IGU

International Geographical Union
Regional Conference of Latin American and Caribbean Countries

July 31 - August 5, 1995
Havana, Cuba

FIELD TRIP GUIDE

MOGOTES IN THE VIÑALES VALLEY, PINAR DEL RIO PROVINCE, CUBA

August 5, 1995

Leslie F. Molerio León
Centro de Hidrología y Calidad de las Aguas, Instituto Nacional de Recursos Hidráulicos
P.O. Box 23, General Peraza 19210
Ciudad de La Habana,
Cuba

CONTENTS

INTRODUCTION

Hundred eighty kilometers to the West of City of La Habana is located the Valley of Viñales (Fig. 1), the most famous cuban karstic valley and one of the most beautiful landscapes of the world. Declared National Monument of Cuba, the valley is developed between the upper Jurassic-lower Cretacic carbonate rockas and the non carbonate lower Jurassic sediments. The Guasasa formation is the in that the walls scarp of the "mogotes" develops. Sometimes, at the base, a softer slope is present associated with the Jagua formational unit. The non carbonated series constitutes, in essence, a metacarbonated and terrigenous complex named San Cayetano formation, composed by slates, shales, schists, sandstones and silts. The youngest sediments are of Paleogene age. However, is typical the stratigraphic inversion due to the overlapping Alpine structure that characterizes the region.

Fig. 1. General location map (after Psczolkowski, 1987)

The bottom of the valley is filled by terrigenous sediments, mainly clays and sands derived from the San Cayetano formation, alternating with loams. silts and lacustrine deposits as a consequence of the hydrologic evolution of the valley, and with limestones resulting of the recession of the carbonate walls of the mogotes. The surface of the bottom of the valley is practically horizontal and meets an average altitude of 100 m above level of the sea, whereas the summit of the "mogotes" reaches heights of about 350 m. For such reason, the vertical walls rises some 250 m over the bottom of the valley, provoking a surprising morphology of elevations of abrupt walls and rounded summits that, in the Cuban toponomy are designated with the name of "mogotes."

In the classical geomorphological literature, these landscapes are commonly referred as "tower karst", "turm-karst)," "hillstacks" or "kegelkarst" and during many years was considered an exclusive morphology of the tropical karst. Similar forms have been reported in China, Viet-Nam, Indonesia and Puerto and also in areas that at the present timeare not tropical, in what constitutes an interesting and ancient controversy on the rol of climate on geomorphology.

From the indigenous vegetation of Viñales hardly remains manifest-ations in the walls of the "mogotes", in some dolines (locally named "hoyos") and in some gallery forests associated to the fluvial courses. In the base of the mogotes are recognized remains of a messofil semideciduous forest represented by almácigos (***Bursera simaruba***), Cuban locust (***Samanea saman***), cedar (***Cedrela odorata***)and ceiba (***Ceiba pentandra***). But in the vertical hillsides and in some bottoms of dolines, in the summit of

the mogotes, some endemic flora or with features of endemysm could be found. The most representative individuals are the palma barrigona (***Gaussia princips***), the ceibón (***Bombax emarginatum***) and the guanito de sierra (***Thrinax microcarpa***) (1).

Very different is the vegetation of the Alturas de Pizarras, elevations built by the slates of the San Cayetano formation. This is the scenario where an impressive aciculifolious forest of pines grows, after which the hole province of Pinar del Río has been named. Most common species are the so-called "female pine" (***Pinus tropicalis***) and the male pine (***Pinus caribaea***). In very remote sectors, they still meet individuals of the "palma de corcho" -the palm of cork- (***Mycrocicas calocoma***) relicts of the Quaternary flora in danger of extintion (2).

The floors are latosolics and of rendzinas in the mogotes, but they are generally scarce developed, except in the bottom of some dolinas ("hoyos") that the farmers of the region take advantage for agriculture. However, in the bottom of the Valley of Viñales thick ferralitic soils develops, intensely cultivated for tobacco.

Like in most of Cuba, in Viñales two seasons, according with the year rainfall distribution are recognized. The rainy period, extended from May to October, where about 1200 mm are recorded, and the dry or less rainy season, from November to April, with some 400 mm fall as an of the last 50 years. Subjected to the influence of heavy (torrential) rains and hurricanes, the height of rainfall and its intensity varies notably in these extraordinary events. So, for example, the Frederick hurricane, in October of 1979, provoked precipitations of the order

of the 400 mm in two days. The hurricane Albert reached 700 mm in 48 hours. The air temperature averages 24oC, with minimal in January (18ºC) and maximum in July (28oC) (3).

In such geographical environment seems that in as early time as the end of the XVI century an intense cultivation of the vine (vid) developed, of whose vineyards (viñas or viñedos) could be derived the name of Viñales. With that name was granted a "corral" to Mrs. Ana Martínez Ramos by Real Order of the Havana city council in October 12th, 1607.

One of their descendants, Andrés Hernández Ramos, donated lands for the construction of the town 1875. Four years later, in 1879, it reaches the category of municipality upon creating an independent city council of the of Pinar del Río. At the present time, in the municipality of Viñales inhabit some 5000 people (1).

In order to facilitate, then, the knowledge of this beautiful region, this Field Trip Guide is structured in four transectos that pretend undertake the most interesting themes of the geology, geomorphology and hidrology of the Valley of Viñales, National Monument (fig. 1).

The first of them (Transect 1), of some 180 kilometers, tie the cities of La Habana and Pinar del Río by means of the National freeway. Most of this journey is along the Southern Coastal Plain of Pinar del Río, a succession of alluvial fans and of old deltas that framed a karstic surface which confers it properties of criptokarst. The north limit is a chain of mountains of low to half height, parallel to the plain and, as it, also intensely karstified: the mountain range (Cordillera) of Guaniguanico. Transect 2, linking

the city of Pinar del Rio with Viñales, allows to concentrate the attention on the geological structure and the relief of the San Cayetano formation along some 25 kilometers, crossing the well-known elevations of the Alturas de Pizarras del Sur. This journey finishes at Los Jazmines Hotel, practically in the contact between the karst and the non-karstic rocks allowing to a general sight of the spectacular morphology of the mogotes.

The third journey (Transect 3) is plenty developed within the mogotes, concentrating the attention on a group of topics of interest, also polemic, concerning the nature of the contact between carbonate and non-carbonate rocks and its morphological effects, on the factors controlling the verticality of the walls of the mogotes, the impressive cave development and the hydrogeologica features of the mogotes slopes.

This trip finishes with a journey through Cueva del Indio, partially navigable, an underground system that reflects the most important features looks of the morphological and hydrological evolution of the territory.

TRANSECT 1: The Southern Coastal Plain of Pinar del Río and the Cordillera de Guaniguanico

1.1. An active Criptokarst: The Southern Plain of Pinar del Río.

The Southern Karstic Plain of Pinar del Río is one of the karstic regions of the country (4). It occupies all the southern part of the county, to the south of the Pinar Fault, between the Bay of Cortés and Majana, extended on a surface of 3495 km².

Fig. 2. Structural skecth map of the Cordillera de Guaniguanico (after 6)

It constitutes a zone of plattaformic deposits of Pg_3 (?)-N age and, partially, an emerged Plio-Quaternary zone over which this fluvio-marine and deltaic plain has been. At the upper parts it shows a combination of erosive and denudative dissected features. In general, the structural and tectonic character is noted in all the landscape, developed in the miocenic carbonated cover. The most southern parts have settled down on Pleistocenic (and younger) tectonic inflection zones. The age of the landscape has been estimated between Q_I (Nebraska) and Q_{III} (Illinois). The age of karstification is not established but, apparently, it has been a process is whose higher levels should be definetely Quaternary. The lower cave levels are recognized down to- 200 m.

It result especially interesting that the deltaic and alluvial deposits covering the plain don't confer conditions of mero (partial) fossilisation to karst. On the contrary, an active criptokarst where the covering deposits transmit, locally, certain pressure to the aquifer, is present. Its load comes from until 50 m of clays of very low permeability. As cover sediments are essentially allocthonous but their poligenism is derived from different sources of sediment contribution: on one hand, the materials derived of the haulage of the San Cayetano formation, mainly to the west of San Diego de los Baños; on the other hand, to the east of San Diego, by the additional erosion of the carbonated rocks. The successive Quaternary marine transgressions and regressions promoted the development of the old deltas and alluvial mixed fans.

Hydrodinamically, it is a holokcarst of some 300 m in thickness, whose base level of erosion is the current level of the sea where partially discharges the regional aquifer. Its groundwater resources has been estimated in 200 Hm^3/ year. The lower cave levels have been recognized by E. Flores (pers.comm) at -160 m.

The general direction of groundwater flow is toward the south, parallel to the fluvial net flowing through the plain. In the half and lower courses it is completely independent of it. The hydraulic gradients are very low, about of 10^{-3}, of the same order that the plain, whose higher heights doesn't surpass 120 m in the zone of articulation with the mountain range of Guaniguanico.

The thickness of the alluvial cover and its so reduced infiltration capacity have constituted one of the most important problems in order to establish the position of the natural recharge zone of the

aquifer. The application of environmental isotope techniques of has allowed (5). So, in the zone of discharge, to the south, they have met underground waters with a ^{14}C age of about 10 000 years, while in the articulation zone, to the north, they meet concentrations of ^{18}O ^{2}H of the same order that those that are recorded for the rain in the mountain, practically without fractionation. These facts suggest a strong natural direct recharge, and it seems that it is in this articulation fringe where the most important natural infiltration takes place.

1.2. The Sierra del Rosario: An Alpine Karst.

The mountain range of the Sierra del Rosario constitutes the eastern orographic system of the Pinar del Río province. With a surface of approximately 500 km2 it is extendedes from the surroundings of the town of Anafe, in La Habana, until the oriental riverbank of the river San Diego (5).

It constitutes a structural landscape of folded regular mountain ranges, dislocated, individualized by diffrential erosion, that evolved starting from primary structural and tectonic planes, of the type of "nappes", on five structural units. In the territory are developed three of them: Quiñones, axial part of the mountain range and Cinco Pesos, according to the terminology of Mossakovsky and Albear (6), and constituted by Jurassic-Paleogene rocks.

In these units erosion and structural surfaces alternate, as a consequence of the interaction between zonal and azonal factors. The stepping of summit levels was produced mainly favored by neotectonic uplifting processes.

Erosion forms and their combinations prevail over the accumulative ones, due to the strong slopes that provoke intense and rapid surface washing. Vertical dissection is notable and could reach 400 m.

The fluvial net is North to South oriented, according to the directions of secondary structures, normal to the structural plan of the region, although some valleys have been established over the plans of the nappe structures. It is common the presence of fluviokarstic valleys and fluviokarstic depressions in the contact between the carbonate and non-carbonate scarps, like the Depresión of Cinco Pesos (7), where they constitute points of absorption of the surface runoff and acts as centers of radial dispersion for the underground runoff.

The particular evolution of karst and its natural individualization originated "mount-islands" , as well as rounded hills and hogbacks, standing out the more resistant strata of the carbonated facies. This process lead to the desorganization of the fluvial net and to a compex succession of genetically differentiated valleys.

Hydrodynamically, the region conforms a merokarst where the position of the non-karstic rocks constitutes the local base level of erosion. The regional base level is defined by the talwegs of the surface fluvial net. Karstification thickness is not well known but it has been estimated in the order of 200 m. The scale of aquosity is similar to the rest of the cuban mountain karsts (8). The most important potential lies within the carbonated rocks of J_3-K age. Here, several karstic aquifers have been recognized. These are local, discontinuous and unconfined, circulating by well-defined conduits of the type of transcurrent or transfluent caves whereas

water entering the system is both of allocthonous and autochtonous origin, giving a hybrid or mixed source. During the dry or less rainy season some yield is founded due to the exclusive contribution of the autochtonous contribution. These conduits, some of notable dimensions, like Los Perdidos Cave System, with more than 30 km of underground galleries, commonly discharges trough emissive caves. These could be of convergent type, when flow and lateral discharge to the rivers dominate or of transfluent type, when the master fluvial net flows at the unsaturated zone (hypodermic flow). Most of this circuits are linked with karstic absortion forms or with surface valleys of hybrid type.

The analysis of the runoff hydrograms shows common characteristics to all underground basins in terms of the autocorrelation function, an index of the system's memory or inertia, of the spectral band, and of the relative importance of their regulatory reserves. In all the studied cases, the "memory effect" is low, with a heavy periodic component, accounting for the high dependence of natural recharge fluctuations with respect to the underground yields. Self-regulation times, as defined by the variance spectra, are very short, while the spectral band is very large, commonly higher than 0,4. Regulatory reserves are, as a consequence, very low, and as an average they not surpass 12 Hm^3/year.

1.3. The Sierra de Los Organos: The Final Term of Karst Evolution in the Tropics?

This region (563 km2) comprises the mountainous territory extended from the western part of San Diego river to the surroundings of the town of Guane. Four groups of overthrusted units ave been recognized here (6): the mogotes belt, the Alturas de Pizarras del Sur, the Alturas de Pizarras del Norte and the metamorphic units occupying the highest positions.

The mogotes landscape is an element of special attention. They constitute a mo Aqui, the (relieve) of (mogotes) constitutes an element of special attention. These constitute a morphology of differentiated petrogenic blocks in the Upper Jurassic-Lower Cretacic calcareous units. Karstification is very varied and particularly spectacular in these landscapes. Could be highlighted the fluviokarstic contact valleys, also named "marginal poljes", whose most famous example is the Viñales Valley; dolines at different levels in the mogotes summits, known in cuban literature as "hoyos de montaña", whose bottoms descend to the levels of the contiguous valleys; impressive canyons (abras) and huge caves. The larger cave systems of Cuba are developed in this region: Palmarito (29 km), Santo Tomás (45 km), Majaguas-Cantera (30 km) and Cueva Fuentes (19 km).

E. Flores (pers. comm) has identified 14 cave levels within the region, ranging from +350 to + 40 m. Hydrodynamically, there are some differences. Certain sectors, linked to the Cuyaguateje basin, seems to be holokarsts, while those linked to the Pan de Azucar basin seems to be, up to now, merokarsts. No general flow directions could be identified, but regionally, the main direction is:

40-220º to whom are associated the cave networks hydrologically active. The better known underground flow is that linked with the fluvial network flowing through caves.

For european researchers this landscape was considered, since Lehmann times, at the middle of 1950's, the archetype of tropical karst. A long discussion followed the firts descriptions of the impressive mogotes morphology and, in particular, with respect to the hypsometric relation among the poljes or dolines and the neighbouring valleys, where was thought to find the answer to their syncronical evolution. Guided by the criteria of the cyclic evolution and the determinant role of climate on landscape evolution, its application to cuban karst and to Tropical Karst, in general, lead to the negative impression that practically the only karstic landscape known was taht represented by the mogotes. However, another factors are more important in the control of the morphological variety and it can be asserted, that with independence to the stronk linkage between the mogotes landscapes an the Humid Tropics, it is not the final stage of karst evolution in these regions.

1.4. Problems of land and water use.

The Southern Coastal Plain of Pinar del Río is a very fertile territory. Their soils are specially able for rice and tobacco agriculture. Till the middle of this century, the intensive exploitation of groundwaters provoked unfavourable side effects on the dynamics of the miocenic aquifer. Most remarkable side effects were: 1/ the deessurization of the aquifer, transforming

it from a semiconfined one to an unconfined system, and 2/ the inland progression of sea water intrusion, with the consequent change of groundwater quality.

The last problem was solved by means of a coherent policy of hydraulic management of surface waters. A succession of canals and diversion dams allowed to substitute irrigation with groundwaters with surface waters, limiting the use of the first ones to domestic and a few industries supply. The southern Hydraulic Complex of Pinar del Río regulates almost the 75% of the hydraulic potential of the province. Seven dams, four master canals and eleven divversion dams, with a total delivering capacity of 535 Hm^3 irrigate 57,8 thousands of hectares. The cost of the inversion reaches 137.6 millions of cuban pesos and it was mainly constructed between 1969 and 1982.

In the mountainous zones, the desconcentration of the population, dedicated to coffee and tobacco agriculture poses a different problem to water supply. It is solved by means of spring's regulation, direct supply from cave lakes and the construction of shallow dug wells. Some important towns has small aqueducts while some irrigation takes place with surface waters.

Specially damaging was the practice, now erradicated, of burning the forests for land preparation to the coffee agriculture in the mountains slopes. This situation is partially reverted cafter the repopulation of the mountains started in the last years.

TRANSECT 2. Pinar del Río-Viñales: The Alturas de Pizarras del Sur.

This transect is Northward oriented and starts at the outer side of Pinar del Río city and ends at Los Jazmines Hotel. Its distinctive feature lies in the fact that it takes place across the overthrusted units of San Cayetano formation.

2.1. Geological structure of San Cayetano formation.

Defined by De Golyer, 70 years ago, with the name of Cayetano formation, the sediments of the now named San Cayetano formation, comprises a very monotonous sequence of shales, slates, clays and sandstones with some conglomerates and limestones intercalated. This deposits are rithmycally stratified but, in the different tectonic units, the sedimentary structures varies.

These sediments are limited to the Western part of Cuba and are very well exposed in the Pinar del Río province, where they built the mountain ranges known as the Alturas de Pizarras del Norte and Alturas de Pizarras del Sur, bordering the mogotes belt of the Sierra de los Organos. The formation thickness ranges between 3000 and 5000 m. Towards the East, en the Sierra del Rosario, the maximum thickness never surpasses 1000 m.

Stratigraphic studies of San Cayetano formation are very frequent. They assign an age of Low to Middle Jurassic, but at the basal part the stratigraphic position is not yet clear. The upper parts rise, in age, up to the Oxfordian, as derived from ammonite

fauna. In any case the sedimentary deposits are younger in the Sierra del Rosario than in the Sierra de los Organos, where de terrigenous deposition stopped earlier (6).

The sediments are tectonically overthrusted over the calcareous units. The overthrusting plane is horizontal with a slight dip towards South. Locally there are also recognized displacements following horizontal fault planes.

Some structural depressions, like "fenster" or tectonic windows allow the outcropping of carbonated units, forming mélange type structures.

Very interesting is the character of the contact between Viñales and San Cayetano units in the Alturas de Pizarras del Sur. The contact plane dips southeast in the same direction of San Cayetano's strata. Piotrowska (9) suposses that, at the present, a retrogressive slide of the Viñales unit is taking place due to a pressure from the Alturas de Pizarras del Sur unit, in the zone between the Infierno and Viñales units, combined with the sliding towards the Southeast of fragmentos of the Viñales unit.

The most important folding structures were developed during the tectonic transport of the main orogenic phase o during later movements. Frequently are observed normal flanks of synclines and anticlynes and large buckles linkez to fracturing of small overthrusts. Dissarmonic folds are less common, while dominate those of flexure of concentric type. In local tension zones boudinage structures are developed. Disjunctive structures are highly variable, from small exfoliation and clivage to huge fault zones.

Recently, the author (10) studied, with some detail, these folds applying a model of continuous deformation resulting from flexure or in interstratal concentric folds, buckles and chevron folds. The model allow to validate that chevron folds are enough stable when the thickness of the competent strata is constant. Dips lower tha n 45□ do not seems to favour this tectonic style. In the case of concentric folds, the shape of the bed varies continuously with the relation between the wave length of the fold and the dominant wave length. Results allow to conclude that the final form of the forld is highly independent of the initial form of the bed.

2.2. Geomorphological features of the Alturas de Pizarras del Sur.

The Alturas de Pizarras exhibits a very rough relief, dominating hills of gentle slopes and rounded summits. Its highest elevation is the Cerro de Cabras, at 484 m above sea level. The fluvial network is the allochtonous source that has deeply dissected this mountain range. It is also the master source of cave development in the territory and in the country. Master streams of those huge caves has their heads in this hills, like the Palmarito, Ancón and Novillo (Palmarito Cave Sistem), Santo Tomás, Bolo and Peñate (Santo Tomás Cave System), Majaguas and Cantera (Majaguas-Cantera Cave System) and El Alcalde (Amistad Cave System). An exceptional case is Fuentes stream, whose heads are located at the north, in the Alturas de Pizarras del Norte and cross the mogotes belt flowing to the South.

Sandy soils dominate. They are very thin due to the constant slope wash. The zone is scarcely populated y less cultivated excluding its forest reserves. Nevertheless, it has important mineral resources in copper, baritine, phosporites among others.

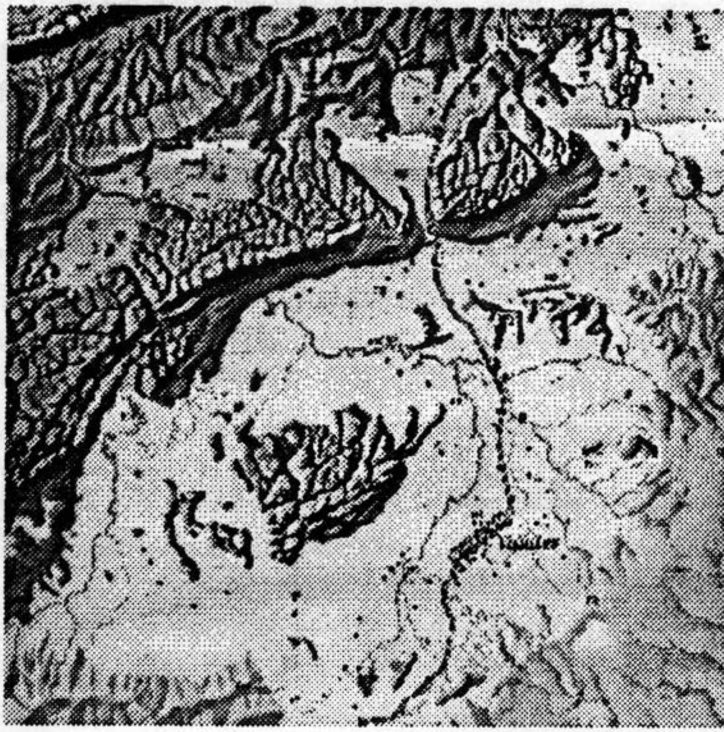
The erosive action of mountain streams has produced gorges and episodic riverbeds. Rill wash and sheet flood are the main processes contributing to the development of the post-Laramic hilly landscape. Vertical dissection ranges between 50 and 100 m, with maxima around 250 m, while horizontal dissection ranges, also, between 50 and less than 100 m. General slopes are between 7 and 25□.

Fifteen years ago the author studied the erosive power of the mountain streams applying the Gruber's simplified formula in the boundaries of dissarticulation. Accounting for Scheidegger's modification to Gruber, it was concluded that the erosive power remains constant for setted slopes with independence of the dissection value. Slopes reced paralell without being lineals, so they were simulated after a partial hyperbolic differential equation that led to satisfactory explanation of the progresive smoothing of the slopes and its evident concave profile.

TRANSECTO 3. The Viñales Valley and its surroundings.

This part of the field trip takes place in the valley and will allow some incursions to the "hoyos de montaña", like Dos Hermanas Valley. Also could be observed some manifestations of the slope receding: the foot-base caves. It is also an opportunity to comment some particularities of the morphogenetical fetaures of the Sierra de Viñales. (fig. 3)

Fig. 3. General map of the Viñales valley and its surroundings (after Lehmann, 1954)



3.1. The morphological effect of the contact between the carbonate and non-carbonate rocks.

Since the end of last century, Cvijic payed attention on the effect of the contact between karstic and non-carbonated rocks upon the morphogenesis of karst landscapes. He defined the fluviokarst as a singular feature where combined effects of fluvial erosion and karstification are present and changes according to the relative position of both units. So, if the fluvial network is established along the contact, in longitudinal direction, an

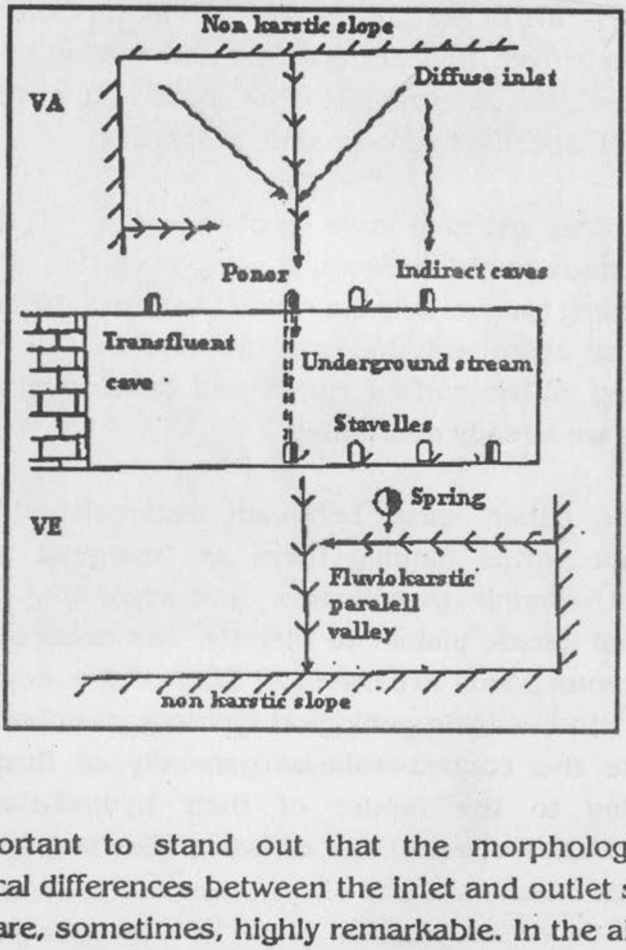
interesting differentiation is observed with karstic forms in one side and fluvial forms in the other side. This is the case, common in our zone, appearing long the Pan de Azúcar Valley and, more to the West, at the El Pesquero Valley and in the lower course of the Cuyaguateje river. They are drainage nets feeded by hybrid waters that controls the development of an emissive or outlet slope in this karst, with specific hydrodynamic properties.

The other extreme case is observed in Viñales. Here, the allochtonous fuvlial network, flowing from the terrigenous hills, cross cutting transversally the contact between the two units. Then the typical absorbent slopes of the mountain range are formed, collecting all the surface runoff and developing the huge cave systems we already mentioned.

In the cuban karst, Lehmann distinguished the particular landscape forms naming them as "marginal poljes", whose classical example was Viñales and separating from them the "marginal karstic plains" to identify *"the calcareous and locally argillaceous plains excavated in front of the mogotes mountain ranges"*. In our hydrogeological typology of cuban karst (12) we separate the contact valleys, generally of fluviokarstic type, according to the nature of their hydrodynamic behavior, in absorbent (collector) and emissive (discharge) types with their combinations.

The morphohydrodynamic association of fig. 4 is very common.

Fig. 4. General sketch of the morphohydrodynamic behavior of the mogotes slopes.



It is important to stand out that the morphological and hydrodynamical differences between the inlet and outlet slopes of the mogotes are, sometimes, highly remarkable. In the absorbent or collecting wall (VA) the foot-base caves are generally associated to paleolakes levels, while in the emissive wall (VE) the foot base caves use to be lateral erosion forms. Stavelles located at the VA are, commonly, vertical shafts acting as "equilibrium chimneys"

draining backflow episodic yields. Stavelles at VE are associated with the water exchange between the surface and underground flows.

It should be pointed out that not necessarilly the paralell fluviokarstic valleys intersect the transversal ones, and only a few paralell streams penetrate enough to be organized underground. This is the most common case for the transversal nets.

The hydrodynamics of surface flow, sediments transport and the geochemical hydrodynamics are different, too, according to the kind of slope. The following features could be established.

In the integrated and well developed underground networks(cave systems) groundwater flow is always non-linear, turbulent, commonly infracritical. Sometimes could be lineal but not of Darcy type. Autochtonous contributions could be, hydraulically and morphologically, very important. All large cave systems shows impoprtant components of mixed waters (oversaturation-saturation-insaturation cycles, mixing chambers) due to the high natural recharge. Flash floods are able to transport heavy sediment loads clogging and washing the underground galleries. This sediment transport is, commonly, independent of those due to the lacustrine phases of the hydrological evolution of the valleys and dolines. Sometimes it is so important that considerably reduces the possibilities of well development at the valley's bottom. Waters from VA are almost insaturated with respect to calcite and emerge saturated, oversaturated or insaturated according to the travle length (mixing length), autochtonous contributions and transit time of water.

3.2. The problem of the steep-sided walls of the mogotes: the José Miguel cave and slope receding

Steep sided walls of the mogotes is it most impressive feature. Several factors contribute to it and was Lehmann who first call the attention in relation with the factors controlling it. His attention was focussed to the foot-base caves, whose instability allow that succesive breakdowns contribute to the maintenance of the verticality of the walls.

Several years ago we studied this problem (11). We considered Lehmann's "füsshöhlen" as a special kind of lateral erosion caves. Frequently they are transformed in an extensive concavity along the base of the mogotes acting as a lake in what implies that the erosive model is lucaustrine and fluvial.

For the lateral erosion analysis we applied the Boussinesq's general model for secondary or crossed currents. It is derived that the depth of the flow channels increases as curvature radii diminishes. So, as depth is higher, more effective should be the secondary currents, accounting that these produce helicoidal flow and erosion. We obtained a modified equation from that og Green and Wilts for the excavation by flow channels, defining an expression to explain the concavity of the eroded rocks as a function of velocity and accumulation height.

Lacustrine erosion is explained by the combination of the wave phase velocity and an equation of diffussion with mass transport which implies paralell laminar flow. The conjugated action of both models explains the adoption of unstablé morphologies of the mogotes walls with anisotropic volume reduction, favoured by the

dominant vertical jointing diminishing rocks cohesion. For internal friction angles up to 45□ the Fellenius nomogram could be applied. For higher values, the critical height depends on the relations between internal friction and rest angles. A lineal recession model for the slope explains, with acceptable accuracy, the cointinuos recession and the conservation of the verticality of the walls. A classic example is observed at the José Miguel cave (fig. 5).

3.3. Karst forms and cave development: Palmarito, one of the longest cuban caves.

An extraordinary variety of karstic forms are developed in the mountains. After our hydrogeological tipification of cuban karst (12) among the colecting or absorbing forms, could be identified: lapies, dolines -generally corrosive or collapse-, ponors and the gorges or abras.

Lapies (karren) are generally uncovered, corrosive, most of them linked to the mogotes as relicts of slope receding. Sometimes are covered by alluvial deposits. Dolines or "hoyos" are impressive. Many of them are excavated at the summit of the mogotes and, with differet deeping phases they can reach the bottom of the neighbouring valley. Sometimes the remain hanged and are linked with previous karstification stages.

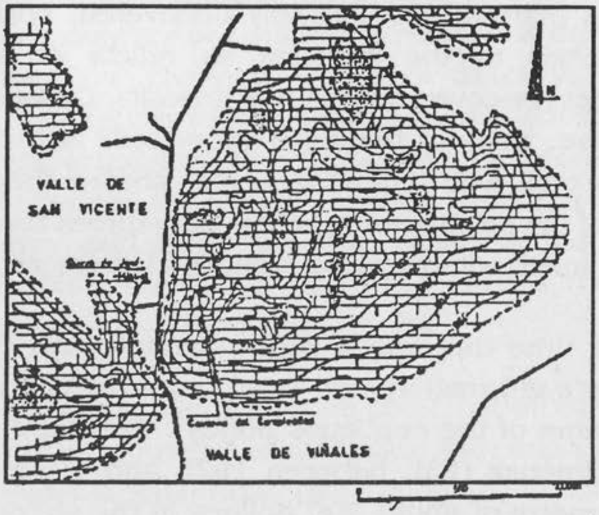
At its time this was a very polemic point. Particularly after Lehmann's affirmation that "in all cases the altitude of the hoyos is the same of the contiguos poljes". Refuted a decade later by Núñez Jiménez (13), between 1975 and 1982 we studied the morphometry of about 200 dolines in the sierras del Pesquero, Sumidero, Resolladero and San Carlos, westward Viñales. A strong

lineal dependence was found between the altitude of the upper border of the doline and the altitude of its bottom (r=92% at 95% significance level). It was also identified a very strong link between the distribution of the dolines and the erosion surface in which it is installed. These relations are the following:

Altitude of dolines bottom	Altitude of erosion surface
91-120	80-100
170-180	
200-220	150-250
240-250-260	

There are also recognized at 290 and 360 m a.s.l. in correspondence with an abandoned slope at 300-350 m a.s.l.

Fig. 5. Location map of the José Miguel and the Cumpleaños caves, after (15)



According to the region, between 50-60% of all dolines are developed at the 150-250 m surface, the best conserved erosion surface of the Sierra de los Organos. An important set of cave levels is also associated to it. At that time we concluded that the dolinization process in the summit of the mogotes shows the following evidences:

1. The dolinization process is normally older than the erosion surface in which dolines are developed and only exceptionally, simultaneous. This doesn't means that acting intemperism could not generate open erosion forms.

2. The progressive development of this group of elements is controlled by the hypsometric position of the erosion base level which controlled the planation of the inmediate upper level. A process that could only was altered in the case of mixed forms or, essentially of suffosive type linked with shafts acting as "equilibrium chimneys".

3. So, the bottom of the dolines are indexes for the position of ancient erosion base levels whose most important relicts, over +200 m are the eroded summits of the mogotes.

Cave development is also remarkable. This is not only due to the high number of recorded, explored or mapped caves, but to their dimensions, as we already mentioned. Figs. 6 and 7 shows one of the last published versions of the surveyed passages of Palmarito Cave System with a total explored galleries -at the moment this notes are written- close to 35 km. Fig. 8 shows the Cumpleaños cave, of less extension but very abundant in constructive forms.

Fig. 6. Sketch map of the development of Palmarito Cave System (after 15)

In the region seems to dominat the transfluent caves, initially excavated by allocthonous waters but with a great contribution of autochtonous waters. There are also many examples of indirect caves, generated by lateral erosion, as are the well-known cases of José Miguel and Los Tomates.

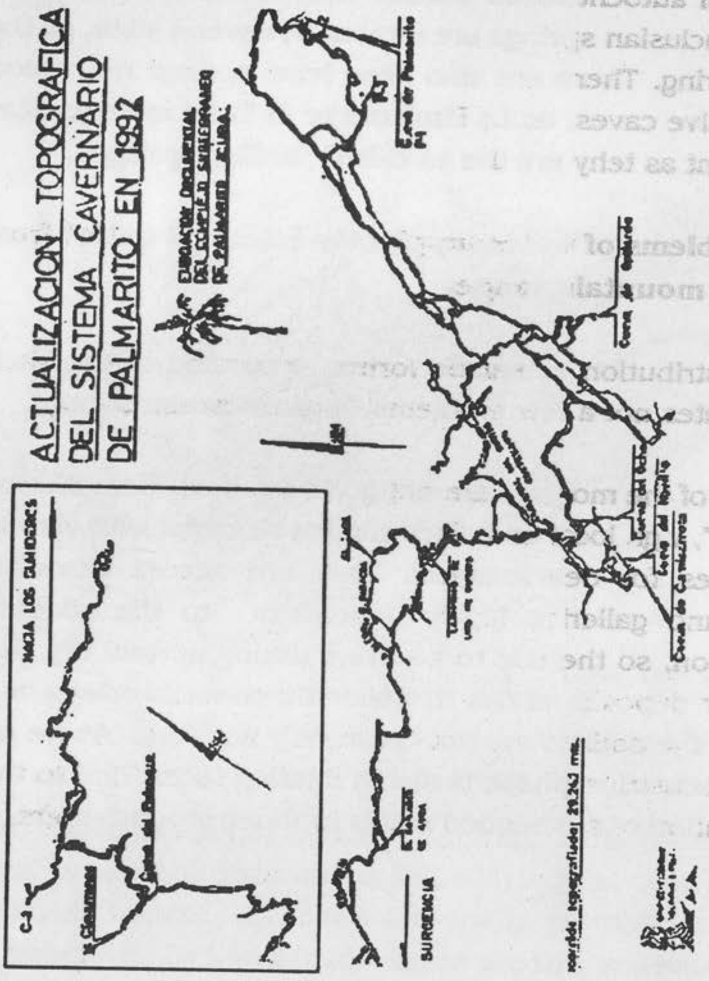
Emissive (discharge) forms are associated to emissive caves, generally of autochtonous waters. They are commonly located at the VE. Vauclusian springs are located in several sites, as the Dos Palmas spring. Thera are also base level springs not associated with emissive caves, as La Pimienta or El Tubo springs. Stavelles are frequent as tehy are the so-called "boiling springs".

3.4. Problems of water supply: the inlet and outlet fronts of the mountain range.

The distribution of karstic forms, according to the sketch of fig. 4, creates not a few problems to groundwater supply.

The VA of the mogotes are not good aquifers. Sometimes there are "tanks", v.gr. local and discontinuos storages with very limited possibilities for development. They are almost associated to underground galleries highly dependent to the allochtonous contribution, so the use to be dried during normal dry seasons. The cover deposits at the fluviokarstic contact valleys or in the bottom of the dolines are not commonly aquifers. As we pointed out, the lacustrine phase is also a limiting factor due to the high concentration of suspended solids in those groundwaters.

Fig.7. Palmarito Cave System (after 13)



Outlet slopes do not always present good quality waters because of the contribution o allochtonous watercourses. In these sense, stavelles and some vauclusian springs are more favourable.

Dos Palmas spring at Ancon Valley has exploitable yields of about 30 lps and La Pimienta spring yields about 50 lpsduring the dry season.

This hydrologic situation provokes that irrigation, mainly for tobacco, comes from surface sources, while domestic supplies come from surface streams filtered at home or from autochtonous sources taht farmers collect in lakes at the interior of the caves.

TRANSECT 4. Cueva del Indio: a masterpiece of the hydrologic evolution of cuban mogotes.

4.1. Cave levels and the problems of the varying base levels.

In Viñales, E. Flores has recognized 10 cave levels ranging from +100 to +400 m a.s.l., generaly associated with the explored cave systems. The superposition of cave levels is one of the most interesting topics concerning the evolution of cuban karst and several hypothesis has been proposed to explain it. Two basic schemes, with its combinations, are the extreme cases: a/ the main cause are the tectonic movements with a continuous uplifting process provoking the vertical deepening of the master water courses; b/ the main cause is due to the variations of the local bas level of erosion as a consequence of the major glacieustatic variations of sea level during Quaternary.

Both end-members has not a few controversial concepts. It seems, in the author opinion, very much coherent to assign the principal role to the second hypothesis. There exist a very strong relation among the ancient positions of Quaternary sea level and

the altitudes of cuban caves. A very high spatial coherence is observed, in this sense, through all the western part of Cuba, as it is derived from recent work of Flores and collaborators. When extended to the Gulf of Mexico and the Caribbean the main weight is assigned to the set of Quaternary sea level fluctuations.

Cueva del Indio, for example is at the present an underground watercourse. Several cave levels are associated to it (fig. 9). The Cumpleaños cave is one of the highest, at +280 m a.s.l. , v.gr. at 130 m above the bottom of the valley. Genetic models of both caves are identical and asincronyc phases of erosion, clogging and washing could be identified as a consequence of the different evolutive degree of the system. The reconstruction of the agradation and degradation profiles suggest that erosion control has been more efficient than uplifting.

4.2. Flow regimes and morphological features: scallop development.

Cave systems are natural models suitable for the study of present and ancient hydrodynamics. At the same time, they allow to identify, quantitatively the contribution volumes of recharge, circulation and discharge.

A special attention has been devoted to this analysis. After different hydraulic models (channels, tubes), scallop analysis, sedimentological studies, among others, it has been possible to characterize the ancient flow regimes of the underground system.

Results has shown that, according to the geometric indexes of the galleries, paleoflow was developed in subcritical stable turbulent regime, around the zone of cuadratic stable turbulent resistance of Nikuradze. Indexes from scallops showed, also, turbulent regime but with the resistance coefficient as a unique function of conduit rugosity. This is an interesting result because supports the idea that, under different boundary conditions, wall scallops are not always generated by the same flow regime.

Fig. 8. Cumpleaños cave (after 15)

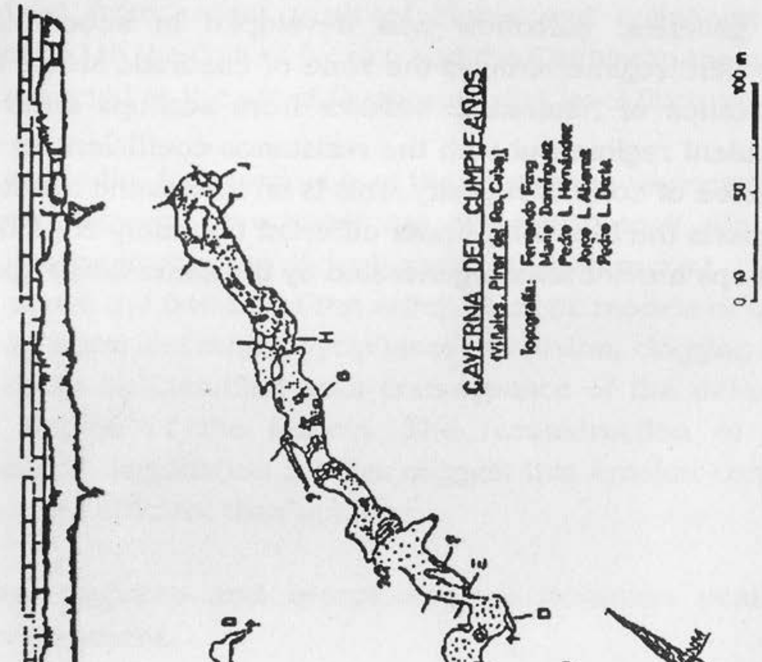
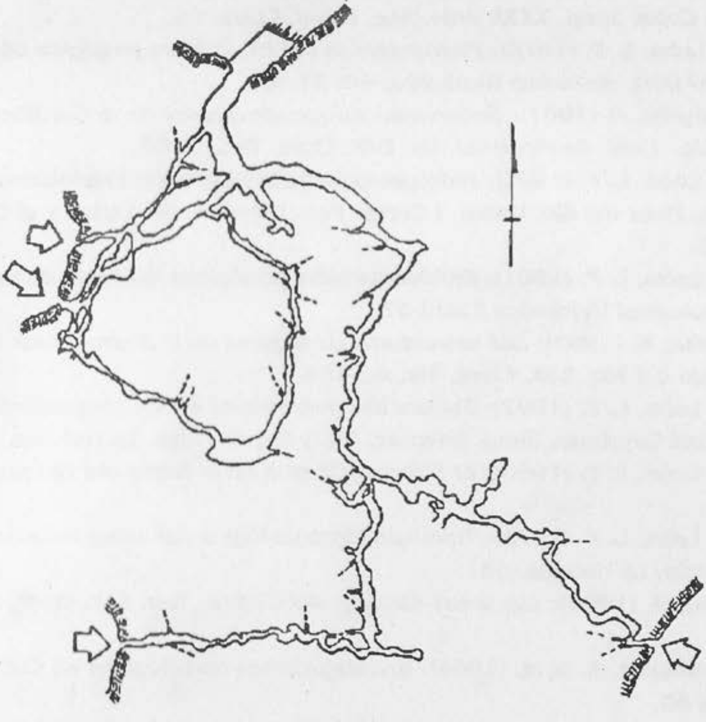


Fig. 9. Sketch map of Cueva del Indio (courtesy of P.L. Hernández Pérez)



LITERATURE

1. Domínguez, M., et al. (1991): *Aspectos generales sobre el entorno geográfico del sistema cavernario de Palmarito.* Lapiaz, Mon. II, Valencia: 43-46.
2. Molerio León, L.F. (1965): *La Palma de Corcho.* Arch. Grupo Espel. Martel, La Habana, 5.
3. Gerhartz, J.L. y A. N. Abraham (1991): *Características climáticas de la región de Viñales y su relación con el funcionamiento hidrológico del Sistema Cavernario de Palmarito* Lapiaz, Mon. II, Valencia : 50-53.
4. Molerio León, L. F. (1975): *Esquema Geoespeleológico de las Regiones Cársicas de Cuba.* Simp. XXXV Aniv. Soc. Espel. Cuba: 65.
5. Molerio León, L. F. (1978): *Fundamentos del Mapa Hidrogeológico de Cuba a escala 1:500 000.* Voluntad Hidráulica, 40: 31-33.
6. Pszczolkowski, A. (1987): *Secuencias miogeosinclinales de la Cordillera de Guaniguanico.* Geol. de Pinar del Río, Edit. Cient. Téc. : 4-84.
7. Molerio León, L. F. (1992): Hidrogeología de la Depresión Fluviocársica de Cinco Pesos, Pinar del Río, Cuba. I Congr. Fed. Espel. Amér. Latina y el Caribe, Viñales, : 65.
8. Molerio León, L. F. (1981): Problemas hidrogeológicos del karst de montaña de Cuba. Voluntad Hidráulica 53:32-37.
9. Piotrowska, K. (1987): *Las estructuras de nappes en la Sierra de los Organos.* Geol. de Pinar del Río, Edit. Cient. Téc.:85-156.
10. Molerio León, L. F. (1992): Simulación matemática de los plegamientos de la formación San Cayetano. Simp. Internac. Inf. y Geociencias, La Habana, : 34.
11. Molerio León, L. F. (1980): *El Sistema Cársico de la Sierra del Pesquero.* Tesis, 180.
12. Molerio León, L. F. (1975): Tipología hidrogeológica del carso cubano. Inst. Hidroeconomía, La Habana, 45.
13. Lehmann, H. (1960): *Las áreas cársicas del Caribe.* Rev. Soc. Geog. de Cuba.
14. Núñez Jiménez, A. et al. (1964): Investigaciones carsológicas en Cuba. Acad. Cienc. Cuba 80.
15. Hernández, P.L. et al. (1992): *La Caverna del Cumpleaños.* Lapiaz, 21 :50-55.