Humboldt Channel.

Springvale Formation. A siliciclastic unit composed of fossiliferous sands, frequently glauconitic, alternating with clays and lignites. They are well exposed along the southern margin of the Caroni Basin of Trinidad. Locally excellent molluscan faunas are developed (Maury, 1925; Putsch, 1942; Jung, 1969a) together with bryozoans, foraminifers, echinoids and fish remains, suggesting an inner neritic environment (Carr-Brown and Frampton, 1979). This unit reaches a maximum thickness of 1.37 km and its Late Pliocene age was established by Carr-Brown and Frampton (1979). The following fauna is present – bivalves: *Pecten (Pecten) archon* Maury, *Dosinia grandis* (Nelson), *Lirophora caroniana* (Maury), *Notocorbula islatrinitatis* (Maury); Gastropods: *Turritella (Broderiptella) planigyrata* Guppy, *Turritella caronensis* Mansfield, *Turriteilla cartagenensis* Brown and Pilsbry, *Petaloconchus sculpturatus alcimus* Mansfield, *Hanetia semiglobosa* (Guppy), *Turbinella nosecana* (H. K. Hodson) – suggesting the zone of *Turritella cartagenensis* proposed by Macsotay (1971) to cover the Late Pliocene of Venezuela. This unit definitely predates the Humboldt Channel.

Talparo Formation. Another siliciclastic unit composed of two sand-clay cycles where the monotonous clay beds alternate with lenticular layers of sandstone and lignite (called the Talparo Formation by Renz, 1942). Its thickness varies between 120 m and 1.21 km, and fills the Caroni Basin. Along the southern outcrops, four members were distinguished: Durham Sand; Caparo Clay; Sum-sum Sand; and Chin-chin Clay. The Caparo clay locally contains shallow-marine molluscs of a similar form to the Matura Formation small-sized fauna (Jung, 1969a). The abundance of charaphyte oogonia in all the clays suggests a lagoonal/fluviatile palaeoenvironment. Towards the north, the unit becomes more sandy and conglomeratic, due to the erosion of the Northern Range (Fig. 1, Area 8). This unit is called the Compare Member and exhibits calcareous sandstones containing plant and molluscan remains: gastropods (*Hemisinus comparanus* Maury) and bivalves [*Corbicula (Cyanocyclas) comparana* Maury (=*Cyrena falconensis* H. K. Hodson), *Corbicula (Cyanocyclas) caroniana* Maury, *Anticorbu1a fluviatilis* (A. Adams) (=*Saxicava trinitaria* Maury, =*Ostomya mencheri* Palmer)].

This oligomictic assemblage is found in most of the Late Miocene-Pleistocene non-marine sediments in eastern and western Venezuela. It suggests close affinity with the proto-Orinoco basin. I consider that the Durham Sand, Caparo Clay and the Compare Road Members, were part of the Humboldt Channel tectono-sedimentary system (Fig. 4). The Sum-sum Sand and the Chin-chin Clay belong to a later cycle of deposition.

5. Macropaleontological Correlation

Table 1 lists 56 taxa of invertebrates. These were found to be common to at least three of the four formations comprising the Humboldt Channel.

In the Humboldt Channel, only the Caiguire Formation is known to contain planktic foraminifers representing the *Globorotalia truncatulinoides truncatulinoides* zone of Pleistocene age (Bermudez and Farias, 1975). The samples were collected from the upper, more marine member (Macsotay, 1976, fig. 3). The molluscan fauna suggests that all formations belong to the *Turritella maiquetiana* biozone, which covers most of the Pleistocene (Macsotay, 1971).

The molluscan assemblages are definitely younger than the well-known Springvale Formation of Trinidad. Carr-Brown and Frampton (1979) showed this unit to belong to the latest Pliocene, and the Talparo Formation overlies the Springvale Formation throughout the Caroni Basin.

The *Larkinia patricia* biozone in western Venezuela overlies shales containing rich microfaunas belonging to the basal Pliocene *Globorotalia margaritae* zone (Hunter, 1978). The *Larkinia patricia* – *Siphocyprea mus* assemblage is found together with an oligomictic marine fauna belonging to the *Turritella cartagenensis* zone (Late Pliocene age) in the Chiguaje Member (Codore Formation). The overlap of the *Larkinia patricia* zone with the *Turritella maiquetiana* zone, is considered as the marker for the Early Pleistocene in the Southern Caribbean.

6. Why a Channel?

Every since the Miocene, there has been a well established community of benthic molluscs in episutural basins of northern South America. The Madden Basin in Panama, the Sinu-Atrato Basin in western Colombia and Ecuador, the Falcon and Tuy-Cariaco basins in Venezuela, have astonishingly similar faunal assemblages through the Miocene and Pliocene (Jung, 1965). The same can be stated up to Late Pliocene times in Trinidad (Maury, 1925; Jung, 1969a). Most of these assemblages were found living on the eastern Venezuelan shelf (Macsotay and Campos, 2001). The exceptions to the rule, are the shallow-marine, lagoonal, muddy inland basins, where the dominant forms are mud- or sand-dwelling filter-feeders and detritivors. The small size of the individuals suggests the short-lived nature of the channel, where the Atlantic

Table 1. Fossils used in correlation (* =indicates extinct). Caiguire Formation (Ca), Chiguana Formation (Ch), Paria Formation (including Güiria) (Pa), Talparo Formation (Ta) - Caparo clay (Cp), Matura sandstones (Mt).

Anthrozoans	
Hanicina areolata (Linné).	**Ca, Pa, TaCp**
Gastropods	
Calliostoma adspersum (Philippi)	**Ca, Ch, Pa**
Calliostoma laticarinatum (Guppy)*	**Ca, Ch, Pa, TaMt**
Eutrochus plicomphalus (Guppy)*	**Ca, Pa, TaMt**
Eutrochus olssoni (Maury)*	**Ca, Ch, TaMt**
Diodora cayenensis (Lamarck)	**Ca, Pa, TaMt**
Nerita fulgurans (Gmelin)	**Ca, Pa, TaMt(cf.)**
Neritina verginea (Linné)	**Ca, Ch, Pa, TaMt**
Nodulus modulus (Linné)	**Ca, Pa**
Modulus carchedonius (Lamarck)	**Pa, TaCp TaMt**
Caecum pulchellum Stimpson	**Ca, Pa, TaMt**
Caecum regulare Carpenter	**Ca, Ch, Pa**
Turritella aff. *planigyrata* Guppy*	**Ca, Ch, TaMt**
Cerithiopsis emersoni (C. B. Adams)	**Ca, Pa, TaMt**
Cheilea equlestris (Linné)	**Ca, Pa, TaMt**
Calyptraea centralis (Conrad)	**Ca, Pa, TaMt**
Pallacera solidula (Guppy)*	**Ca, Ch, Pa**
Pallacera maracaibensis (Weisbord)*	**Ca, Ch?, Pa**
Fasciolaria crassinoda Weisbord	**Ca, Ch, Pa, TaMt(cf.)**
Strombus cf. *pugilis* Linné	**Ca, Ch, Pa**
Melongena melongena (Linné)	**Ca, Ch, Pa, TaMt**
Leucozonia nassa Gmelin	**Ca, Pa**
Olivella fundarugata Weisbord	**Ca, Ch, Pa, TaMt**
Siphocypraea mus (Linne)	**Ca, Ch, Pa?, TaCp, TaMt**
Bivalves	
Nuculana karkmartini Weisbord	**Ca, Ch, TaMt**
Scapharca cumanensis (Dall)*	**Ca, Pa , TaMt**
Scapharca lienosa (Sowerby)	**Ca, Pa, TaMt(cf.)**
Scapharca cf. *baughmani* (Hertlein)	**Ca, Ch, Pa, TaMt(cf.)**
larkinia patricia (Sowerby) & var.	**Ca, Ch, Pa, TaCp**
Arcopsis adamsi (E. A. Smith)	**Ca, Ch, Pa, TaMt**
Noetia bisulcata Guppy	**Ca, Ch, Pa, TaMt**
Atrina seminuda (Lamarck)	**Ca, Pa, TaMt**
Aequipecten gibbus antecessor (Weisbord)*	**Ca, Pa, TaMt**
Argopecen imitata Weisbord*	**Ca, Pa, TaMt(cf.)**
Leptopecten aff. *desultoria* (Weisbord)*	**Ca, Pa, TaMt(cf.)**
0strea cf. *libella* (Weisbord)	**Ca, Pa, TaMt(cf.)**
Lopha vespertina venezuelana (Weisbord)*	**Ca, Ch, Pa**
Crassostrea patagonica (d'Orbigny)*	**Ca, Ch, TaCp**
Crassostrea rhizophorae (Guilding)	**Ca, Ch, TaMt**
Anomia simplex d'Orbigny	**Ca, Pa, TaMt**
Crassine1la martinicensis (d'Orbigny)	**Ca, Pa, TaMt**
Corbicula comparana Maury*	**Ca, Pa, TaCp**
Trachycardium sanctidavidis (Maury)*	**Ca, Ch, Pa, TaMt**
Trigoniiocardia periiniaris (Maury)*	**Ca, Pa, TaMt**
Parvilucina ephraimi (Weisbord)	**Ca, Ch(cf.), Pa**
Lucina roigi Maury*	**Ca, Pa, TaMt**
Chione cancellata (Linné)	**Ca, Pa, TaMt**
Lirophora sanctidavidis (Maury)*	**Ca, Pa, TaMt**
Anomalocardia brasiliana (Gmelin)	**Ca, Ch, Pa, TaCp, TaMt**
Anomalocardia cf. *venezuelana* (Weisbold)*	**Ca, Ch(cf.), Pa**
Protothaca pictoriha (Lamarck)	**Ca, Ch, TaCp**
Solena ob1iqua (Spengler)	**Ca, Pa, TaMt**
Caryocorbula caribaea (d'Orbigny)	**Ca, Ch, Pa, TaMt**
Juliacorbula aequivalvis (Philippi)	**Ca, Ch, Pa, TaMt**
Caryocorbula helenae (Maury)*	**Ca, Ch, TaMt**
Cirripedes	
Balanus eburrieus Gould	**Ca, Ch, Pa(cf.), TaMt(cf.)**

equatorial currents and the trade winds, introduced marine water from the east. The margins of the channel, mostly sedimentary and metasedimentary rocks, contributed with great amounts of fine-grained sediments, which were deposited and transported westward. Long dry-seasons created evaporitic embayments and lagoons, where mud with a high organic content was deposited together with gypsum, jarosite and other sulphates. Dysoxic conditions formed in the deeper portions of the channel.

7. Tectonic Origin

The general tectonic picture of eastern Venezuela was one of permanent and periodical compressive phases, expressed through transpressional deformations. This transpression started in western Venezuela during Late Eocene-Oligocene time, and migrated eastward, until recent times, where it is still active in Trinidad (Stephan *et al.*, 1994). Eastern Venezuela and Trinidad show evidence of the transpression having climaxed at 10-12 Ma, after which transtension dominated regional development (Pindell, 1994). Transtension in the east agrees with re-evaluated Caribbean-American relative plate motions. Evidence towards the transtension hypothesis is: structural kinematics of Northern Range rocks; seismic expression of faults in the entire region; rapid subsidence of the Margarita-Carupano-Tobago platforms (Pindell, 1994). We can add some additional evidence: along the El Pilar Fault Zone, transtension was active during Late Pliocene time, allowing the deposition of fanglomerates and lake sediments with thicknesses of hundreds of metres to several kilometres (Fig. 2). The Trinidadian extension of this graben accumulated marine sediments.

During Early Pleistocene times, an active graben allowed enough subsidence to allow marine waters to flow across its full east-west extension. This event created the Humboldt Channel which lasted for about a maximum of 660 ky. Tectonic inversion folded and uplifted the sediments of the Humboldt Channel at about 1,140 ka. This tectonic inversion was active in the Caroni Basin, in north-central Sucre State, and left the Gulf of Cariaco and Cariaco Trough as subsequent grabens. These grabens, although undergoing subsidence, suffered deformation, suggesting that the transpressive activity continued until Recent times. The northern Gulf of Paria suffered active compression from the southeast, deforming and obducting the Plio-Pleistocene sediments under the Paria peninsula metamorphics during Late Pleistocene and Holocene times (G. New-Combe, personal communication).

None of the previous tectonic evolution models allows any open space along the El Pilar Fault Zone after Early Pliocene time (Erlich and Barrett, 1992; Rohr, 1990; Algar, 1995). Detailed studies of the geology along the El Pilar Fault Zone geothermal areas, indicates that in all the studied outcrops, this fault is a reverse fault, dipping northward, and is displaced by right-lateral strike-slip faults, that are very active (Macsotay *et al*., 1985; Rivas *et al*., 1985).

8. CONCLUSIONS

Araya-Paria and Northern Range metamorphic terranes were rapidly uplifted during Late Pliocene time and small fore-deep basins were formed, by activity along the El Pilar Fault Zone. During the Late Pliocene, these small basins formed fresh-water lakes in Venezuela, and shallow marine sediments were laid down in the Caroni Basin of Trinidad.

During the Early Pleistocene, transtensional tectonics deepened and widened the small, isolated basins, creating a continuous trough. The opening of this graben coincided with the Early Pleistocene transgression (HST: 1700 ka, Haq *et al*., 1987), and was flooded by shallow, marine waters creating the Humboldt Channel.

During Middle and Late Pleistocene times, compressive stresses deformed the sedimentary sequence, closing the channel. On the Venezuelan side, the El Pilar Fault Zone became deflected towards the SE, along the Bohordal-Soldado-Los Bajos faults, with right-lateral displacement. This segment started subducting the metamorphic Paria range and the Cumacatal and Paria formations entered into the oil window. The El Pilar-Cumana segment became faulted and folded; the Caroni Basin also, but to a lesser degree. To the west, the Cariaco Trough kept subsiding, but its sediments are flexured.

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