MEMOIRS OF THE FACULTY OF SCIENCE, KYOTO UNIVERSITY, SERIES OF GEOL. & MINERAL.,
Vol. LVIII, Nos. 1 & 2, pp. 41-66, 1996

# Geology of the La Tatacoa "Desert" (Huila, Colombia): Precisions on the Stratigraphy of the Honda Group, the Evolution of the "Pata High" and the Presence of the La Venta Fauna

By

Carlos VILLARROEL A.*, Takeshi SETOGUCHI**, Jorge BRIEVA* and Carlos MACÍA*

(Manuscript received August 31, 1995)

**Abstract**

Middle Miocene fluviatile sequences are developed over a wide area of the La Tatacoa "desert" (the La Victoria and Villavieja Formations of the Honda Group). In contrast, pre-Miocene rocks, which range from possible Upper Palaeozoic calcareous deposits to Jurassic volcanics of the Prado Member (Saldaña Formation) and the Cretaceous sediments of the Monserrate Formation, outcrop only in small and irregular patches.

Since the 1950's many different stratigraphic schemes have been proposed for the La Tatacoa Neogene sequence. A critical analysis and discussion of these various proposals is needed to establish a stratigraphic scheme that meets the requirements of both scientific accuracy and practical need. Based on the analysis of this kind, it is suggested that the level "group" must be retained for the Honda lithostratigraphic unit. Similar considerations suggest that the Honda Group can be subdivided into two formations: La Victoria (sensu Guerrero, 1994) and Villavieja. The validity of defining Baraya and Cerro Colorado Members, occupying the lowest and highest part of the sequence respectively, can also be established. However the previously defined informal divisions that involve treating other units as members and/or beds are disregarded, because they are considered superfluous and serve only to create confusion.

Geological research of the region has reached a detailed level of understanding, and this combined with the present geographic location, can be used to discuss various aspects of the tectonosedimentary development of the northern part of the Upper Magdalena Valley. Based on the characteristics of the stratigraphic sequence and on the results of radiometric dating, different stages in the geological development of the region during the Neogene can be defined. This geological development has to be set in a context, which includes the influence of the Central Cordillera, the elevation of the "Patá High" (=Natagaima High or Natagaima Arch) and the uplifting of the Eastern Cordillera. Finally, aspects related to the presence (appearence?), expansion and extinction of the La Venta Fauna are considered within the context of the proposed tectonosedimentary scheme.

## Resumen

En el mapa geológico adjunto, correspondiente al "desierto" de La Tatacoa (Fig. 5),

* Universidad Nacional de Colombia, Bogotá, Depto. de Geociencias. Apdo. aéreo 14490, Bogotá, Colombia

** Department of Geology & Mineralogy, Faculty of Science, Kyoto University, Kyoto 606-01, Japan

puede observarse que las secuencias fluviátiles del Mioceno Medio, que pertenecen a las formaciones La Victoria y Villavieja del Grupo Honda, afloran en forma muy extensa; por el contrario, las rocas pre-miocenas, correspondientes a depósitos calcáreos del Palaeozoico Superior(?), a vulcanitas jurásicas del Miembro Prado de la Formación Saldaña, y a sedimentitas cretácicas de la Formación Monserrate, lo hacen sólo en pequeños y aislados sectores.

A partir de los años cincuenta, la gran mayoría de autores que ha trabajado la secuencia neogena de La Tatacoa ha utilizado esquemas estratigráficos diferentes, por lo cual, se analiza y discute críticamente cada uno de ellos con el objetivo de proponer uno, que además de responder a exigencias formales, posea valor práctico. En este entendido, se insiste en la necesidad de adoptar para el Honda un rango estratigráfico de nivel Grupo, asimismo, se acepta la división de éste en dos formaciones: La Victoria (sensu Guerrero, 1994) y Villavieja; en esta última unidad se reconoce la validez de los miembros Baraya, en la base, y Cerro Colorado, en el tope; en tanto que se valora la división informal de Fields (1959), se desestima la proposición de otras unidades de rango miembro y/o capa, por considerar que además de innecesarias son factores de confusión.

El detalle que se ha alcanzado en el conocimiento geológico de la región, sumado a su ubicación geográfica actual, permite precisar aspectos relacionados con el desarrollo tectonosedimentario de la parte norte del Valle Superior del Magdalena; en tal sentido, basados en las características de la secuencia estratigráfica y en las dataciones radiométricas que se poseen, se consideran las etapas por las que ha atravesado el desarrollo geológico de la región durante el Neogeno, dentro de un marco que comprende la influencia de la Cordillera Central, la evolución del Alto del Patá (=Alto o Arco de Natagaima), y el levantamiento de la Cordillera Oriental.

Finalmente, en el contexto del esquema tectonosedimentario propuesto se encuadran aspectos relacionados con la presencia, expansión y extinción de la Fauna de La Venta.

## Introduction

Since the early 1940's, when the so-called "desert" of La Tatacoa started to be known as one of the most important Cenozoic fossil vertebrate localities in South America, the region has been the focus of numerous stratigraphic and palaeontologic studies. Furthermore, even before this time, many companies linked to the petroleum industry were interested in the region. It is, therefore, not surprising that geological research of this region has reached a high level of understanding and refinement compared to other regions.

There is detailed information available on stratigraphy (litho-, chrono-, bio- & magnetostratigraphy), sedimentology (palaeoenvironmental reconstructions based on the fauna and sedimentary structures), tectonics, geophysical characteristics (mainly seismic

data), and palaeontology (characteristics and composition of the so-called La Venta Fauna). This wealth of data allows us to reconstruct the development of the area during the Tertiary in considerable detail.

## Geographic Characteristics and Geologic Location

The study area is located about 35-40 km to the NNE of Neiva (Fig. 1). It extends from the eastern riverside of the Magdalena River and corresponds to the entire region usually referred to as the "desert" of La Tatacoa. The landscape is flat, and gently in-

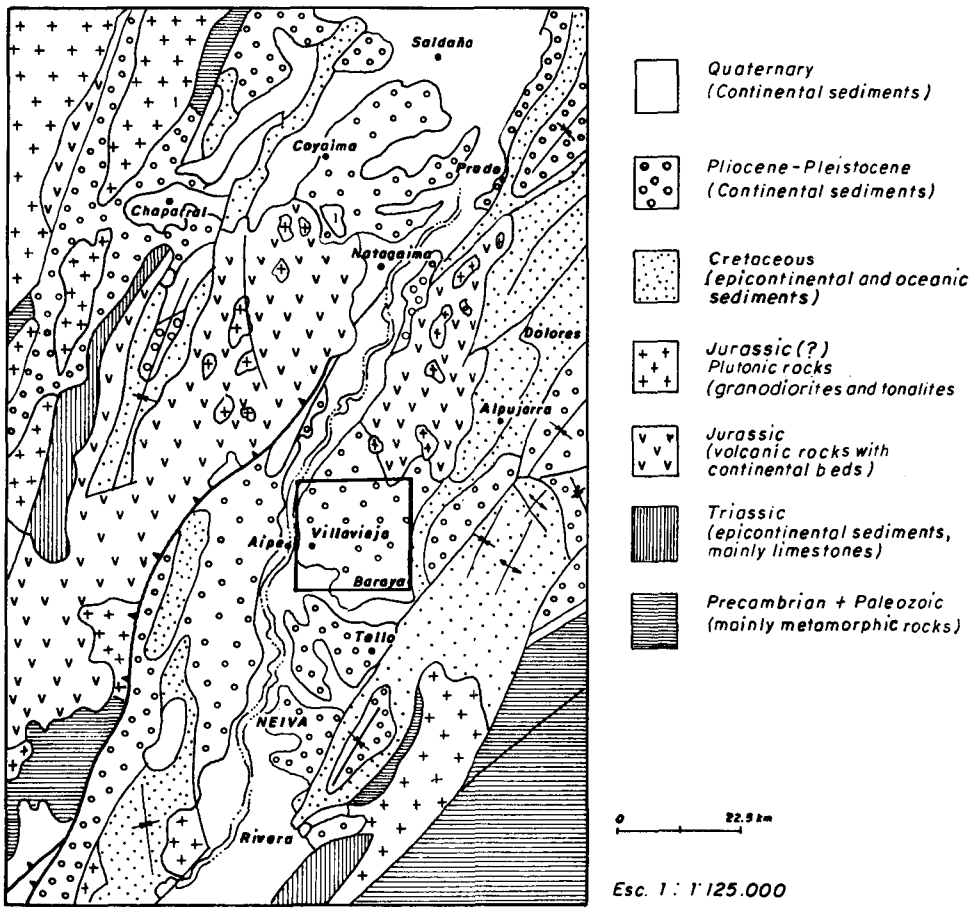


Fig. 1. Geological map of the Neiva and Girardot Sub-basins (Upper Magdalena Valley) and adjacent parts of the Central and Eastern Cordilleras (simplified from INGEOMINAS, 1988). The square indicates the location of the geological map of La Tatacoa "desert".

clined to the west, although locally there are some small rounded hills such as the Cerro Gordo, Tenerife and La Becerrera Hills. The medium altitude above sea level is approximately 580 m.

Geologically the study area is part of the northern extreme of the Neiva Sub-basin of the Upper Magdalena Valley. This corresponds to the high part and the southern slope of the "Alto del Patá" (LOZANO & SOTO, 1992), or "Arco de Natagaima" (ALVAREZ & MOROS 1986, MOJICA & FRANCO 1990). During the Mesozoic and Cenozoic, its geological evolution is, therefore, linked to the development of Central and Eastern Cordilleras of the Colombian Andean System.

## Stratigraphy

The units corresponding to the Honda Group cover most of the "desert". The main outcropping units, their ages, and the names adopted in this paper are given in the stratigraphic column of Fig. 2. In the following we divide the stratigraphic column into 4 and describe the characteristics of each.

### Upper Palaeozoic (?)

#### Introduction

The only outcrop of this unit occurs as a small hill 15 km to the NNW of Baraya, on the western flank of the La Becerrera Hill. The lithology is dark grey limestone and marbly limestone that is very hard and stratified in beds 50 cm or more in thickness. Hydrothermal veins are common.

#### Age and correlations

MOJICA & VILLARROEL (1989:101) suggest that this suite of calcareous rocks may be of Upper Palaeozoic age. This suggestion is based on the similarity in lithology with rocks of that age outcropping to the west of San Antonio and in the Cerro Neiva (Neiva Hill). MOJICA & FRANCO (1992:2, Fig. 2) have named this the Aguascalientes Formation, and postulated correlations with the Payandé Formation, of similar lithology, but of Triassic age. This suggestion is, however, unlikely since this younger unit is limited to the central part of Tolima Department. However, a final solution of this problem awaits the discovery of correlatable fossils.

Recent field observations have led us to conclude that the Becerrera outcrop is, in fact, a large block (xenolith) included in the porphyritic andesites of the Saldaña Formation. This conclusion in compatible with the strong fracturing of the limestones, and also with the fact that small xenoliths of limestone and quartzitic sandstones are found inside the same andesites 1 km farther north on the western flank of Tenerife Hill.

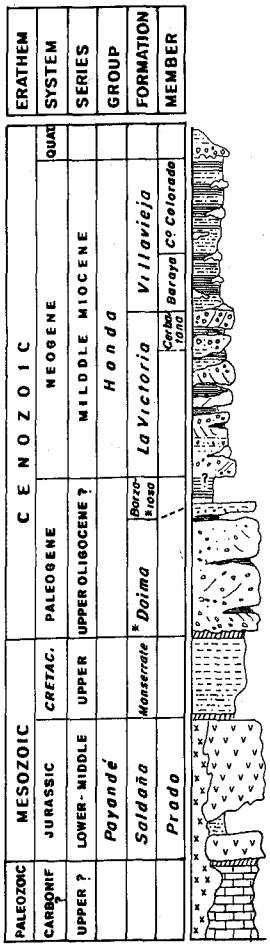


Fig. 2. Stratigraphic column showing litostratigraphic units discussed in the present paper; those marked by (*) can be found only in the subsurface.

## The Payandé Group
## The Saldaña Formation (sensu Cediel et al. 1980:93)
## The Prado Member

### Introduction

Even though the Lower to Middle Jurassic volcanics of the Prado Member (Mojica & Llinás, 1984:95) have been important as source rocks of the Cenozoic units, their actual position in the study area is limited to two main regions, the Cerro Gordo (located to the NW in the geologic map, Fig. 5) and a N-S trending chain of hills, known as Tenerife and La Becerrera (NE of the geologic map). As discussed later, both elevated regions can be interpreted as palaeo-highs of the so-called "economic basement" and, as

such, they belong to the Patá High.

### Lithology

The Prado Member consists of andesitic porphyries, although an intercalation of stratified reddish-brown siltstones is also found in the western flank of La Becerrera Hill. Observations of thin sections from Cerro Gordo show that the andesitic porphyry contains phenocrysts of intermediate plagioclase and clinopyroxene. The matrix is microcrystalline, and mafic regions are altered to chlorite. Hydrothermal alteration is shown by the development of epidote, calcite, chlorite, cericite, silex (chalcedony, quartz), anatase and brookite. These rocks may represent either lava flows or a volcanic neck. A thin section of sedimentary xenolith from the andesitic porphyry of Cerro Gordo was also examined. It is a quartzose siltstone, reddish-brown in colour, in which grains of quartz of volcanic origin, chert fragments, micas (white mica) and opaque minerals can be distinguished within a clay matrix. The xenolith may have originated in red beds similar to those from the Saldaña Formation.

## The Monserrate Formation

### Introduction and lithology

This formation outcrops in an exiguous extension of the study area, which, regionally speaking, is part of the western flank of the San Antonio Syncline (Servicio Geológico Nacional, 1959) or Caracolí Syncline (GÓMEZ, 1993). The core of this syncline consists of Honda Group rocks and is found to the east of the eastern limit of the study area. The unit was studied in the Las Lajas Creek (Hacienda Buenavista), 5 km north of Baraya, where two lithologic groups can be differentiated. A basal group is truncated by the Baraya Fault (Saltarén Fault, according to GÓMEZ, 1993), and consists of strongly folded siliceous siltstones, light grey in colour, that make up a series of low rounded hills (Filo Pecho de Gallo). These hills are located to the west of the ridge that corresponds to the Monserrate Formation. The lithological characteristics and stratigraphic position of this formation suggest that it may correspond to the (so-called) Olini Group. Nevertheless, in view of the fact that the outcropping thickness is never very great, it is convenient to combine it with the Monserrate Formation on the geologic map. The overlying lithologic group coincides with a conspicuous SSW-NNE trending crest (El Boquerón Hill, Saltarén Crest) to the north of Baraya, which in this sector marks the eastern limit to the Upper Magdalena Valley. This group is composed of whitish fine-grained quartzitic sandstones, that are very hard and are stratified in thick beds of up to 2 m. Locally abundant ichnofossils of the *Thalassinoides* type are present in the base of some beds.

## The Honda Group

### Introduction

Extensive and well-exposed outcrops of this group are found in the "desert" area.

Geologic studies of the Honda Group have had a rather haphazard development, and this has enormously complicated the overall stratigraphy of this group. For instance, it is common to find an excessive number of toponyms designating lithostratigraphic units of different ranks, inappropriate modifications of preexisting denominations, duplications of names, and unwarranted interpretation of established results. For these reasons, we believe that it is necessary to take a fresh look at the data and to establish a clearer and less cumbersome nomenclature for the stratigraphy of the Honda Group.

In the following we consider geological data from diverse disciplines. Our purpose is to establish parameters that enable us to correlate not only the group but also the minor units throughout the Upper and Middle Magdalena Valley.

Nomenclatural considerations[1]

a) To the Group level

The first attribution of the sediments of La Tatacoa to the Honda Formation can be found in Royo y Gómez (1942 and 1946). The Servicio Geológico Nacional (1959: Map N8, Neiva) adopts this suggestion, and it is also followed by many later authors (Beltrán & Gallo, 1968; Van Houten & Travis, 1968; Wellman, 1968; Fuquen et al., 1989; Wiel, 1991; Wiel & Berg, 1992; Gómez & Diederix, 1993). Stirton (1953) likewise employs the Honda toponym, however he assigns it the rank of group. Authors such as Fields (1959) and Wellman (1970) follow this proposition, and Wellman further divides the group into two formations. As can be seen in the geologic papers of the Neiva Subbasin, Honda has been used as the name for both a group and a formation. Despite this discrepancy most authors adopt one or the other without any discussion on their relative merits. A notable exception is Wiel (1991:42) and Wiel & Berg (1992:157), for whom "this subdivision (that of Wellman, 1970) proved to be untenable in the southern Neiva Basin because small isolated outcrops cannot be determined on the formational level". We disagree, however, and don't think that the difficulty in the identification of the formations of the Honda Group in small and isolated outcrops invalidates the division of the group. Moreover Wellman (1970) was indeed able to differentiate two formations in the same sequence studied by the above mentioned authors and in the La Tatacoa desert. Our results (this paper), those of Takai et al. (1992) and Guerrero's (1993 and 1994) are all in agreement in considering the Honda unit a group and not a formation.

[1] In the following discussion, the reader should refer to the Correlation Chart (Fig. 3)

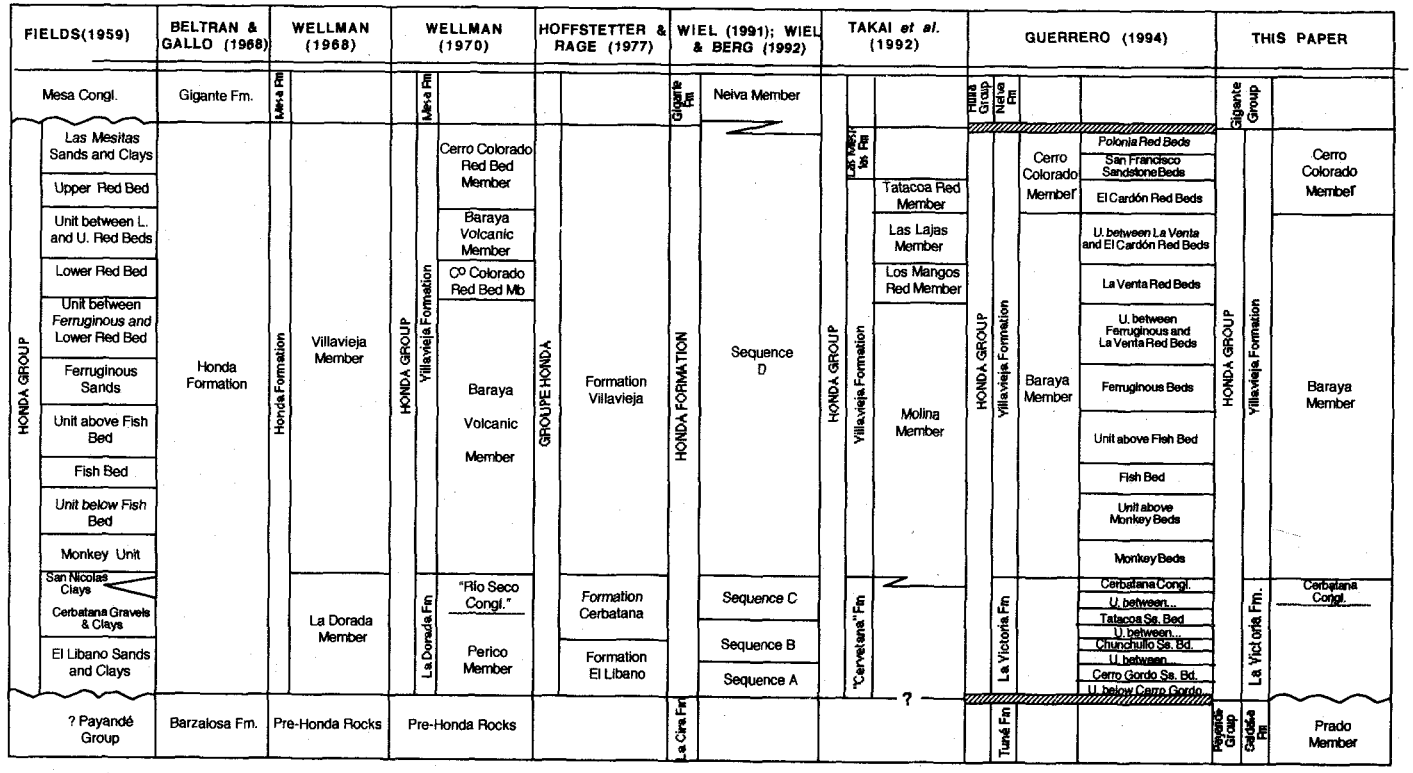


Fig. 3. Correlations chart.

**b) To the Formation level**

As mentioned above, WELLMAN (1970) is considered to have been the first to make a formal division of the Honda Group into the La Dorada and Villavieja Formations. In his doctoral thesis, WELLMAN (1968) recognized the Honda as a formation and the other two units as members. Some years later, HOFFSTETTER & RAGE (1977) accepted the validity both of the Honda Group and the Villavieja Formation, but they don't recognize the La Dorada Formation, because they state that it was defined very far from the "desert" area, and for the corresponding sequences they propose the El Líbano and Cerbatana Formations. These two formations are based on those used by FIELDS (1959). In this respect it is necessary to raise a point related to the boundary between the Cerbatana and Villavieja Formations. TAKAI et al. (1992) and GUERRERO (1993, 1994) have proved that the "San Nicolás Clays" are not part of the "Cerbatana Gravels and Clays", as Fields thought (Op. cit.), but are equivalent to the "Monkey Units". This implies that they belong to the base of the overlying Villavieja Formation. It is worth mentioning that the thickness of the Cerbatana Conglomerate is, in reality, much thinner than the 238.5 m reported by Fields; perhaps only 9 m according to GUERRERO (1994) or 40-45 m according to our measurements. These results show that the recognition of the Cerbatana Conglomerate as a formational unit is not acceptable. Moreover, the same kind of argument would also bring into question the validity of the El Líbano Formation (sensu Hoffstetter & Rage), implying that further redefinition may be necessary in the future.

Recently, TAKAI et al. (1992) proposed a new stratigraphic scheme in which two new formations are added: Cervetana (sic)[2](*) and Las Mesitas, as well as new toponyms with the rank of member inside the Villavieja Formation (Molina, Los Mangos, Las Lajas and Tatacoa). The proposal of Takai et al. (Op. Cit.) to introduce the "Cervetana" and Las Mesitas Formations do not meet the formal requirements for such divisions. A certain amount of redefinition is also required for the "Cervetana" Formation of Takai et al., which was proposed by HOFFSTETTER & RAGE (1977), and for the original suggestion of FIELDS (1959). In particular, the upper and lower limits should be fixed, and some of the units included in the Cervetana Formation by TAKAI et al., the "San Nicolás Clays", in fact belong to the overlying Villavieja Formation. It is important to be clear about this boundary. Information about the lower limit of the formation varies considerably from one study to the next, not only because of its transitional nature but also because of estimates of thickness of the formation. The Las Mesitas Formations is lithologically rather featureless and it is difficult to draw a clear distinction from the Villavieja Forma-

[2] The Proposed modification of the toponym 'Cerbatana' by 'Cervetana' (TAKAI et al., 1992:6, note of page) is difficult to justify, since in the topographic maps of the IGAC (#302: Aipe, Scale 1:100.000, 1973, and #302-IV-B, Scale 1:25.000) the eponymous creek is designated as "Q. La Cerbatana"; there is moreover, good historical precedent for this name which has been used without modifications since 1959, when Fields first proposed it.

tion, which underlies it. In a similar way, information about the upper limit of the Cervetana Formation is lacking in TAKAI et al. (1992). As shown in the correlation chart (Fig. 3), the new formation, together with the "Tatacoa Red Member" (sensu TAKAI et al., 1992), would be equivalent to the upper member ("Cerro Colorado Member") of the Villavieja Formation of the scheme developed by WELLMAN (1992).

Finally, GUERRERO (1990, MS thesis) proposes a new variant, which is partially complemented in his doctoral thesis (1993). He proposes to introduce a new 'La Victoria' Formation for the sedimentary set that lies nonconformably upon the volcanics of the Prado Member, in the Chacarón Hill, and which is capped by the "Cerbatana Conglomerate Beds" (GUERRERO 1990, MS). The La Victoria Formation is equivalent to the El Líbano and Cerbatana Units (excluding the "San Nicolás Clays") of FIELDS (1959), or alternatively what Wellman (1970) calls 'Perico', the upper member of his "Dorada Formation". In our opinion, the detailed and exact definitions by GUERRERO (1994) are important, because they overcome these inconsistencies and nomenclatural inaccuracies that have been created around the definition of the basal sequence of the Honda Group. We, therefore, adopt it in this paper.

With the exception of Takai et al. (Op. Cit.), whose proposals have already been discussed, most recent authors follow the proposal by WELLMAN (1970), that is, to designate the upper sequence of the Honda Group with the name 'Villavieja'.

**c) To the Member and Bed level**

Further confusion has arisen from formal or informal proposals of an exaggerated number of lithostratigraphic units within each of the formations. In fact, based on the divisions by FIELDS (1959) and WELLMAN (1970), stratigraphic schemes with several members and/or beds have been proposed, in which some aspects of major or minor importance have been ignored, as explained below.

Fields (Op. Cit.) made the first detailed division of the Honda Group into minor units. He recognizes 12 units inside the sequence that outcrops between Cerro Gordo and Las Mesitas (ESE of Villavieja). This scheme was established mainly in order to trace minor units whose presence can help locate fossil remains. As FIELDS (1959:405) clearly states, in no case are these proposed divisions seen as formal lithostratigraphic units. The scheme of Fields is, however, an excellent practical tool which is still used and will be valuable for making further progress in detailed bio- and chronostratigraphic studies.

In contrast WELLMAN (1970) subdivides the complete the Honda sequence outcropping in the Neiva Sub-basin (Fig. 3) into three formal members: "Perico Member", "Baraya Volcanic Member" and "Cerro Colorado Red Bed Member". In modern studies, the "Perico Member" of "La Dorada Formation" is no longer used. The other two, which are assigned to the Villavieja Formation, are, however, still in common use. Despite the widespread use of these two members, their boundary is not clearly defined.

WELLMAN (Op. Cit.:2358) states that "In the type area, the Villavieja Formation consists of two alternations of volcanic and red bed facies", and this is illustrated in the geologic column of his figure 5 (p. 2361). Wellman does not clearly state how he came to this conclusion. It is possible, however, that the column does not reflect an interdigitation of the members, because such relationships have not been observed by any other geologist working in the "desert" area. GUERRERO (1994) adopts the proposal of WELLMAN (1970) without considering any possible overlap of the members, and fixes the boundary at the base of the thick reddish silt-clay set that is widely exposed in the El Cardón sector (E of Villavieja). The lithofacial characteristics of both members are readily distinguished in the field, since they were formed under different sedimentological conditions during the formation process of the Upper Magdalena Valley. Stratigraphically, it is more appropriate to include the lower package of the "Cerro Colorado Red Member" by WELLMAN (1970) (="Ferruginous Sands" by Fields, 1959) in the Baraya Member.

Finally, the division of the Honda Group made by GUERRERO (1994 and 1993, Fig. 3b) into 19 units of Bed rank seems excessive to us. The International Stratigraphic Guide (1980:37) and the North American Stratigraphic Code (1983, Art. 26, Remarks (a)) recommend the formal designation of only a limited number of Beds, which due to their particular characteristics would be sufficient to indicate or show any litho-, bio- or chronostratigraphic event inside the sequence. Furthermore, this type of approach would avoid unnecessary complication in the stratigraphic nomenclature of the region.

### The La Victoria Formation

This formation was originally defined by GUERRERO (1991) in his Master Thesis, and further expounded by the same author (1993:13) in his Doctoral Thesis. Details of this work are soon to be published.

Type locality: Following the work of Guerrero the type locality is placed in the "La Venta area", where the corresponding type sections were measured.

Toponym: The name was taken from La Victoria town, located 15 km to the NNE of Villavieja, on the road that connects this town with the San Alfonso municipality.

Partially or completely equivalent denominations: The principal alternative names for the corresponding part of the stratigraphic column are summarized in the correlation chart (Fig. 3).

Lithology: The La Victoria Formation shows a predominance of sandstones, conglomeratic sandstones and conglomerates (75%) over claystones and siltstones (25%). In the

Cerbatana Conglomerate, that corresponds to the upper 45 m of the formation, conglomerates are abundant and are stratified in thick banks that can reach 10 m; a matrix-supported texture predominates, although a clast-supported texture is also present at some levels. Trough-cross stratification is common, and it is also common to find normal-grading stratification and imbrication of clasts. The palaeochannels lie erosively above silt and clay banks, and irregularly-shaped clayey clasts are commonly found near the base. The clasts are predominantly "milky" quartz, chert and volcanic rocks; the diameter of the clasts locally reaches 15 cm, although the average value is around 7 cm. Medium to coarse-grained sandstones and conglomeratic sandstones are interstratified in the conglomerates, and their thickness can reach 2 m. Their grain composition is the same as that of the conglomerates, and in general terms they have the appearance of "salt and pepper sandstones". The sandstones and conglomeratic sandstones commonly show the development of hardened layers due to cementation by calcium carbonate mainly on the tops. These structures, that locally form crusts of considerable extent, may also take the form of rounded or oval concretions of different sizes. The continuity of the cross and graded stratification and clast imbrication in the concretions prove that they originated as secondary structures. Their genesis has been studied by OHNO (1988).

The less common siltstones and claystones are present mainly as two or three packages with a highly variable thickness (Fig. 4); typically ranging from 1 to 11 m. In each of these packages it is possible to differentiate approximately 1 m thick sets which have colours or tones (reddish-brown, greenish-grey and greyish).

Below the Cerbatana Conglomerate, the conglomerates are reduced to thin and sporadic occurrences in which the clasts reach only 2 to 3 cm in diameter. The sandstones are stratified in banks of 1.5 to 2 m thick, and they are mainly fine- to medium-grained, show good sorting, and the grains are subangular to subrounded. These lithologies can still be regarded in common terminology as "salt and pepper sandstones". The main sedimentary structure is medium-scale trough-cross stratification. The silty and clayey packets show similar lithologic characteristics to those found within the Cerbatana Conglomerate, but they are more abundant and their thickness is only around 3 m.

The above sedimentological observations show that the La Victoria Formation developed as the result of fluvial processes. According to GUERRERO (1994), the lower part of the unit was deposited by a meandering stream system, while the upper part (Cerbatana Conglomerate, sensu Guerrero, Op. Cit.) was deposited by a net of braided rivers (Fig. 4). The palaeocurrent trends indicate that the rivers flowed mainly to the E and to the ESE.

Observations: The La Victoria Formation was introduced to designate the basal formational unit of the Honda Group outcropping in the La Tatacoa "desert". The term replaces the "Perico Member" of the "La Dorada Formation" (WELLMAN, 1970). Accord-

ing to the original definition, the base of the unit lies nonconformably upon the volcano-sedimentary rocks of the Prado Member. The whole Formation composed of the Cerbatana Conglomerate (partially equivalent to the "Cerbatana Conglomerate Beds", by Guerrero, 1994, and possibly equivalent to the "Río Seco Conglomerates" by WELLMAN, 1970), conformably underlies the basal siltstones and claystones of the Villavieja Formation.

Use of the La Victoria toponym allows us not only to overcome the uncertainty that is derived from the formational name established in a very distant locality (La Dorada Formation of the Middle Magdalena Valley), but also to overcome the confusion created by previous proposals. With regard to the first point it is necessary to remember that PORTA (1966) initially proposed a nomenclature for the Middle Magdalena Valley sequence that differs to that of WELLMAN (1968, 1970). We emphasize that the use of the "La Dorada Formation" ought to be abandoned not only in the Upper Valley, but also in the Middle Valley.

Despite the above discussion, we admit that the use of the La Victoria Formation is at present limited to the Neiva Sub-basin. It is expected, however, that further studies will allow us to correlate the unit with others outcropping in the Girardot Sub-basin and in the Middle Magdalena Valley.

Age: GUERRERO (1993, Figs. 7a and 7b) reports seven radiometric ages. Five of them (13.34±0.41, 13.78±0.08, 13.77±0.05, 13.59±0.17, 13.69±0.14 Ma) correspond to samples from close to the outcropping base of the unit (Fig. 4), while the other two radiometric ages (12.49±0.11, 12.65±0.26 Ma) belong to samples taken from the Cerbatana Conglomerate. The Calculation of the ages was made in volcanic clasts included in the unit, implying that the sedimentation was somewhat younger than the mentioned values.

An alternative approach is taken by HAYASHIDA (1984) and GUERRERO (1993). They also use palaeomagnetic studies to discuss the age of the formation. According to the Global Stratigraphic Chart of the International Union of Geological Sciences (IUGS) the ages obtained locate the La Victoria Formation in the Serravallian Stage of the late Middle Miocene.

### The Villavieja Formation

Original proposition: The Villavieja toponym was initially used by WELLMAN (1968:13) in his Doctoral Thesis with the rank of member. Two years later, the same author (1970:2357) made a formal proposal of this terminology, but this time with the rank of formation.

Type locality: The Villavieja municipality, 35 km to the NNE of Neiva, located on the

eastern riverside of the Magdalena River, is, according to the original designation, the eponymous locality for the formation.

Lithology: Siltstones and claystones (75%) predominate over the sandstones and the conglomeratic sandstones (25%) in the formation (Fig. 4). The siltstones and claystones occur as packages that can exceed 8 m in thickness, and are intercalated with thin beds of fine- to medium-grained sandstones with an average thickness of 10 cm. The claystones and the siltstones are stratified in banks approximately 1.5 m thick, and are greenish, reddish-brown or bluish-grey in colour. Weathered surfaces show "cauliflower erosion". The sandstone and conglomeratic sandstones show a distinct lenticularity and, in most cases, their thicknesses does not exceed 1.5 to 2.5 m. It is common to find the lateral transitions between the sandstones to the siltstones.

The most abundant type of sandstone is fine- to medium-grained, which is not so hard and has a light-grey colour, with the appearance of salt and pepper sandstones. Such sandstone commonly shows small- to medium-scale trough-cross stratification.

In the Baraya Member two thin yellowish-brown and reddish-brown sandstone and siltstone levels are present, which correspond to the "Ferruginous Sands" and "Lower Red Beds" of FIELDS (1959).

According to GUERRERO (1994), the Baraya Member and the lower part of the Cerro Colorado Member were deposited by meandering rivers, smaller than those that gave origin to the lower part of the La Victoria Formation. The upper part of the Cerro Colorado Member may have been deposited by meandering and anastomosing rivers (Fig. 4).

The palaeocurrent trends measured in the Baraya Member and in the lower part of the Cerro Colorado Member indicate that the rivers flowed in the same direction as those of the La Victoria Formation, that is towards the E and the ESE; however, Guerrero (Op. Cit.) mentions that in the upper part of the Cerro Colorado Member the palaeocurrents indicate a westward trend.

Age: Eight radiometric ages are known for this formation. Six of them were obtained by the Fission Track method, three of which correspond to the Baraya Member (16.1±0.9, 14.6±1.1, 15.7±1.1 Ma; TAKEMURA & DANHARA, 1986), and the other three to the Cerro Colorado Member (12.6±0.5, 13.6±0.7, 13.6±0.5 Ma; TAKEMURA et al., 1992). GUERRERO (1994: Fig. 7c) also reports two other ages: 13.0±0.88 and 12.21±0.11 Ma. The first one corresponds to a recalculation of the ages given by TAKEMURA & DANHARA (Op. Cit.), and the second one was obtained by using the Ar/Ar method on a sample from near the base of the Cerro Colorado Member (Fig. 4).

Even though there are minor discrepancies that result when considering the stratigraphic position of the dated levels, the complete section of the Villavieja Formation can be assigned to the Serravallian Stage; that is the late Middle Miocene of the Global Stra-

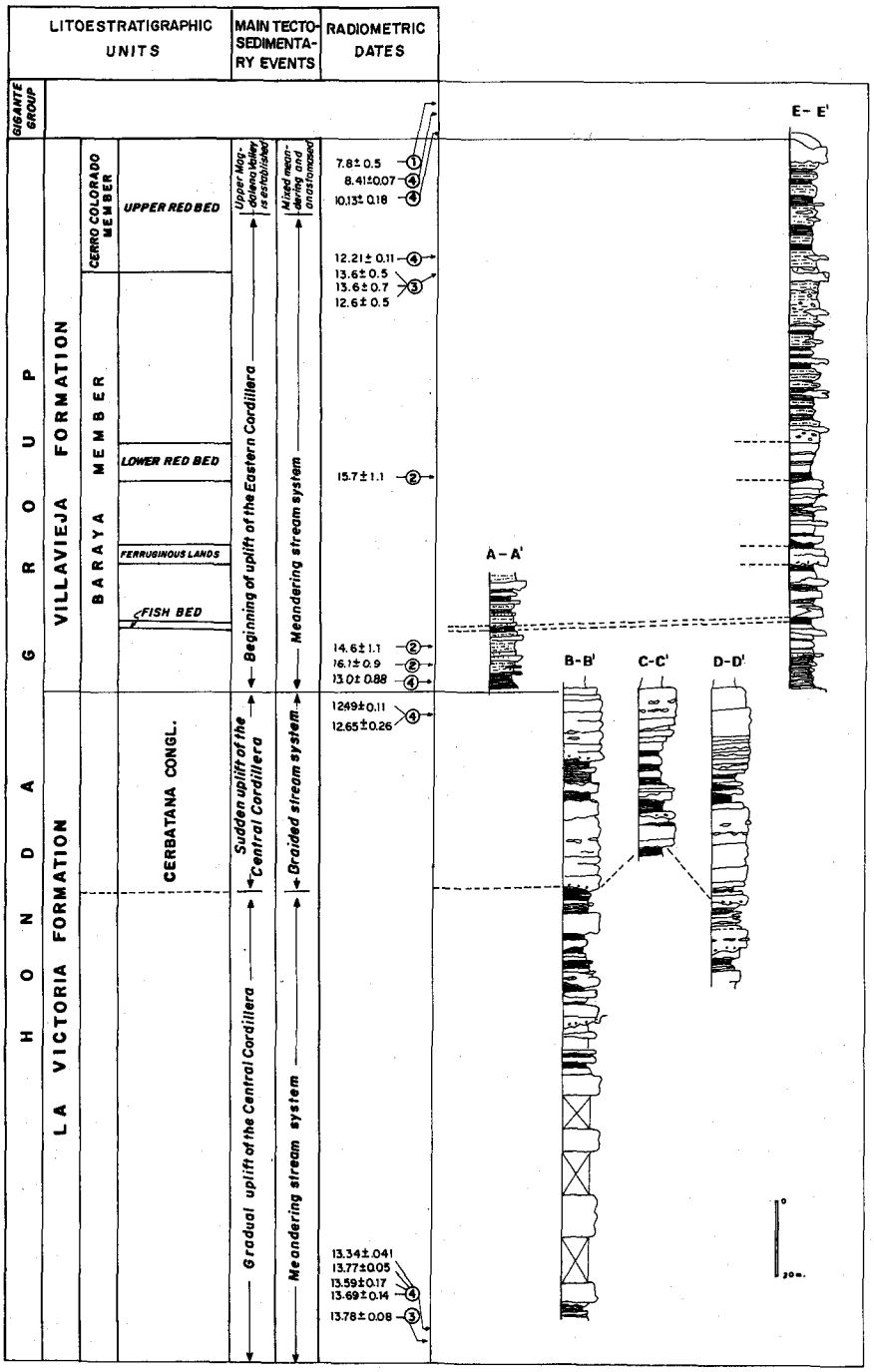


Fig. 4. Ages and tectono-sedimentary development of the litostratigraphic units of the Honda Group.

tigraphic Chart by IUGS (1989).

## Structural Geology

Throughout the region, in general, the dip of the beds is low, and the axes of anticlines and synclines are therefore widely separated. However, two exceptions are the anticline associated with the Andalucía Fault, and the syncline cut by the Baraya Fault, which are quite tight, and their flanks, near to the fault planes, are locally vertical or even overturned in some sectors (Figs. 5 and 6).

Except for some small folds and faults, located between the two faults just mentioned, and some small steeply dipping normal faults, all the major structures have a NNE-SSW trend.

The Andalucía Fault is important in the area, since it dips steeply to the NW, despite being near to the western flank of the Eastern Cordillera. This fact suggests that the fault is genetically linked with the Chusma Fault System. In other words we can consider it as the eastern front of the Patá High, because subsurface data show that volcanics of the Saldaña Formation, that underlie the Tertiary sediments, are thrust over Cretaceous and Tertiary rocks (see Ramírez & Zuluaga, 1993: seismic line PC-13-81).

In contrast, the Baraya Fault, which is also a reverse fault, dips towards the E and is part of the Garzón-Suaza Fault System, that in turn is part of the system which defines the limit between the Eastern Cordillera and the Upper Magdalena Valley.

## Tectonosedimentary Evolution of the Northern Part of the Neiva Sub-Basin

Since the 1950's, several authors have tried to throw light on the environmental conditions that prevailed during the deposition of the sediments of the Honda Group. FIELDS (1959) was the first to tackle this problem, and he did so using the results of palaeontological and sedimentological studies. Van Houten & Travis (1968) considered the development of the area within a regional frame, however, due to the nature of the paper, the conclusions are very generalized. Later, WELLMAN (1968, 1970) and GUERRERO (1994) tackle the problem focusing on the petrological and sedimentological aspects.

In the last few years, several scientists (Cf. MOJICA & FRANCO, 1992; KROONENBERG et al., 1990; SCHAMEL, 1991: GUERRERO, 1993, 1994), and some students from the Department of Geosciences of the National University of Colombia (these last ones in unpublished undergraduate theses), have analyzed the tectonosedimentary development of the Upper Magdalena Valley. However, only very few of them, for instance MOJICA & FRANCO (Op. Cit.) and LOZANO & SOTO (1992), have made more than incidental reference to the evolution of the Patá High.

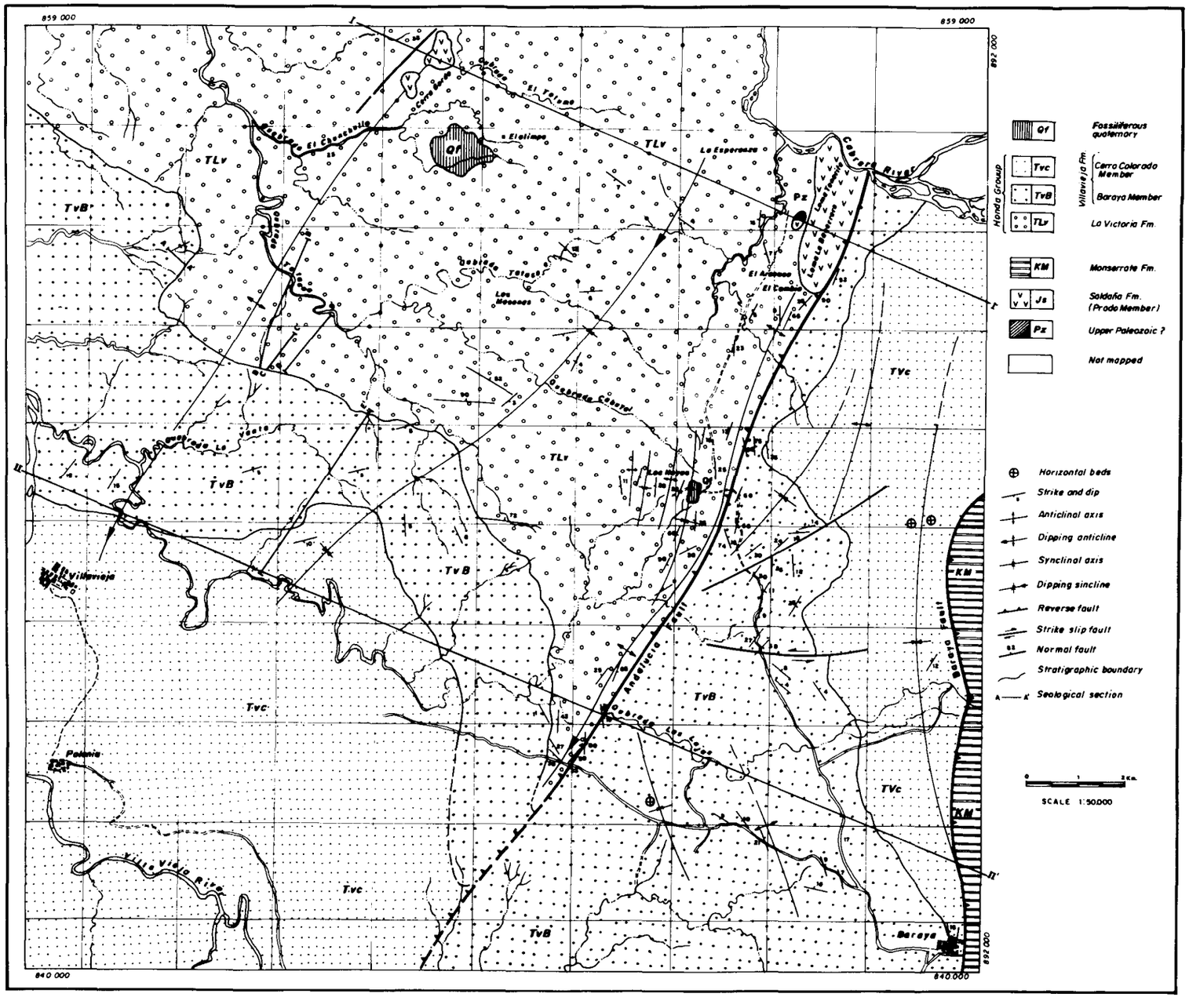


Fig. 5. Geological Map of La Tatacoa "desert". The lines I-I' and II-II' correspond to the Geological sections of the Fig. 6.

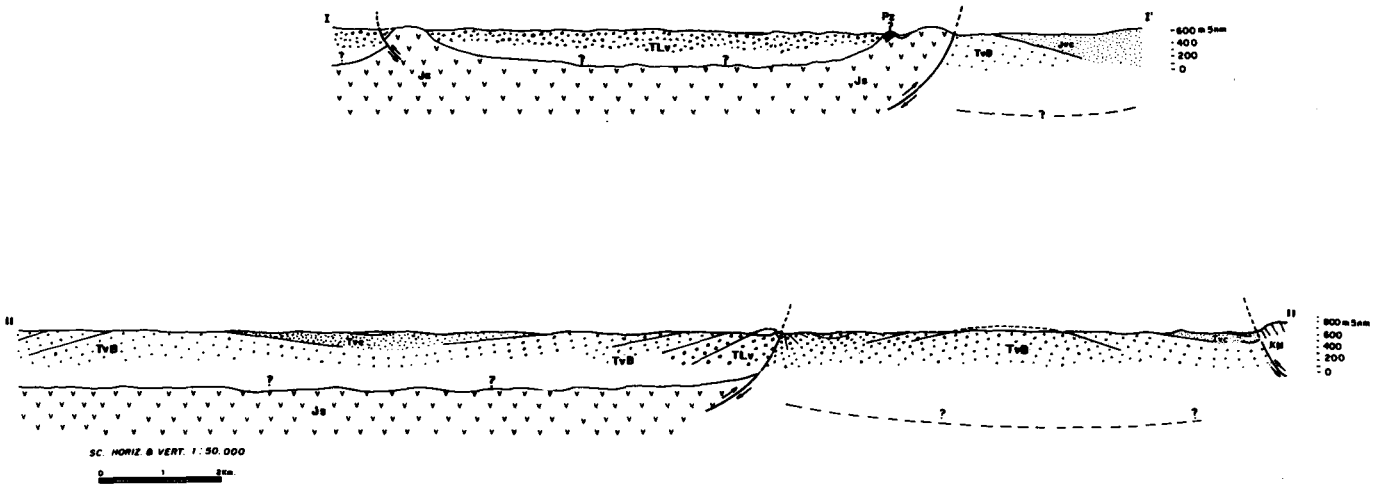


Fig. 6. Geological sections.

In explaining the tectonic development of the Upper Magdalena Valley, MOJICA & FRANCO (1992) synthesized the orogenic events that occurred since the Late Palaeozoic, and defined two distinct cycles: one of extensional tectonics that occurred between the Late Palaeozoic or early Mesozoic and the Early Tertiary; and a second phase of compressional tectonics, responsible for the configuration of the present Central and Eastern Cordilleras, and, therefore, also for the configuration of the Upper Magdalena Valley. For these authors (Op. Cit:46), the period of exposure and erosion of the Patá High occurred mainly during the Oligocene, because sediments of the Honda Group lie directly upon the volcanics of the Prado Member.

From the above reasoning it seems that the Patá High was a morphostructural element that had great influence upon the configuration and the sedimentation of the Upper Magdalena Valley. The Patá High is important partly, because it seems to have separated the Girardot and Neiva Sub-basins during the Oligocene and Miocene, but also because it was undergoing active uplift throughout the Pliocene. With regard to this, the following observations and particular points can be made.

The Patá High[3] can be treated as a positive structure that separates the Neiva and Girardot Sub-basins; the core of the High is nonconformably overlain by Tertiary sediments, and is composed of volcano-sedimentary rocks of the Saldaña Formation. The subsurface data allow us to deduce that the basement of the High in the Patá region conforms to a kind of hill in a transverse position relative to the Magdalena River Valley.

In the Jurassic the basement of this area formed part of a broad continuous volcano-sedimentary "mantle". The fact that nowadays it occurs in a topographically lower position than the volcanic cores outcropping in the Central and Eastern Cordillera is a result of thrusting along the Chusma and Garzón-Suaza fault systems, which are responsible for the depression of the Upper Magdalena Valley (Fig. 1).

The results of both subsurface and surface studies suggest that the most prominent part of the High is found in the Patá region, with a general falling-away to both the north and south. The seismic line TV-7815 and the profiles A-A' and B-B' given by ALVAREZ & MOROS (1986, annex 2, Fig. 3) can be used to calculate that to the south of Natagaima, the slope of the basement high is approximately 23 degrees. However, further to the south, in the Patá sector, the balanced-sections given by LOZANO & SOTO (1992) considering to the seismic lines PC-P-10-86 and PC-P-6-86 suggest that the slope is a mere 2 degrees. We don't have quantitative information for the region south of this sector, but the presence of outcrops of the Cretaceous-Neogene sequence in the Upper Valley in Yaguará (SW of Neiva), that has been eroded in the High, indicates that the volcano-sedimentary basement also has a southward dip in this region.

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[3] SCHAMEL (1991:Fig. 11) use the name "Patá Arch" for a different structure to the one of the present paper.

In the Patá and La Tatacoa areas the sediments of the La Victoria Formation lie nonconformably upon the Jurassic volcanics of the Prado Member, outcropping as small palaeohighs (Chacarón and Gordo Hills, Motoso, Tenerife and La Becerrera Hills, and those ones near to San Alfonso). Geologic sections based on seismic profiles (Lozano & Soto, 1992; Raamírez & Zuluaga, 1993) show that about 700 m of sediments are preserved below the exposed levels of the Jurassic palaeohighs. It is not known if this lower sequence belongs to the La Victoria Formation in its entirety, or if, on the other hand, part of it corresponds to one or more of the different lithostratigrafic units. Lozano & Soto (Op. Cit.) consider that this lithologic package can be attributed to the Barzalosa and Doima Formations. This implies that both of these Formations lie nonconformably upon the volcanic basement.

The information in the literature is difficult to use to help clarify this issue, because neither the stratigraphic relationships nor the ages of the Barzalosa (located above) and Doima Formations are clearly established. In 1968 (Fig. 3) Beltrán & Gallo proposed a correlation chart for the Upper Magdalena Valley, according to which the Barzalosa-Doima pair (which is equivalent to that one considered composed of the Upper Gualanday and La Cira, according to Servicio Geológico Nacional, 1959), consists of a lithologic sequence that unconformably overlies the Potrerillo Formation, and underlies the Honda Group. Schamel (1991, Fig. 3) suggests that an angular unconformity separates the Doima Formation from the overlying the Barzalosa-Honda sequences.

The Servicio Geológico Nacional (1959) assigns the above-mentioned units to the "lower Upper Oligocene" and "upper Upper Oligocene". However, Beltrán & Gallo (1968) attribute them to the Upper Oligocene-Lower Miocene, while Schamel (1991) assigns the Doima to the Early Oligocene, and assigns both the Barzalosa Formation and the Honda Group to the Miocene. Because there is no reliable information on the number of units, and because of the lack of the position of the unconformities that separate them, the age of the orogenic phase that caused the nonconformity between Jurassic volcanics and the Tertiary is also uncertain. With our present state of knowledge we can only state that this phase took place sometime between the Late Oligocene and the Early Miocene.

On the surface, the lowest stratigraphic levels of the La Victoria Formation outcrop between the Natagaima and the Patá High. Strata progressively young to both the north and south of this sector. This fact is particularly clear to the south, from the Patá High toward Polonia, where strata that correspond from the lower part of the La Victoria Formation until the Gigante Group start to appear. Moreover, it can be seen that the distribution of the lithostratigraphic units is not only independent from the NNE-SSW orientation of the structural axis but also apparently accommodative to the transverse nature of the Patá High. It is, therefore, possible to deduce that the last phase of uplift of the High occurred in the Late Pliocene and/or the Early Pleistocene. This in turn

means that it postdates folding of the sediments of the Honda and Gigante Groups, and it was older than the deposition of the horizontal fossiliferous strata of the Quaternary, that lie with angular unconformity upon the Honda and Gigante Groups. It can be observed, for instance, at the outcrop in Los Hoyos (Villarroel et al., 1989) and at the beginning of the Chunchullo Creek (see Geological Map).

In the 1960's several authors suggested that the uplift of the Eastern Cordillera took place during the Neogene. HARRINGTON (1962:1805) recognizes that the process started in the Early Tertiary, although he suggests that the major movement was in the Early Miocene. VAN HOUTEN & TRAVIS (1968) consider that the main part of the uplift took place in the Pliocene, but that the process began as early as the Miocene. However, in the last few years, thanks to detailed sedimentologic studies and radiometric dating, more precise ages of the tectonosedimentary events have been attained. For example, WIEL (1991) and WEIL & BERG (1992) estimate that the uplift of the Eastern Cordillera occurred between 13.9±2.3 and 9.2±2.0 Ma (ages calculated using fission tracks in apatite), while GUERRERO (1993) considers that the main part of the uplift occurred around 11.8 Ma (Fig. 4).

In the desert area, no signs of the uplifting of the Eastern Cordillera have been found either before or during the deposition of the La Victoria Formation. In contrast, the Cerbatana Conglomerate, that was deposited 15–16 Ma according to the data of TAKEMURA & DANHARA (1985), or around 12–13 Ma according to GUERRERO (1993), probably marks a period of uplift of the Central Cordillera. The deposition of the Baraya Member could then have taken place in a flatland with a gentle slope that developed as a consequence of the incipient uplifting of the Eastern Cordillera as suggested by GUERRERO (1993). This general scenario is supported mainly by the presence of a silty-clayey lithology, and local development of swampy and lacustrian deposits ("Fish Beds"), as well as the great variation in the trend of the palaeocurrents. In a similar way, the occurrence of the red beds in the Cerro Colorado Member might also be explained as the result of the establishing the Upper Magdalena Valley as a sedimentary basin isolated from the Amazonian basin. Two further observations are in good agreement with this hypothesis. The first is an abrupt change in the palaeocurrents trend: according to WELLMAN (1970), GUERRERO (1993) and our own data, the palaeocurrents in the La Victoria Formation and in the Baraya Member of the Villavieja Formation indicate a dominatly E or ESE flow, while according to Guerrero (Op. Cit.), in the Cerro Colorado Member, the palaeocurrents indicate a westward flow. The second observation is the occurrence of medium, subangular clasts of Cretaceous siltstones of the Olini Group, within conglomeratic horizons of the Cerro Colorado Member to the N of Baraya.

We should, however, point out that our conclusions about the isolation of the Upper Magdalena basin are based solely on the Garzon Massif. This is because it is still unclear which of the following two tectonic histories should be adopted:

1. The uplift of the Eastern Cordillera was produced simultaneously along all its extension.

2. The Eastern Cordillera developed in a series of steps initially as a series of isolated rises, and then in the Pliocene the whole Eastern Andean block was uplifted (VAN HOUTEN & TRAVIS, 1968).

## Presence, Expansion and Extinction of the La Venta Fauna

Most of the palaeontological studies related to the La Venta Fauna are taxonomic in nature. Little has been written about such fauna in the La Tatacoa area, in particular the causes of its concentration in a reduced geographic area, and the causes of its abrupt extinction remain outstanding issues. To understand and explain these aspects of the La Venta Fauna, they must be considered in the context of dynamic tectonosedimentary processes, in particular the progressive and gradual uplifting of the Eastern Cordillera. We suggest that the influence of this process was the fundamental cause of the faunal extinction. The uplifting of the Eastern Cordillera caused the geographical isolation of the Upper Magdalena Valley from the Amazonian region, and also brought about a reduction in the total inhabitable land area as a consequence of the development of a new drainage pattern. The rivers and creeks that flowed down the flanks of both Cordilleras, started to feed into the incipient Magdalena River. In such a geographic frame, the history of the La Venta Fauna can be divided into two phases. The first phase is pre-Cordilleran, and during this period settlement of the region occurred by immigration of animals from the Amazonian region. The second phase is post-Cordilleran, and during this period isolation of the La Venta Fauna occurred due to the progressive uplifting of the mountain chain. During both phases, the already uplifted Central Cordillera is likely to have acted as an insurmountable, physical barrier to land animals. The absence of mammal fossils in the thick Neogene sequence of the Cauca River Valley gives support to this hypothesis.

During the pre-Cordilleran phase, divers animal groups were able to settle in the region. The "Coyaima Fauna" (composed of notoungulates, interatherids, leontinids, edentates, rodents and astrapotherids; STIRTON, 1953), discovered 65 km to the north of Villavieja, is the oldest fauna yet discovered in the Upper Magdalena region and, could therefore give an idea of the mammal types that first became established. However, the strata outcropping between the Patá and Coyaima town are subhorizontal, and it is possible that the horizon containing the "Coyaima Fauna" is not, in fact, stratigraphically much lower than those containing the La Venta Fauna. This observation and the facts that the composition of both faunas are similar, and that they have some elements in common (Cf. *Huilatherium pluriplicatum* and *Miocochilis*, the latter one according to GUERRERO, 1993:88), suggest that the "Coyaima Fauna" cannot be as old as Late Oligocene

(STIRTON, 1953:10), or pre-Friasian as considered by HIRSHFELD (1985:52).

The discovery of notohippid *Argyrohippus* reported by PORTA (1966:237) cannot be used in the above discussion. This fossil was reportedly found in the sediments of the Honda Group, close to Natagaima. Neither a description nor an illustration of the fossil remains have ever been published, and the fact that in Argentina this genus is restricted to the Oligocene, suggests that the fossil may have been misidentified. If this is the case we can speculate that the material in fact is a *Huilatherium*, because the juvenile form of the leontinid of La Venta is very similar to the notohippid adults (Villarroel, paper in preparation).

From a tectonosedimentologic point of view, it is probable that the deposition of the Villavieja Formation coincided with the onset of the uplifting of the Eastern Cordillera. During this period lakes and swamps were formed, in which divers types of fish from the Amazon area were abundant. Turtles, crocodiles and mammals were soon added to this fauna. This scenario is clearly shown by the development of the stratigraphic levels aptly referred to by FIELDS (1959) as "Fish Beds", and those which are found in the Cerro Colorado Member, north of Baraya.

The uplift of the Cordillera brought about a progressive isolation of the animals. This process ended with the deposition of the upper part of the Cerro Colorado Member. At this time the Eastern Cordillera had risen for enough to form a physical barrier difficult to cross for most animals.

It is probable that the presence of an isolated small fauna in Carmen de Apical (located 120 Km to the NNE of Villavieja) is connected to the uplift of the Eastern Cordillera. This fauna occurs in sediments of the Honda Group (STIRTON, 1953), and is coeval with that of the La Venta Fauna. Its presence can be interpreted as the result of the migration of some groups of animals along the Magdalena River Valley, where they finally became extinct as a consequence of the change in environmental conditions. The absence or at least scarcity of fossils in the sector between La Tatacoa and Carmen the Apicalcan be explained by the erosion of the middle and upper levels of the La Victoria Formation as well as the complete Villavieja Formation, which is connected to the Plio- and Pleistocene elevation of the Patá High.

With in this context it is also possible to account for the extinction of the primates. These primates lead a precarious existence in their habitat and became extinct together with the rest of the taxa, even before a return of animals to the wild forests of the Amazonian region became impossible.

## Acknowledgments

We wish to express our sincere gratitude to Doctor Javier Guerrero, who gave us access to data from his unpublished papers. The Department of Geosciences of the

National University of Colombia, and the Department of Geology & Mineralogy of Kyoto University, Japan, provided facilities in support of this research.

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