

Basement faults and uplift in the Colombian Llanos

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with 5 figures

Zusammenfassung. Wiederholte Bewegungen im Verwerfungssystem des präkambrischen Basement beeinflussten die Mächtigkeit und die Verbreitung der phanerozoischen Schichten in den Ruckfaltungsbecken der colombianischen Llanos. Nordlich von 6° N ist die allgemeine Fließrichtung des Arauca, Casanare und des östlichen Teils der Meta Flüsse genau O-W. Das Gebiet zwischen 6° N und 2° N enthält ONO-WSW Lineamente. Südlich von 2° N und südlich der Inirida und Guayabero Flüsse sind die Fließrichtungen zunehmend uneinheitlich mit einem vorherrschenden N-S-Trend, besonders westlich von 71° W. Aus Überlegungen zur Plattentektonik sollten die Bewegungen nördlich von 2° N entlang der Hauptbasement-Verwerfungen rechtslateral sein und nach dem Süden zu linkslateral.

Die Hebung des Basements erfolgte entlang der Serrania de la Macarena. Dieses Gebiet wird durch Erdbeben gekennzeichnet und dient als Wasserscheide. Die Serrania besteht aus einer Serie von Schichten vom Präkambrium bis zum Oligozän, die nach ONO einfallen mit einem Streichen ähnlich dem des Rückens nach NNW-SSO. Entlang dem Südrand der Serrania haben die Guaviare und Guayabero Flüsse einen ONO-WSW-Trend. Wird ein ähnlicher Trend der Meta-Metica Flüsse nach WSW verlängert, dann wurde diese Verlängerung entlang der Nordgrenze der Serrania liegen. Damit kann die Serrania de la Macarena als ein Verwerfungsblock interpretiert werden, der das subandine Becken teilweise zerschneidet. Die Wiederholung von Basement-Schwellen scheint Teil des tektonischen Stils in dem subandinen Ruckfaltungsbecken zu sein.

Summary. Recurrent movements of Precambrian-aged basement fault systems has influenced the thickness and distribution of Phanerozoic strata in the Colombian Llanos backarc basin. North of 6° N, the overall river trend of the Arauca, Casanare and the eastern part of the Meta rivers is virtually E-W. The area between 6° N and 2° N contains ENE-WSW lineaments. South of 2° N and south of the Inirida and Guayabero rivers, the trends are increasingly disorganized with a predominance of N-S trends, especially west of 71° W. From plate tectonic considerations, movement north of 2° N along principal inferred basement faults should be right-lateral and left-lateral to the south.

Basement uplift has occurred along the Serrania de la Macarena. This feature is marked by earthquakes and serves as a drainage divide. The Serrania is a series of beds from Precambrian through Oligocene, dipping to the ENE with a strike similar to that of the ridge crest, NNW-SSE. Along the southern edge of the Serrania lies the ENE-WSW trend of the Guaviare-Guayabero rivers. If a similar trend of the Meta-Metica rivers is extended to the WSW, then the extension would lie along the northern limit of the Serrania. Thus, the Serrania de la Macarena can be interpreted as a thrust block, partially cutting the sub-Andean basin. Repetitiveness of basement swells appears to be part of the tectonic style of the sub-Andean backarc basin.

1. Introduction

Colombia is situated in the northwestern corner of South America (fig 1). There it is limited by two major plate boundaries, one along the Caribbean continental margin and the other along the Pacific margin. The northern boundary is marked principally by strike-slip movement, while the Pacific boundary is a subduction zone (MOLNAR & SYKES 1969).

Most of the geology of the western half of Colombia south of 7° – 8° N can be explained by subduction (CUREAU 1979; BARRERO-LOZANO 1979). It is, after all, a classic marine-continental convergence zone (DICKINSON 1978). Standard references of the regional geology include (JACOBS and others 1963, BURGL 1961, RAMIREZ & ALDRICH 1977, Tectonic Map of South America 1978, Geologic Map of South America 1964, Handbook of South American Geology 1956, MOLNAR & SYKES 1969, HEY and others 1977, IRVING 1971, JORDAN 1975, MINISTER and others 1974).

To the east of the Eastern Cordillera fold-thrust belt lies the retroarc basin, the Llanos. The Llanos are the plains that cover the eastern half of the country, a savanna of gently eastward sloping grass-covered surfaces, here and there intersected by tree-lined streams. The eastern limit of the savanna occurs where the regional slope becomes almost imperceptible and the Amazon Basin jungle vegetation takes over.

The overall structure of the Colombian retroarc basin (see DICKINSON 1978 for generalized discussion of retroarc basins) is that it is asymmetrical with a westward thickening

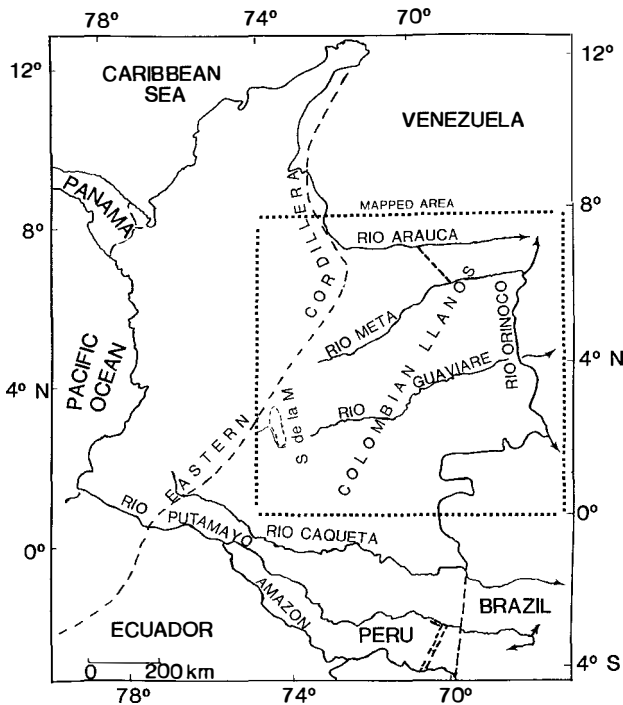


Fig 1. Location map of study area (Serrania de la Macarena is denoted as S de L)

sediment wedge from only tens and hundreds of meters of thickness along the Colombian-Brazilian border to up to possibly ten kilometers depth along the eastern front of the Eastern Cordillera (FORERO ESQUERA 1974, Tectonic Map of South America 1978, CALDWELL and others, in press, ORLANDO FORERO E and KEN BISHOP, personal communications 1978–1979). Paleozoic, Mesozoic, and Cenozoic rocks are present here. Paleozoic-aged intrusives and Cretaceous sediments have been reported in the west of the basin (FORERO ESQUERA 1974, Geologic Map of South America 1964). The wide eastern flank is characterized by a basement dip of less than 1° . There is a slight steepening of basement dip on approaching the axial zone of the basin adjacent to the Eastern Cordillera.

While there is considerable understanding of the regional tectonics within a subduction zone (i.e., DEWEY & BIRD 1970, DICKINSON 1969, 1973, 1978, TALWANI & PITMAN 1977), there is still much uncertainty concerning intraplate tectonics (see BALLY and others 1980). In this paper, we shall infer a regional tectonic fabric in the Llanos and Amazonian jungle-covered eastern half of Colombia and present speculative explanations.

2 Descriptions of linear map and underlying assumptions

In order to map the tectonic fabric of the Llanos, a linear map was prepared (fig 2). A "linear" is defined in this report as gently curved alignments of topographic features including river and stream segments. The term "lineament" will be reserved for those linears or group of aligned linears which can be interpreted to have tectonic significance (from SANDERS & HICKS 1979).

The only data available for this study are the distribution of rivers (fig 3), relatively well mapped from surveys conducted by geologists, from areal photographs, and from LANDSAT data (ARANGO CALAD and others 1976), and various topographic maps prepared by the Instituto Geografico "Augustin Codazzi", Ministerio de Hacienda & Credito Publico, Bogota. All segments of the rivers mapped as straight are marked as linears (fig 2). Those segments which are characterized by numerous meanders, yet with an overall linear trend, are also considered linear (fig 2).

The assumption underlying this effort is that rivers will find the path of least resistance (fig 3). Such a path is presumably a fracture zone extending downward to an area of broken basement. Several origins for large basement fractures have been suggested (see SAUNDERS & HICKS 1979). Chronologically as to age of tectonic influence, the suggested origins include crustal breakage from earliest Archean times to the present from whatever cause, e.g., sea-floor spreading, subduction, orogeny, meteorite impact, etc. Given a planetary crust covered by large plates of heterogeneous composition possibly moving over thousands of kilometers, inhomogeneous stress fields must be expected. Minor tectonic stresses could also include seismic energy from the globe-shaking earthquakes (>7.5 Richter scale), earth tides, plate extension or compression due to migration over a changing planetary geoidal arc, and thermal mechanics caused by volcanism and by solar radiation. Thus, these multiple minor stresses, acting on fractures in the lithified basement, can trigger the propagation of planes or zones of movement up through a sedimentary cover to exert a surficial control as on drainage. Minor movements, measured in millimeters, might be all that is needed to keep a fracture active, "open" and relatively easily erodible.

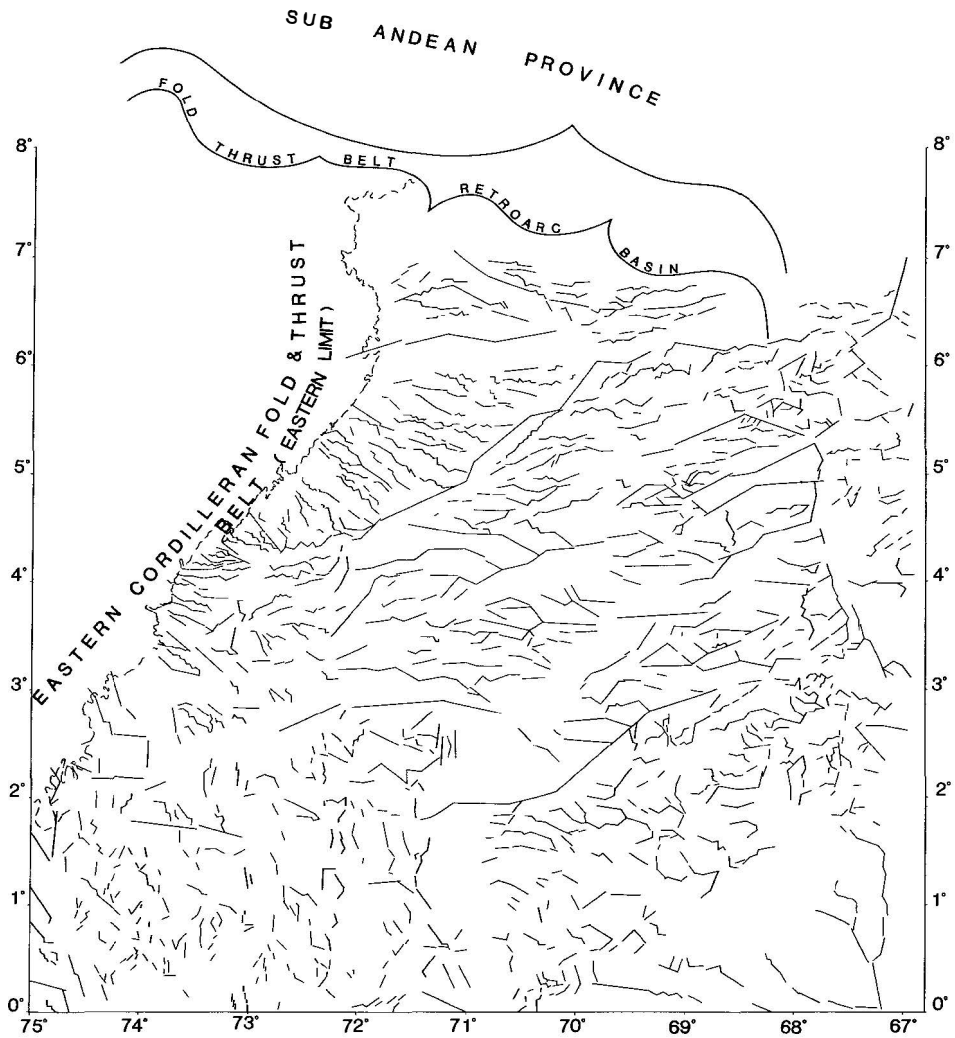


Fig 2 Lineament map of the Colombian Llanos area. Those linear riverine trends and overall linear trends characterized by meanders are shown as lines. Regional patterns suggest there is tectonic significance and thus, are lineaments

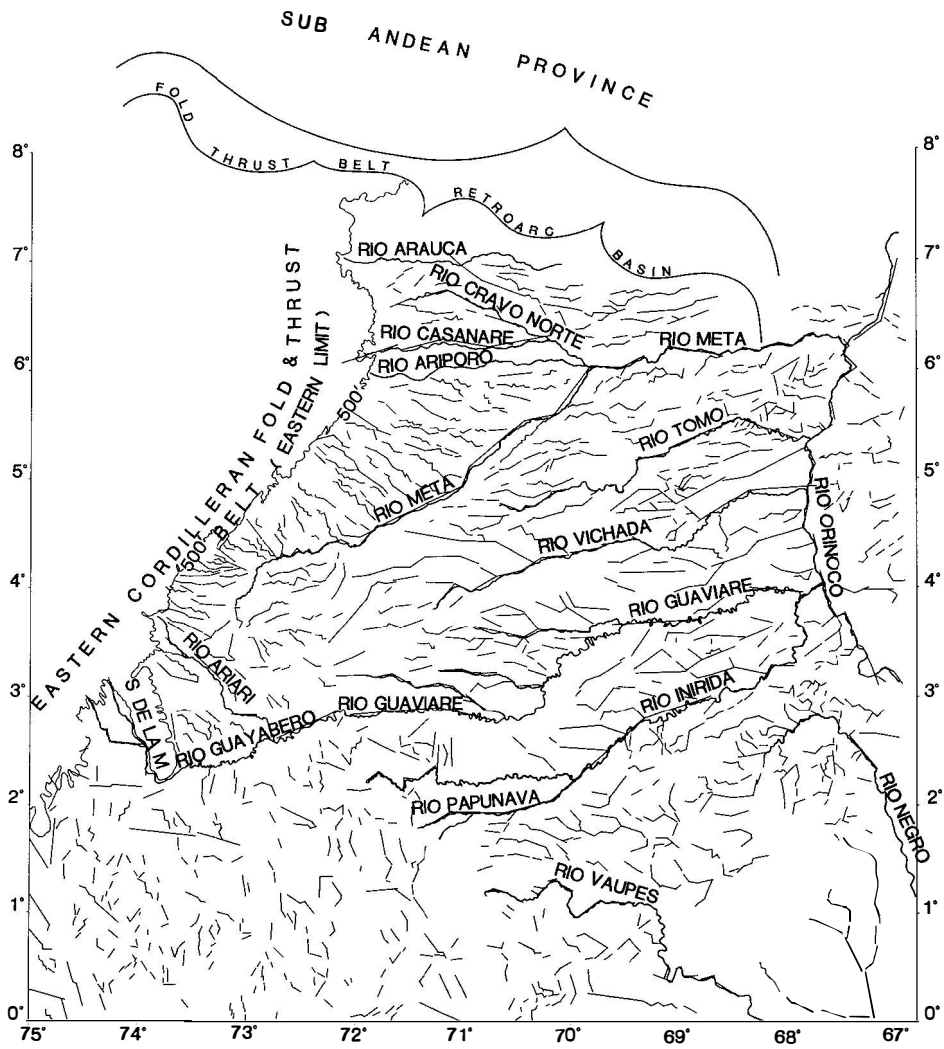


Fig 3 Lineaments and major rivers shown together The darker lines indicate rivers and the light the lineaments

3 *Interpretation of lineament map*

The principal linears are marked by the major rivers – the Arauca, Aríporo, Meta, Tomo, Vichada, Guaviare and Inirida (fig. 3). North of 6° N, the area of the Arauca, Aríporo, and the eastern end of the Meta rivers, east of 70° W, are approximately lying east-west. The area between 6° N and 2° N is marked by ENE–WSW lineaments. South of 2° N and south of the Inirida and Guayabero and the western portion of the Guaviare rivers, the trends are increasingly disorganized with a predominance of north-south trends, especially west of 71° W. South of 2° N, the principal rivers drain southward to the Amazon. North and west of the western portion of the Meta, west of approximately 71° W and of the Metica river, the river trends are roughly parallel to the regional slope and perpendicular to the axis of folding and thrust faults along the Eastern Cordillera.

Many of the linear systems, while having an overall uniaxial trend, can be interpreted in terms of a series of “dog legs” – low angle zig-zags. A ready explanation is not apparent. Thus, with the existence of recognizable riverine patterns, these linear trends may, with confidence, be thought of as lineaments with some tectonic significance.

An area of increased complexity is that surrounding the Serranía de la Macarena. The Serranía is underlain by a series of beds, from Precambrian through Oligocene, dipping to the ENE with a strike similar to that of the ridge crest, NNW–SSE. Along the western face of the ridge complex, the dipping beds are exposed (ARANGO CALAD and others 1976). To the South lies the ENE–WSW trend of the Guaviare-Guayabero river systems. If a similar trend of the Meta-Metica river system is extended to the WSW, then the extension would lie along the northern limit of the Serranía.

After the general riverine patterns were presented at a monthly meeting (26 February 1981, at Bogotá, Colombia) of the “Sociedad Colombiana de Geólogos y Geofísicos” by one of us (AL), supportive data for faulting along the inferred fracture trends became available.

Faulting along the southern edge of the Serranía de la Macarena is noted by juxtaposition of Cretaceous and lower Tertiary sediments separated by the Guayabero River ($\approx 2^{\circ}15'N \approx 73^{\circ}45'–73^{\circ}50'W$) and the orthogonal (N–S and E–W) distribution of rivers between the Serranía and the Eastern Cordillera and their relationship to mapped faults trending WNW–ESE, over the crest of the Serranía is evidence of faulting (RODRIGO ALVAREZ ALVAREZ, personal communication, 27 February 1981). Also, from the same communication, the juxtaposition of dissimilarly aged sediments on different sides of the Guayabero River near 3° N $70^{\circ}30'W$ requires faulting. Hernando Duenas Jimenez mentioned a commercial report, based on “LANDSAT” and side-looking airborne radar (SLAR) imagery, on the geologic structure of the Colombian Amazonic area (see DE BOORDER 1980). Similar trends between the two studies are the lineaments of Mitu, Cuyarí, and Papunaua (see DE BOORDER 1980, fig. 1) and our trends based on the Inirida River east of 70° W (fig. 3).

4 *Epicenter distribution*

Preliminary epicenter determinations have been prepared by the Geophysical Institute of the Universidad Javeriana (Bogotá) using data collected by the Colombian seismology net. This net was first installed in mid-1967 and has consisted of some six to nine seismo-

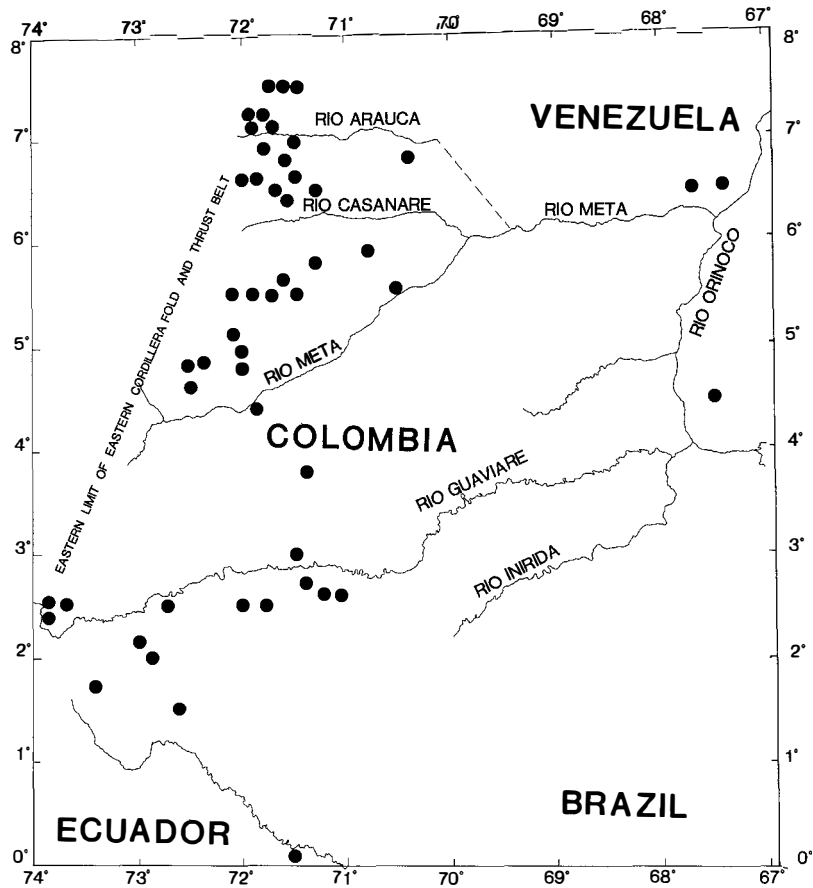


Fig 4 Epicenters calculated from Colombian seismograph net from mid-1967 to April 1979 Eastern Cordillera marked by extensive activity are arbitrarily deleted here Note poorly developed seismic patterns centered about the Rio Guaviare west of 71° W and lying west of the Rio Meta Data density does not permit an unambiguous interpretation

graphs, the number varying with equipment availability This net, unfortunately for this study, is located in the western and central parts of the country It has collected data of lower intensity (and therefore, more) motions than can be obtained by the World-Wide Standardized Seismograph Net (WWSSN) The accuracy of determinations appears to about ± 25 km. There are poorly developed low-level seismic patterns centered about the Rio Guaviare, west of 71° W and also lying west of the Rio Meta (fig 4) (In this report, the Spanish word "Rio" will be used interchangeably with the English word "River") These epicenters from both the Colombian and the WWSSN, are all shallow, less than 70 km deep, with many only 20–40 km deep The Eastern Cordillera fold-thrust belt is

marked by abundant earthquakes. Thus, there is seismic activity throughout the area of the Llanos. Data density does not allow an unambiguous interpretation.

5 Basement control of sediment

A preliminary compilation of well hole data has been prepared. These wells were drilled on the Llanos savanna (from south to north, the well log data used are from the following

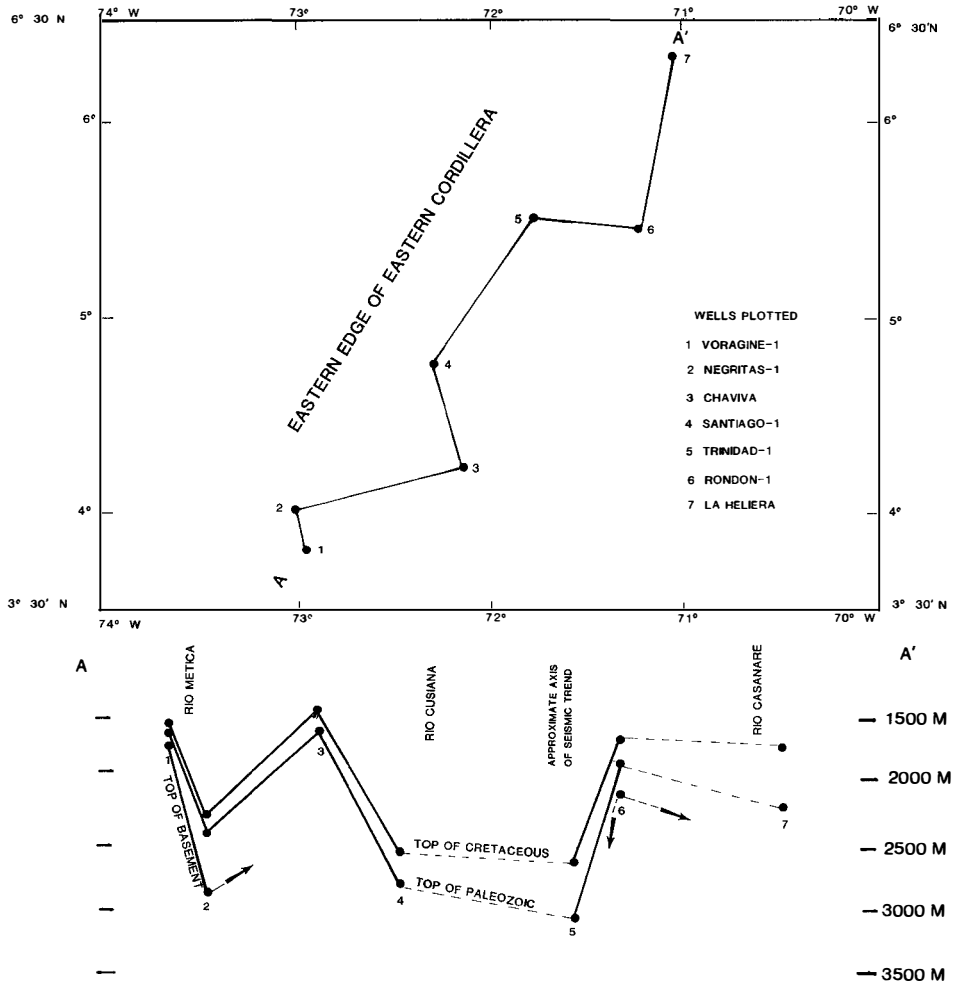


Fig 5 Profile of principal stratigraphic horizons as determined from well log data, from wells drilled on the Llanos savanna. The profile extends from 3° 50'N to 6° 15'N. The following wells Voragine-1, Negritas-1, Chivava, Santiago, Trinidad-1, Rondon-1, and La Heliera

wells: Voragine-1, Negritas-1, Chaviva, Santiago, Trinidad-1, Rondon-1, and La Heliera) These data show that in the areas where the major river-lineament trends of the Meta and Casanare approach the Eastern Cordillera, the basement is deeper than on adjacent inter-riverine areas. The basinal deepening appears to have been persistent through time with Tertiary, Mesozoic, and Paleozoic sections thickening over the basin, fault-controlled area (see WEIMER 1980, for a discussion of similar processes, i.e., recurrent movement on a presumably Precambrian-aged basement fault and its influence on subsequent sedimentation, in the central Colorado area).

The inter-riverine "high" was broken in one area. We note that the localized basement deepening roughly coincides with the seismic trend lying to the west of the Rio Meta (fig. 5). We speculate that a basement fracture, unmarked by a river, lies between the proposed faults marked by the Casanare and Meta-Metica rivers.

A drainage divide known as the Vaupes Swell (KEN BISHOP, personal communication, 23 February 1981) lies to the south of the western part of the Rio Guaviare (west of 71° W) and south of the Rio Inirida. To the south, the flow is toward the south and southeast. The poorly developed seismic pattern centered about the Rio Guaviare (fig. 5) roughly coincides with this drainage divide. Thus, in the area there is a topographic upland or "bugle" (however slight), a major change in the river patterns, and some earthquake activity. We propose that this feature be called the Colombian Llanos 2° N Basement Fault (CL 2° NBF).

6 *Discussions and speculations*

Let us suppose that these riverine trends are indeed fault controlled. Thus, the Serrania can be interpreted as a thrust block dipping to the ENE with the limits of thrust motion marked by the overall inferred basement trends not shown by the Guaviare-Guayabero and the Meta-Metica riverine systems.

The implication of this interpretation is that the crustal block between these two river systems has migrated westward relative to the areas adjacent to it. We offer a speculative hypothesis to explain such a proposed westward block movement. The eastern limit of this area of E-W and ENE-WSW trends, presumed basement faults, coincides with the national boundary along the axis of the generally north-south trending Atapapo-Orinoco river systems. The Atapapo River extends from approximately $3^{\circ}15'N$ to $3^{\circ}45'N$ in the area about $67^{\circ}20'W$. North of $3^{\circ}45'N$ to $6^{\circ}N$, the axis of the Orinoco River bends westward to a maximum near $4^{\circ}30'N$ $67^{\circ}50'W$, a total westward displacement of about 50–70 km. Further northward, where the Orinoco River no longer serves in the role of a national boundary at approximately $6^{\circ}N$ $67^{\circ}15'N$, the river has turned eastward and will continue so turning to the latitude of $7^{\circ}N$, at which point, the overall trend will be toward the ENE.

Thus, if the overall trend of the Atapapo-Orinoco river system could be said to lie along the $67^{\circ}10'W$, then the area in question between the Meta-Metica and Guaviare-Guayabero river systems has indeed moved westward some 50–70 km. Such a lateral "movement" would be entirely adequate to cause the thrust structure seen along the Serrania de la Macarena.

It is noted that the overall riverine trends of the Llanos do not appear to be continued further to the east beyond the Orinoco River where the Precambrian Basement is exposed

(GLYNN PENFIELD, telephonic communication, 15 May 1981) Thus, the argument that the riverine trends are indeed controlled by reactivated Precambrian-aged faults is weakened, unless the reactivation of basement faults has been controlled or dominated by the Mesozoic-Tertiary plate convergence and the buildup of volcanic arcs, fold-thrust belts, etc., in the Colombian Llanos

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