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NOTES ON THE SHIFTING COURSE OF THE ANCIENT RIO ORINOCO FROM LATE CRETACEOUS TO OLIGOCENE TIME

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RESUMEN

La distribución de mares y tierras durante el lapso Cretácico Superior-Oligoceno sugiere que, a finales del Cretácico, el río Orinoco fluía hacia el noroeste. Durante el Oligoceno temprano, la dirección de su curso migró gradualmente en el sentido de las agujas del reloj y el Orinoco fluyó finalmente a través del abra de Chivacoa hacia el norte, descargando sus aguas en el extremo oriental de la cuenca de Falcón.

Sólo finalizando el Oligoceno pudo el Orinoco irrumpir hacia el este, a través de la silla formada por el alto de El Baúl y el escudo de Guayana y desembocar en la cuenca de Venezuela oriental y más tarde en el Atlántico.

ABSTRACT

The distribution of land and sea during late Cretaceous to Oligocene time suggests that at the close of the Cretaceous the Orinoco River flowed towards northwest. During the early Oligocene the trend of its course shifted gradually clockwise and the Orinoco flowed finally through the Chivacoa gap towards north and discharged into the easternmost Falcón Basin. Only late in the Oligocene could the Orinoco break through towards east the saddle between the El Baúl Swell and the Guayana Shield and pour into the Eastern Venezuela Basin and later into the South Atlantic.

INTRODUCTION

The possibility of ancient Rio Orinoco repeatedly shifting its course is a problem which fascinated me for many years while I was engaged in geologic exploration work in the Barquisimeto area, the Mérida Andes and along the Barinas mountain front. The more I observed the 6 Km to 16 Km wide, broad-floored valley of San Felipe on the many exploration flights over the area, the more I was convinced that, at a certain time in its history, a large river flowed through this valley and carved it out. As seen from the air, it was obvious that Rio Yaracuy was just a remnant of a once much larger stream system.

In early 1954, while working for Atlantic Refining Co. in Caracas, I prepared a short memorandum with the same title as this paper. In these notes I intend only to discuss, in a very general way, what happened to Rio Orinoco since late Cretaceous time, though it would be tempting to analyse the various stream piracies in the Barquisimeto area.

No attempt was made to update my notes or to consider any publications issued in 1954 or later. After 25 years I am completely out of touch with recent developments in Venezuelan geology. However, I still think that those ideas should be further investigated to prove or disprove them. This is the reason why I would like to submit them for the critical appraisal of muy colleagues in Venezuela.

HYPOTHESIS PROPOSED

In early Eocene time the Mérida Andes hat not yet emerged so that the Orinoco River was flowing to the northwest, west of the El Baúl landmass and west of the rising Cordillera de la Costa into the area of the Maracaibo Basin of today. But during the late Eocene the Mérida Andes started to rise and caused the gradual migration of the channels of the Orinoco into the depression formed between the incipient Mérida Andes and the Cordillera de la Costa and into the Chivacoa Gap and the San Felipe valley, the trend of which was controlled by a large-scale strike-slip fault, the Boconó fault of today. The El Baúl landmass still formed a barrier to the east. Further orogenic activities in the Mérida Andes and the Caribbean Mountains during the Oligocene closed the Chivacoa gap and forced the waters of the Orinoco to spill over the shallow saddle between the El Baúl swell and the Guayana Shield and to flow towards east into the Atlantic.

PRESENTATION OF WORKING HYPOTHESIS

The ideas of the shifting course of the ancient Rio Orinoco are presented in five sketch maps. The purpose of the maps is to show the distribution of land and sea during

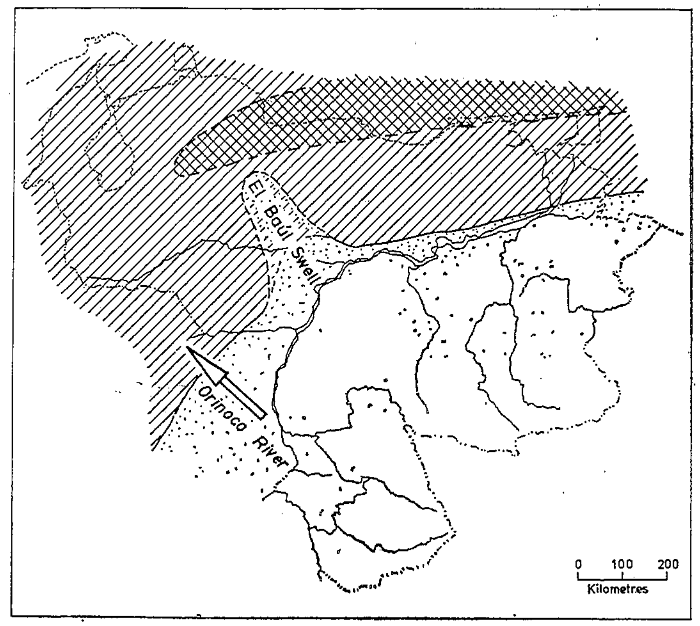

Fig. 1. Late Cretaceous time. See MENCHER *et al.* (1953: 698, Figure 3) and PATTERSON and WILSON (1953: 2711).

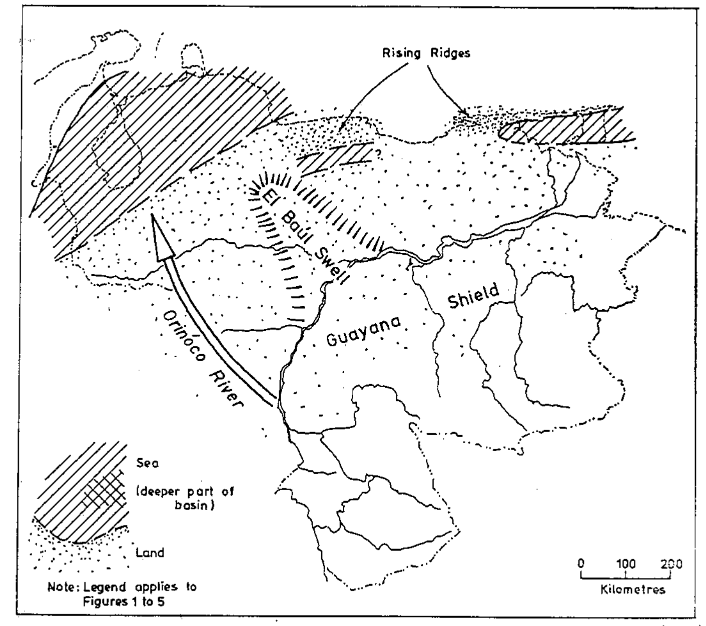

Fig. 2. Early Eocene time. See MENCHER *et al.* (1953: 704, Figure 4).

certain time intervals and to indicate the probable course of the ancient Rio Orinoco. These illustrations were not prepared as paleogeologic or paleogeographic maps. Therefore, the coast line, the drainage system and the boundary of Venezuela are shown only to facilitate general orientation.

Late Cretaceous time, fig. 1

This is the time of maximum landward spread of the Cretaceous seas. The epicontinental sea covered almost all the area of the Venezuelan Llanos of today. Contrary to Mencher, who does not indicate a landmass extending from the Guayana Shield towards the region of El Baúl, there are enough criteria to demonstrate that the El Baúl Swell existed already as a prong. From the study of PATTERSON and WILSON (1953:2711) it is known that the Cretaceous beds are thickening steadily from the area of El Baúl towards east. Further, there is no certainty that Cretaceous sediments were ever deposited on the igneous and metamorphic rocks of El Baúl.

The Guayana Shield was sloping gently under the epicontinental sea and the big streams went down the general direction of the slope. Thus, it can be visualized that the late Cretaceous Orinoco flowed towards west-northwest.

Early Eocene time, fig. 2

At the close of the Cretaceous the sea withdrew and during early Eocene time the largest part of the Llanos of today was land. Its bedrock was formed by upper Cretaceous beds which were now differentially eroded to a peneplain. Until today no evidence has been produced to demonstrate that the Andes had already emerged, but in the northern part of Central and Eastern Venezuela the first ridges of the Cordillera de la Costa were slowly rising.

It would appear that the El Baúl Swell was then a low positive landmass. The reef limestones within the equivalents of the Guasare Formation and within the Trujillo indicate proximity to the shore line of this early Eocene sea. A huge

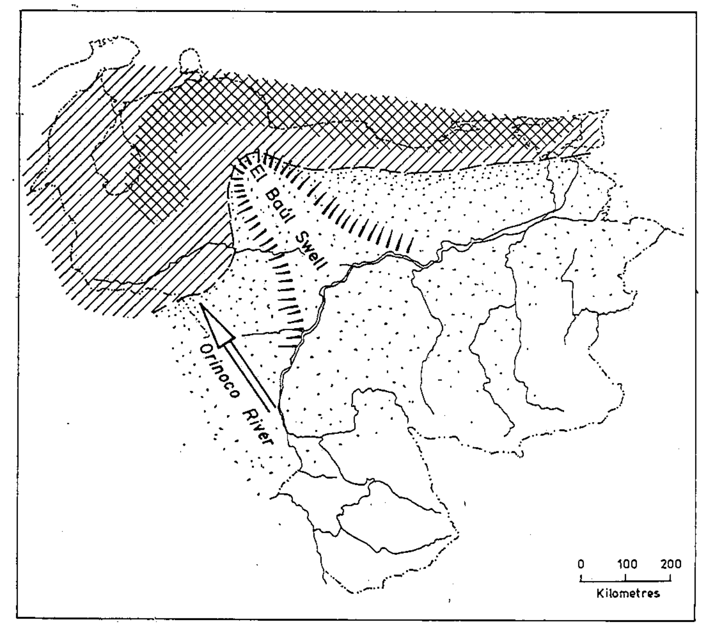

Fig. 3. Late Eocene time. See MENCHER *et al.* (1953: 709, Figure 5).

amount of detritus was spilled into the area of the Maracaibo Basing by big streams, presumably the ancient Orinoco River and its branches, laying down the Trujillo Formation.

Late Eocene time, fig. 3

The Eocene sea transgressed deeper into the continent. The many orbitoidal limestones which appear in different regions at different levels in the sequence indicate similar near-shore environments. Thick shale beds were laid down in the central part of the Maracaibo Basin (Pauji lithotope). The late Eocene sea reached the El Baúl Swell but did not

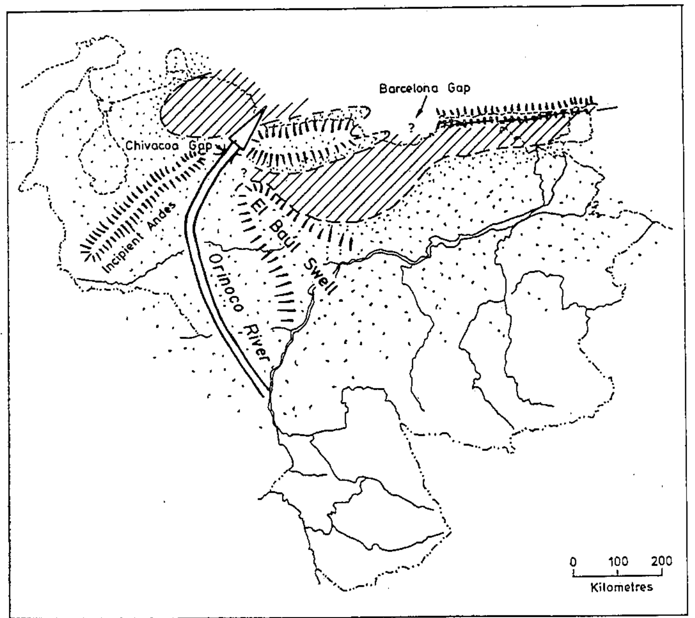

Fig. 4. Early Oligocene time. Deposition of La Pascua-Roblecito and of basal Naricual, including Areo shale.

cover it and swung around its low hills. Therefore, the ancient Orinoco must have flowed west of the El Baúl hills into the Maracaibo Basin.

Early Oligocene time, fig. 4

During the late Eocene the first orogenic movements in the Mérida Andes and a rejuvenation in the Cordillera de la Costa can be discerned. With the uplift of the Andes and the further rising of the Cordillera de la Costa, the Eocene sea regressed and only two embayments were left, one in the Falcón trough and the second along the south foot of the Cordillera de la Costa. In connection with the rising Cordillera de la Costa, this adjacent basin to the south was gradually subsiding so that thick sediments could accumulate. Later the early Oligocene sea slowly encroached on the land mass of the Guayana Shield. The La Pascua sandstones which grade laterally and vertically into the finely laminated Roblecito shales are the initial deposits of this transgressive sea. No loaded streams debouched into the northern Guárico embayment during deposition of the Roblecito shales. The extremely regular and fine bedding reflects a quiet sea. It seems that through the Barcelona gap the Roblecito sea had a connetion with the Caribbean. One arm of the embayment covered the depression in front of the Cordillera de la Costa of Eastern Venezuela and continued eastwards to Trinidad.

Thus the El Baúl Swell still formed a barrier between the ancient Eastern Venezuela Basin and the low lands to the southeast of the rising Andes. As pointed out the ancient Orinoco did not cross the El Baúl Swell and did not flow into the Roblecito sea of northern Guárico.

In the place of the Andes of today there were low ridges building a barrier to the northwest. However, a depression between the plunging Andes and the western Cordillera de la Costa opened a channel for the Orinoco towards the eastern Falcón trough. This depression, which is controlled by the Boconó fault and is an outstanding tectonic feature of Central Venezuela, will be called the "Chivacoa gap". This

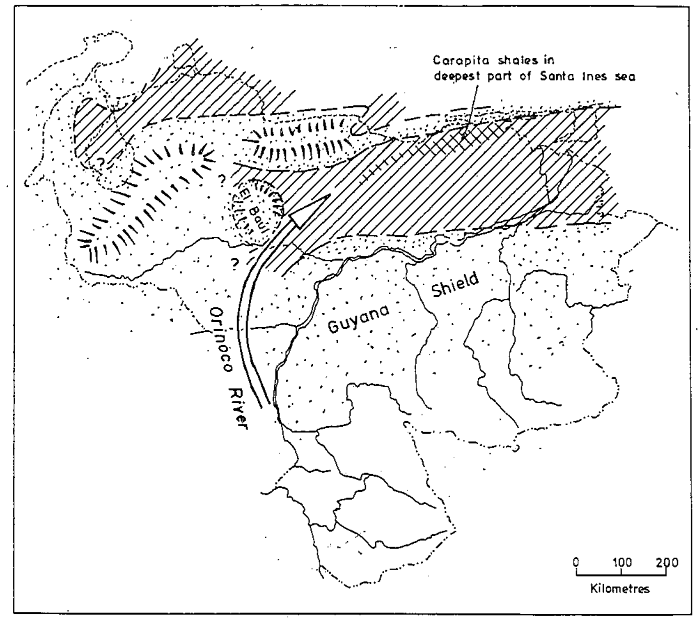

Fig. 5. At close of early Oligocene time and during Oligocene time in general. Beginning of Chaguaramas Oficina depositicn.

gap is very obvious when flying from Barquisimeto to Caracas on the regular routes used by the airlines or when driving along the highway from Barquisimeto to Puerto Cabello.

At Close of early Oligocene, fig. 5

Continuous orogenic movements in the Andes and the Caribbean mountains increased erosion. Huge piedmont fans from the Andes closed the Chivacoa gap and pushed the Orinoco southeast towards the Guayana Shield and over the lowest part of the El Baúl Swell. The loaded Orinoco discharged now into the Eastern Venezuela Basin depositing "on coastal flats channel and bar sands, carbonaceous marine to brackish shale, lignites, and claystones" (HEDBERG, 1950: 1212), of the Chaguaramas, Periquito and Oficina Formations.

Along the southern foot of the Caribbean mountains of Northeastern Venezuela similar beds derived from the erosion of the mountains to the north were laid down during early Oligocene time alternating with typical coald swamp deposits (Naricual Formation). Later, the foraminiferal shales of the Carapita Formation were deposited in the central part of the Eastern Venezuela Basin.

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APLICACION DE LOS RESIDUOS DE REGRESION LINEAL EN LA EXPLORACION GEOQUIMICA

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R E S U M E N

El análisis de datos geoquímicos en la exploración de yacimientos minerales no puede ser divorciado de la aplicación de técnicas estadísticas. Una de dichas técnicas, la regresión lineal, puede ser utilizada para minimizar los efectos que tienen los parámetros naturales en la producción de falsas anomalías. Al incluir en el modelo de regresión a todos aquellos parámetros naturales medibles, la única variable independiente no considerada será la mineralización, la cual, a su vez, causará una distribución no normal de los residuos de regresión. Los residuos de regresión, por lo tanto, constituyen valores de concentración "filtrados", dependientes solamente de los efectos de la mineralización; esto traerá como consecuencia, que los residuos serán mejores indicadores de zonas anómalas que los valores absolutos de concentración.

A B S T R A C T

When handling geochemical data for mineral exploration purposes, the statistical analysis can not be set aside. One of the statistical techniques, the linear regression, could be used to minimize the effect of natural parameters on the development of false anomalies. Once the regression model includes all the measurable natural parameters, the only independent variable not considered will be mineralization, which will cause a non normal distribution on the residuals after regression. Hence, the residual will be "filtered" values, only dependent on mineralization effects; this will make the residuals better indicators of mineralization than the absolute concentration values.

I N T R O D U C C I O N

La aplicación del análisis estadístico a datos geoquímicos constituye hoy día una práctica usual y necesaria. El volumen de datos generados en los estudios geoquímicos es en su mayoría muy grande para ser "asimilado" sin la ayuda de la computadora y el análisis estadístico. Esto sin menoscabo de la importancia del razonamiento del geoquímico investigador. Los métodos estadísticos utilizados son muy variados y la selección depende de las necesidades y pericia de dicho investigador. El problema usual surge de la "interpretación" que se le dé a los parámetros estadísticos obtenidos. El balance entre la teoría matemática y el significado físico de los parámetros está en manos de quien realiza la investigación.

Entre los variados métodos estadísticos aplicables a datos geoquímicos está el de regresión lineal múltiple, objeto del presente trabajo. Matemáticamente, una ecuación de regresión lineal múltiple puede ser expresada como:

$$Y = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_m X_m + e \quad (1)$$

donde Y es la variable dependiente, las X_i son las variables independientes, los b_i son los parámetros de regresión y "e" el residuo o error. Es de hacer notar que esta ecuación asume una distribución normal del residuo "e" alrededor de los valores de dicha regresión (DAVIS, 1973: 199, 200), como se observa en la Fig. 1.

Dicha distribución normal es cierta única y exclusivamente en el caso de que el modelo de regresión sea realmente representativo del fenómeno analizado; en otras palabras, cuando todas y cada una de las X_i sean incorporadas en el modelo.

Generalmente esta consideración de todas las variables independientes es poco menos que imposible; sin embargo, se pueden seleccionar aquellas variables efectivamente significativas, obviando otras cuya influencia sobre la variable dependiente no sea determinante. De esta forma el subíndice "m" en la ecuación 1 sería un número finito, y lo que es más importante, asequible en cuanto a tiempo, esfuerzo y costo para el proyecto a desarrollar.

En nuestro caso de prospección geoquímica, en el cual