VEGETATION PATTERNS AND SOILS IN THE MAPIMI BOLSON (Chihuahuan Desert - Mexico). I. VEGETATION ARCS.

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ABSTRACT.

Particular vegetation types called "brousse tigrée", "vegetation arcs" or "vegetation stripes" have been described for several arid lands in the world, mainly in Africa and Middle East.

In this paper this vegetation type is described for the first time for the Mapimi area.

It consists of a mosaic of bare areas and vegetation arcs whose major axes (of 20 to 70 m long) are always perpendicular to the slope. Its position in the landscape, morpho-analytical soil characteristics, species composition and distribution along the geomorphological gradient are described.

Hypotheses on the origin and evolution of the pattern are analyzed. Its present dynamics seems to be explained by the effects of sheet water runoff and a particular microtopography where the vegetation plays a major role.

I. INTRODUCTION.

Around 1950 the development of aerial survey of plant formations showed evidence, in the arid and semi-arid zones, the existence of peculiar types of patterns corresponding to plant communities concentrated in dark parallel stripes, alternating with light bare areas. CLOS-ARCEDUC (1956) coined the french term "brousse tigrée" corresponding to what anglo-saxon authors label as "vegetation arcs" or "vegetation stripes". In Africa, these types of formations have been observed in all the arid zone from Mauritania to Somalia. Numerous works deal with their description, their floristic composition and attempt to explain their genesis. We can mention the works of: AUDRY and ROSSETI (1962) in Mauritania, BOUDET (1972) in Mali, LEPRUN (1979) in Mali and Upper Volta, BOULET, GAVAUD and BOCQUIER (1964) in Niger, WHITE (1970) in Niger, WORRAL (1959) in Sudan, BOALER and HODGE (1964) and HEMMING (1965) in Somalia. Outside of Africa, this type of formations has been reported in Jordania by WHITE (1969), in Australia by LITCHFIELD and MABBUT (1962) and in U.S.A. by IVES (1946).

Various hypotheses have been proposed, regarding the causes responsible for the formation of these stripes, their genesis and dynamics.

The study of air photographs has shown the existence of this type of formations, locally called "mogotes", in the area of the Bolson de Mapimi. The area where we particularly studied them is included in the Mapimi Biosphere Reserve. However, other observations have let us notice their presence in other zones, particularly more to the south of the basin of the Nazas river. This work describes this type of patterns in an area where it had not yet been reported, and gives certain data that supports or invalidates the hypotheses that have been emitted.

II. GENERAL DESCRIPTION OF THE ENVIRONMENT.

The study area is located in the Mapimi Biosphere Reserve (Fig. 1), in a region called "Bolson de Mapimi", belonging to the Chihuahuan Desert, as SCHMIDT has defined it (1979).

The Mapimi Biosphere Reserve occupies an area of approximately 160,000 ha. It is delimited by Northern latitudes 26°30' to 26°52', and by Western longitudes 103°32' to 103°58'.

Figure 2, from MONTAÑA and BREIMER (1981), delimitates the main landscape units established according to geomorphology, soils and vegetation. The areas of relief and their pediment (sierras and bajadas) have an altitude between 1200 and 1500 m (3935 to 4920 ft) and are constituted by volcanic rocks (basalt, andesites, rhyolites) (landscape Units Va, Vb and VII), of calcareous rocks (Unit VI) of the cretaceous age, and of a colluvial-alluvial cover of the aforementioned materials which have been spread over glacis (pediments). The landscape Units I and II correspond to an alluvial plain (playa) which collects most of the surface water and concentrates them in a lagoon located in the northwest corner, a depression with a high saline concentration. On the northern part of the Reserve we go progressivley past an area of transition between the fluvial and the eolian reliefs (Unit IV) to an area of ancient sand dunes (Unit III) fixed by the vegetation.

The soils are essentially yermosols and xerosols (F.A.O. classification) divided into areas of "playa" and of "lower bajada", presenting horizons enriched with salts (most often NaCl), gypsum and calcium. On the reliefs and their pediments ("sierras" and "upper bajada"), soils of the lithosol and regosol type prevail. Locally, around the "Laguna de las Palomas", solontchaks, with a high concentration of NaCl, have developed.

The vegetation is constituted, on one hand, of a microphyllous desert "matorral" dominated by *Larrea tridentata* with a variable degree of presence of succulent species, and on the other hand, of steppes with half-shrubby halophytes occupying the lower part.

The climate is of altitudinal arid tropical type, with an annual rainfall average of 271 mm, showing great variability; the coefficient of variation is of 42% (Ceballos station 1956-1981). The estival rains from June to September inclusive, which represent 60.7% of the annual total, have a stormy characteristic and take the form of localized showers, with high intensities. The annual average of temperatures is of 20.2°C. The minima average for the coldest month (January) is of 1.5°C and that of the maxima for the hottest month (June) is of 37.2°C.

The human occupation of the Reserve is quite scattered and unimportant. The population is distributed in a few "ranchos" and "ejidos"* whose main economic activity is extensive cattle breeding.

III. DESCRIPTION OF THE VEGETATION ARC OR "MOGOTE" PATTERN.

This type of formation appears in the middle part of the toposequences of landscape Unit V (Figure 2).

The classic sequence begins uphill with a pediment called "upper bajada", covered with a scattered but regular vegetation (average cover degree 20.3%), constituted by a "matorral" with *Larrea tridentata* and *Opuntia* sp. In this area, the surface soil is constituted by materials of colluvial origin, with a high proportion of coarse elements, resting on the altered bedrock (limestone, marl...) in place. At that level, surface erosion cuts are present constituting axes for drainage. The central part of transect is occupied by the vegetation of "brousse tigrée" or "mogotes", parallel vegetation stripes alternating with bare ground with a very light plant cover (4.4% as an average along the transect).

* "Ejidos" is a mexican type of land tenure. The State is the owner of the land, but he commits it to a farmer's group for its utilization.

In general, the soil is a yermosol with a medium texture very poor in organic matter and presenting, locally, low salinity. We can note the absence of an organized drainage axis, the drainage being mostly sheet-flow.

Lastly the arrival zone, there is a low area of accumulation of run-off water occupied by a grassy formation with *Hilaria mutica* (43.5% average cover degree) dotted with a few half-shrubs, and strewn with bare areas of irregular forms. The soils is also a yermosol, but with a fine texture and medium salinity appearing at half-depth.

We have chosen for this study two representative sequences, one located on the north-west of "cerro San Ignacio", which has been the object of the greatest number of observations. The other is located on the south-west of that same "cerro".

On the first sequence we have chosen a transect of 1037 m cutting (see Figure 3):

- The "matorral" area, length 40 m, average slope 0.90%
- The "mogotes" area, length 675 m, average slope 0.62%
- The low zone with *Hilaria*, lenght 322 m, average slope 0.23%

In the "mogotes" area the stripes of dense vegetation are arranged perpendicularly to the line of greatest slope. Their width varies from 20 to 70 m, the widest stripes being those located towards the bottom of the toposequence. The total of the vegetation stripes represents 29.6% of the length of transect I and 24.3% of transect II.

The width of the bare areas is quite variable, from 40 to 250 m, and there does not seem to be any correlation between the width of those areas and the width of the adjacent vegetation stripes. The average slope of the vegetation stripes is 0.55%, meanwhile that of the bare areas is 0.65%.

The slope at the level of the stripes is not regular; figure 4 shows the transversal topographic profile of a vegetation stripe. The slope is very weak, even non-existant, uphill of the "mogote", quite irregular in the "mogote", and shows an abrupt step down of 10 to 15 cm downhill.

IV. STUDY OF THE SOILS AND VEGETATION OF A VEGETATION ARC OR "MOGOTE".

A. Characteristics of the soils of the "mogote".

We have studied the characteristics of the soils of the "mogote" along a transect orientated according to the line of greatest slope, and cutting the "mogote" in its central part. Three pedologic profiles have been described and analyzed:

- MOG 1 = downhill area of the "mogote"
- MOG 2 = inside of the vegetation stripe
- MOG 4 = uphill edge of the "mogote"

Profile MOG 1 = localized below the "mogote", in a zone without vegetation - slope less than 1% - the micro-relief is not accentuated on the surface. Without seedlings - very low stoniness on the surface (stones, pebbles).

A11 Horizon. 0 t0 4 cm = light brownish gray (7.5 YR 7/2) dry, gray-brown (7.5 YR 5/3) moist - high effervescence with acid - few coarse elements, 5% cover, gravelly - sandy loam - fine angular blocky structure, very fragile aggregates - few pores - friable - very few fine roots - abrupt smooth boundary.

A12 Horizon. 4 to 18/26 cm = gray-brown (7.5 YR 5/3) dry, brown (7.5 YR 4/4) moist - high effervescence with acid - coarse elements, 30% cover, gravelly and cobbly - sandy loam - medium subangular blocky structure, fragile aggregates - few very fine pores, tubular and intergranular - friable - few fine horizontal roots, localized - clear undulating boundary.

B21 Horizon. 18/26 to 35/40 cm = gray-brown to gray-orange (7.5 YR 5.5/3) dry, brown to gray-brown (7.5 YR 4.5/3) moist - high effervescence with acid - coarse elements covering 5%, gravelly - clay - very strong medium angular blocky structure - very few pores - porosity inter-aggregates - firm - hard - few fine horizontal and vertical roots - clear smooth boundary.

B22 Horizon. 35/40 to 58/68 cm = gray-orange (7.5 YR 6/3) dry, gray-brown (7.5 YR 5/3) moist - high effervescence with acid - coarse elements 5% cover, gravelly - clay - very strong medium angular blocky structure, very compact aggregates, with locally thin platy structure - very few pores, inter-aggregate porosity - firm - hard - few fine localized roots - clear undulating boundary.

IIB23 Horizon. 58/68 to 90 cm = gray-orange (7.5 YR 7/3) dry, gray-orange (7.5 YR 6/3) moist - very high effervescence with acid - no coarse elements - clay - strong fine angular blocky structure - very few pore, tubular and inter-aggregate porosity- no roots, very firm - hard - clear smooth boundary.

IIB3 Horizon. 90 to 100 cm = gray-orange (7.5 YR 6.5/3) dry, gray-brown to gray-orange (7.5 YR 5.5/3) moist - very high effervescence with acid - clay loam - horizon of transition, constituted of small plates of marl a few millimeters thick, juxtaposed to very fine angular clayed aggregates stuck on the layers - very few pores - no roots - very firm - hard - clear smooth boundary.

IIC Horizon. 100 to 150 cm observed = gray-orange (7.5 YR 6/3) dry, gray-brown (7.5 YR 5/3) moist - no coarse elements - very high effervescence with acid - marly material cut up into polyhedrons and plates increasing their dimensions with depth, from a few millimeters to 5-6 cm - very massive - very hard - not porosity - no roots.

Classification = "Yermosol haplico" (F.A.O.), Camborthid (soil-taxonomy). The top sixty centimeters of the soil are constituted by a material of colluvial-alluvial origin, formed by a mixture of fine earth and of coarse elements. This allochtonous supply has come to cover the original material, constituted of a marly rock altered in its upper part.

The texture (Table I), from sandy-loam on the surface, changes rapidly to clayed, then clay-loam to silt-loam at the level of the bed-rock. The pH are over 8 and the conductivity is low (1 to 2 mmhos/cm). The content in calcium increases from the top to the bottom of the profile, from 12 to 37%: we deal with a primary calcium carbonate, of lithologic origin. The organic matter in low quantity (less than 1%) is well developed, with C/N ratios very low close to 6.

Table I. Analytical data for the MOG 1 profile.

Depth (cm)	Horizon	Texture (0-2 mm fraction)%			pH Water	Organic Carbon (%)	Nitrogen (%)	C/N	CaCO3 (%)	CEC (meq/100g)	Electrical Conductivity (mmho/cm)
		Clay	Silt	Sand							
0- 3	A11	13.4	30.0	56.6	8.1	0.50	0.081	6.2	12.2	21.7	0.75
7-14	A12	17.4	20.4	62.2	8.1	0.46	0.078	5.9	12.2	20.9	1.5
23-33	B21	40.3	25.7	34.0	8.5	0.30	0.053	5.7	24.5	20.7	
46-58	B22	44.3	25.7	30.0	8.3	0.24	0.042	5.7	26.5	20.2	2.25
66-80	IIB23	40.3	41.6	18.1	8.6	—	—	—	37.7	19.9	2.0
90-100	IIB3	30.3	49.6	20.1	8.7	—	—	—	35.7	16.0	1.0
116-124	IIC	21.1	38.7	40.2	—	—	—	—	—	—	—
144-150	IIC	15.0	20.4	64.6	—	—	—	—	—	—	—

Profile MOG 2 = localized inside the "mogote". Ground surface formed of micro-mounds of tuffs of *Hilaria mutica* alternating with depressions 10 cm deep created by the footsteps of bovines during wet periods. Vegetation with a global cover of 50 to 60%, with herbaceous strata and shrub strata.

A11 Horizon. 0 to 4 cm = light brownish gray (7.5 YR 7/2) dry, brown (7.5 YR 4/3) moist - high effervescence with acid - coarse elements, 5% cover, gravelly - loam - fine subangular blocky structure (tendency to granular) -

few pores - friable - soft - few fine roots - clear smooth boundary.

A12 Horizon. 4 to 18 cm = gray-orange (7.5 YR 6.5/3) dry, gray-brown (7.5 YR 5/3) moist - high effervescence with acid - coarse elements, 20% cover, gravelly - sandy clay - strong fine angular blocky structure - few pores, very fine pores, tubular and inter-granulate porosity - firm - fine and medium inclined roots - gradual smooth boundary.

B21 Horizon. 18 to 40 cm = gray-orange (7.5 YR 6/3) dry, gray-brown (7.5 YR 5/4) moist - high effervescence with acid - coarse elements, 25% cover, gravelly - sandy clay loam - weak fine angular blocky structure, tendency to massive - few fine pores, tubular and integranular porosity - very firm - few fine and medium horizontal and inclined roots - gradual smooth boundary.

B22 Horizon. 40 to 60/70 cm = gray-orange (7.5 YR 7/3) dry, gray-orange (7.5 YR 6/3) moist - high effervescence with acid - coarse elements, 35% cover, gravelly, few stones of volcanic rock - sandy clay loam - massive structure - very hard - very firm - very few pores - intergranulate porosity - few fine vertical and inclined roots - abrupt undulating boundary.

IIB23 Horizon. 60/70 to 85/95 cm = gray-orange (7.5 YR 6.5/3) dry, gray-brown to gray-orange (7.5 YR 5.5/3) moist - no coarse elements - very high effervescence with acid - clay loam - strong medium angular blocky structure - few fine and medium tubular pores - very firm - few fine roots - gradual undulating boundary.

IIB3 Horizon. 85/95 to 110 cm = transition horizon constituted of fine earth, with a clayed-silty texture, in fine polyhedral aggregates, juxtaposed to plates of marl - medley of colors, with brown and light-beige areas -

few pores - no coarse elements - very high effervescence to acid - very few fine and very fine roots - firm - gradual smooth boundary.

IIC Horizon. 110 to 140 cm observed - very little alterated marl, cut up in plates and polyhedrons - no roots - no coarse elements - very high effervescence to acid.

Classification = "Yermosol haplico" (F.A.O.), Camborthid (soil-taxonomy).

Table II. Analytical data for the MOG 2 profile.

Depth (cm)	Horizon	Texture (0-2 mm fraction)%			pH water	Organic Carbon (%)	Nitrogen (%)	C/N	CaCO3 (%)	CEC (meq/ 100g)	Electrical Conductivity (mmho/cm)
		Clay	Silt	Sand							
0- 3	A11	14.3	42.3	43.4	8.1	1.70	0.042	40.5	25.8	13.3	1.0
6-14	A12	38.6	6.0	55.4	8.2	0.50	0.042	11.9	22.5	15.3	0.6
25-33	B21	27.4	14.4	58.2	7.4	0.28	0.050	5.6	20.5	22.4	0.65
48-58	B22	29.4	18.4	52.2	8.2	0.22	0.022	10.0	19.9	20.4	0.5
71-79	IIB23	39.4	42.4	18.2	8.4	—	—	—	21.3	33.7	0.75
97-105	IIB3	37.4	48.0	14.7	8.8	—	—	—	18.5	36.7	2.0
130-140	IIC	41.0	24.7	34.3	—	—	—	—	—	—	—

Very similar profile, morphologically and analytically (Table II) to MOG 1 above mentioned, but in comparison to the latter we note a stronger proportion of coarse elements in the upper part of the profile, of colluvial-alluvial origin, and a coarser texture at medium depth and finer at the base. But overall we note the influence of the plant cover which is present:

- as a greater quantity of roots, well scattered in the profile and down to a depth of 1 meter, when they did not go under 60 cm in the MOG 1 profile with a localized repartition and in small quantity.

- as the content in organic carbon of the superficial part of the soil which reaches 1.7%. It is a very undeveloped organic matter with a high (40) C/N originating from the periodic supplies to the bedding ground (of leaves essentially). But the greatest part of this "humus" mineralizes very quickly, since from the A12 horizon on we find again a low content and C/N similar to those of profile MOG 1.

The influence of this organic matter on the characteristics of the soil, combined with a relative abundance of roots, is important because it favours, at least in the 20 to 30 upper centimeters, a finer and more rounded structure (tendency to granular) which, giving a better aeration and a better porosity to the soil, increases permeability.

But this influence is limited to the upper part, since from a depth of 30 cm, we find again compact horizons, very few pores, and very little permeability.

Profile MOG 4 = located on the uphill limit of the "mogote", is identical to MOG 1 and MOG 2, as well in the succession of pedologic horizons and of materials as in the analytical characteristics (Table III). We can note, at most, the influence of the proximity of the "mogote", whose vegetation by its fallouts of rough organic matter, provokes an increase of the content in humus of the superficial part of the soil (1% of organic carbon with a C/N close to 20), which still stays lower to what we have observed inside the "mogote" itself. This increase in the organic matter content is, however, sufficient to provoke a beginning of amelioration of the physical properties of the surface soil (aeration, porosity, structure...) and an increase in permeability which will favor a better infiltration of runoff water in this zone, just uphill of the "mogote".

Table III. Analytical data for the MOG 4 profile.

Depth (cm)	Horizon	Texture (%)			pH water	Organic Carbon (%)	Nitrogen (%)	C/N	CEC (meq/ 100g)	CaCO3 (%)
		Clay	Silt	Sand						
0- 3	A11	13.4	30.7	55.9	8.0	1.03	0.053	19.4	20.4	14.3
8-15	A12	14.3	42.3	43.4	8.5	0.34	—	—	20.1	—
22-31	B21	40.7	28.3	31.0	8.4	0.26	0.070	3.7	23.9	25.5
39-48	B22	40.7	36.3	23.0	8.4	0.20	0.061	3.3	21.7	29.6
60-72	IIB23	42.7	41.9	15.4	8.0	—	—	—	20.2	30.6
82-92	IIB3	32.7	53.9	13.4	7.7	—	—	—	—	27.5
118-123	IIC	23.1	22.7	54.2	—	—	—	—	—	—

This uphill area above the "mogote" is divided into two zones: an "arrival" or "pioneer" zone, about 8 meters wide, located immediately uphill of the "mogote", and a "transit" or "gravelly" zone which lies between the "pioneer zone" and the uphill.

In the "transit zone", the surface of the soil is covered by about 50 to 60% of gravels and of a few stones of mixed nature (basalt, sandstone, limestone...). Between those coarse elements, the surface of the soil, when dry, is smooth and not too porous, which, combined with a high proportion of gravels, creates an environment more favorable to runoff than to infiltration.

In the "pioneer zone", the upper part of the soil is constituted of a film about 1 cm thick, of silty texture (52 to 66% of clay and silt, of which 40 to 50% is silt), without coarse elements, which contrasts clearly with the corresponding part of the "transit zone" soil, of essentially sandy texture (28 to 40% clay and silt, of which 16 to 21% is silt), and containing numerous gravels. We can note the absence of coarse elements on the soil surface of this "pioneer" zone. The silty superficial film, under the desiccant action, splits to become disjunctive polyhedrons with turned up edges, which favors infiltration at this level in the underlying horizons with a sandy texture and a good porosity. We should note in this "arrival area" the great number of seedlings of *Tridens pulchellus*, *Sida leprosa*, *Sphaeralcea angustifolia*...

During rainy periods, and according to the state of the surface of the soil, particular dynamics take place in the water processing from the uphill area to downhill of the "mogote". The "gravelly" area, not very favorable to infiltration, witnesses the creation and organization of an extensive runoff, which is considerably slowed down when it reaches the "mogote", in the "arrival area". The latter, due to the morphology of its surface, is favorable to infiltration, and so complementary water supply occurs in the "arrival area", and likely too in the uphill part of the "mogote"*.

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* This water supply contains fine elements in suspension, probably in weak quantities, but following the "block" when arriving into the "mogote", they deposit and produce the surface silty film which is observed in the "arrival area".

These water dynamics can only help the development and increase of the vegetation, essentially uphill of the "mogote", and the progressive colonization by the vegetation of the "arrival area".

At the "mogote" level, the pedologic cover is homogeneous and only the surface part of the ground registers noticeable variations. These essentially come from the vegetation cover, which, indirectly, improve the physical properties of the ground: structure, porosity, permeability... This results in a particular water dynamic up and downhill of the "mogote" which probably favors a "rising" or moving uphill of the"mogote" itself in the longer run.

B. Characteristics of the vegetation.

Table IV shows the repartition of the main species along the transect, according to their interception by segments method, GOUNOT (1969). We can make out eight groups of species according to their amplitude of repartition:

- The first group only occupies the interfluves of the "upper bajada", they are typical species of the desert microphyll matorral: *Fouquieria splendens*, *Opuntia imbricata*, *Euphorbia antisyphilitica*, *Castela tortuosa*...

- The second group appears, both in the interfluves of the "upper bajada" and in the bare areas. They are essentially: *Opuntia microdasys*, *Opuntia rastrera*, *Echinocereus conglomeratus*, *Agave asperrima*, in addition to which come feable quantities of *Bahia absinthifolia* and *Tridens pulchellus*.

- The third group concerns the species present in the runoff gullies in the "mogotes" and sometimes in the arrival zone with *Hilaria*; those are species which seem to need more favorable hydric conditions, in areas with water accumulation. They are: *Flourensia cernua, Prosopis juliflora, Hilaria mutica, Trichachne californica...*

- Group four is made up of species pertaining to the "upper bajada" forming the "matorral", but with a broader extension and which may also be found in the "mogotes"; they are: *Larrea tridentata, Cordia greggi, Opuntia leptocaulis var. brevispina, Jatropha dioica...*

- The fifth group limited to the bare areas seems to be made up essentially of cactaceaes, which benefit from the lack of concurrence of other species; we may name: *Opuntia schotii, Escobaria tuberculosa, Peniocereus greggi, Echinocereus* sp., to which it is fit to add *Haplopappus trianthus*, with a looser repartition and which appears in certain "mogotes".

- Group six is constituted by the species essentially present in the uphill edge of the "mogote" called "front", and includes annual species and not well developed chamephytes: *Bouteloua barbata, Eragrostis sp., Panicum hallii, Sphaeralcea angustifolia, Sida leprosa, Hoffmanseggia glauca...* Some of these species, also present in the clayed arrival zone, seem to be linked to the soils with a favorable water balance and rich in fine elements.

- The seventh group appears in our area exclusively in the dense vegetation stripes of the "mogotes". They are: *Parthenium incanum, Aloysia lycioides, Trichloris crinita, Viguiera sp., Perezia nana...*

- Group eight is made up of species peculiar to the arrival zone with water accumulation and soil rich in fine elements where they are associated to *Hilaria*; they are: *Ziziphus obtusifolia, Koeberlinia spinosa, Opuntia violacea...*

Each vegetation stripe has a marked zoning of species which led us to distinguish five areas. Figure 4 shows the representation of that zoning on a transect across a "mogote", and the repartition of the main species. From uphill to downhill we distinguish:

- A frontal zone, almost flat, presenting superficial deposits of fine elements, colonized by a low and diffuse vegetation characterized by the abundance of *Tridens pulchellus*, but numerous species are present: perennial herbs of shallows with clayed soils: *Sida leprosa, Euphorbia dentosa, Sphaeralcea angustifolia, Hoffmanseggia glauca*; annual graminaes: *Bouteloua barbata, Eragrostis sp., Chloris sp...*; a few perennial graminaes of very reduced size due to grazing: *Panicum hallii, Trichloris crinita, Trichachne californica...*, and, otherwise, species of the "mogote" in their juvenile state: *Hilaria mutica, Flourensia cernua, Prosopis juliflora* (seedling), and, sometimes quite abundantly, species with a broad extension such as *Haplopappus trianthus* and *Opuntia leptocaulis*.

This zone, from 3 to 8 m wide, constitutes the pioneer zone upwards of the "mogote". The structure of the vegetation and the state of the surface of the ground shows that there is an upslope migration, but that it must be very slow and we may think that it is not regular, but may happen in fits and starts when favored by auspicious climatic conditions.

- The preceding zone is limited immediately downhill by a screen of dense vegetation, constituted by herbaceous strata with perennial tussocks of *Hilaria mutica*, from 15 to 60 cm high, dominated by a dense shrub strata of 1.0 to 1.5 m almost uniquely constituted of *Flourensia cernua*. The *Hilaria* herbaceous strata occupies in a more or less covering fashion the whole "mogote".

- Behind this screen of *Flourensia*, we find a dense bushy area of 1.5 to 2.5 m presenting a wider specific diversity with: *Prosopis juliflora*, *Aloysia lycioides*, *Lippia graveolens*, *Parthenium incanum*... It is in this area that we find the species peculiar to the "mogote".

Then we find an area with a less bushy strata, poorer in species, composed essentially of older *Prosopis* and of a few *Acacia constricta*, dominating the herbaceous strata with *Hilaria mutica*.

- The "mogote" ends with an area occupied by old and withering tussocks of *Hilaria* and a few shrubs. It presents a difference in level from 10 to 15 cm with the bare zone downill.

- Downhill of the "mogote", the bare area includes a few cactaceaes and the rests of dead shrubs: *Flourensia*, *Larrea*, *Prosopis*... Nevertheless, the latter has a diameter inferior to that of those in the "mogote".

This zoning of the vegetation, seems to be the trend in all the vegetation stripes observed, although, the dimensions of each zone are variable.

DISCUSSION.

The various works done on similar types of formations show that we may consider three situations as for the origin of the vegetation stripes. Sometimes, the origin is aeolian, the stripes are perpendicular to the direction of the dominant winds or to their resultant; it is the case observed by IVES (1946) in the U.S.A., and by WHITE (1969) in Jordania, the hydric factor only seems to take place at the level of the differences in salt content. Sometimes, the origin is linked to the existence of an expansive runoff creating a water balance favorable at the level of the vegetation stripes, the dynamic action of the wind adding up to it, by its supply of sand uphill of the vegetation arcs; those are then perpendicular to the line of greatest slope, but their dynamics are quite rapid as a result of the wind action, as is the case in Sudan (WORRAL, 1959), in Mali (LEPRUN, 1979), and in Mauritania (AUDRY and ROSSETI, 1962). In the whole of the other cases (Niger, Upper Volta, Somalia, etc.) and in the situation studied here, the superficial dynamics of the water appear as the essential factor, the wind being a weak secundary factor. The occurrence and formation of "brousse tigrée" seems to originate, in arid regions, of a conjunction of factors, between the relief (weak but regular slope: 0.25 to 1%), the soil (richness in fine elements and little permeability) and the climate (rare rains, of high intensity), which leads to the existence of an important sheet-flow.

As for the mechanism of implantation of this type of formation, GREIG-SMITH (1979) and WHITE (1971) have emitted two likely hypotheses, one based on a more or less homogeneous cover, with concentration of the vegetation and disappearance of the vegetation in the interstripes, and the other based on a non-existent or very little cover, the vegetation stripes form natural barriers interrupting the runoff.

In our case, the hypothesis which presently seems more likely seems to be linked to the slow geomorphologic evolution of a slope initially occupied by an already complex vegetation: desert matorral with differentiation of the interfluves and gullies of organized runoff. The regressive evolution of the runoff gullies, their progressive disappearance downhill and their replacement by an area of sheet-flow. The implanted species linked to the runoff axes locally form islands of denser vegetation, the plant group gets structured by forming an obstacle against the runoff and it leads to the disappearance of the downhill matorral.

The stability of this type of pattern depends partly on the stability of the vegetation stripes; those seem to be in equilibrium with the conditions of local water supply. They present dynamics of upslope migration; this dynamics appear to be slow and irregular. The displacement has not been measured. It also depends partly on the stability of the bare zones which are the areas for the collecting and supplying of water to the vegetation stripes, and act as natural impluviums. Their stability result from the difficulty of implantation of the vegetation, essentially related to the state of the surface of the soils: layer of gravels, sealing, poor permeability, but also to the sweeping of the seeds by the wind in the dry season.

It then seems that this type of pattern holds a stable equilibrium in relation with the factors of the existing environment: soil, relief and climate and perhaps constitutes an efficient adaptation to the utilization of water in this arid environment.

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TABLE IV. Repartition of the main species along the transect.

MAIN SPECIES	Upper Bajada		Bare Areas	Mogotes		HILARIA GRASSLAND
	INTERFLUVES	GULLIES		FRONT	BODY	
FOUQUIERIA SPLENDENS	+					
CASTELA TORTUOSA	+					
OPUNTIA IMBRICATA	+					
EUPHORBIA ANTISYPHILITICA	+					
MAMMILLARIA SP.	+					
ACACIA CONSTRICTA	+				+	
OPUNTIA MICRODASYS	+		R			
OPUNTIA RASTRERA	+		+			
ECHINOCEREUS CONGLOMERATUS	+		+			
AGAVE ASPERRIMA	+		+			
BAHIA ABSINTHIFOLIA	+		R	+		
TRIDENS PULCHELLUS	R		R	+		
FLOURENSIA CERNVA		+		G	+	
PROSOPIS JULIFLORA		+		G	+	+
HILARIA MUTICA		+		G	+	+
SETARIA SP.		+			+	
TRICHACHNE CALIFORNICA		+		+	+	
PAPPOPHORUM MUCRONULATUM		+			+	
LIPPIA GRAVEOLENS		R			+	
JATROPHA DIOICA	+	+				
CORDIA GREGII	+	+			R	
MUHLENBERGIA SP.	R	+			+	
LARREA TRIDENTATA	+	+	+	R	R	
OPUNTIA LEPTOCAULIS	+	+	+	+	+	+
ESCOBARIA TUBERCULOSA			+			
OPUNTIA SCHOTTII			+			
PENIOCEREUS GREGGII			+			
ECHINOCEREUS SP.			+			R
HAPLOPAPPUS TRIANTHUS			+	+	+	

MAIN SPECIES	Upper Bajada		Bare Areas	Mogotes		HILARIA GRASSLAND
	INTERFLUVES	GULLIES		FRONT	BODY	
BOUTELOUA BARBATA				+		
ERAGROSTIS SP.				+		
PANICUM HALLII				+		
CHLORIS SP.				+	+	
SPHAERALCEA ANGUSTIFOLIA				+		+
SIDA LEPROSA				+		+
EUPHORBIA DENTOSA				+		+
HOFFMANSEGIA GLAUCA				+	+	+
HELIOTROPIUM MOLLE				+	+	+
PARTHENIUM INCANUM					+	
ALOYSIA LYCIOIDES					+	
TRICHLORIS CRINITA					+	
VIGUIERA SP.					+	
COMMELINA COELESTIS					+	
PEREZIA NANA					+	
SOLANUM ELEAGNIFOLIUM					+	+
IBERVILLEA TENUISECTA					+	+
ZIZYPHUS OBTUSIFOLIA						+
KOEBERLINIA SPINOSA						+
OPUNTIA VIOLACEA						+

R = species with small cover

G = seedling

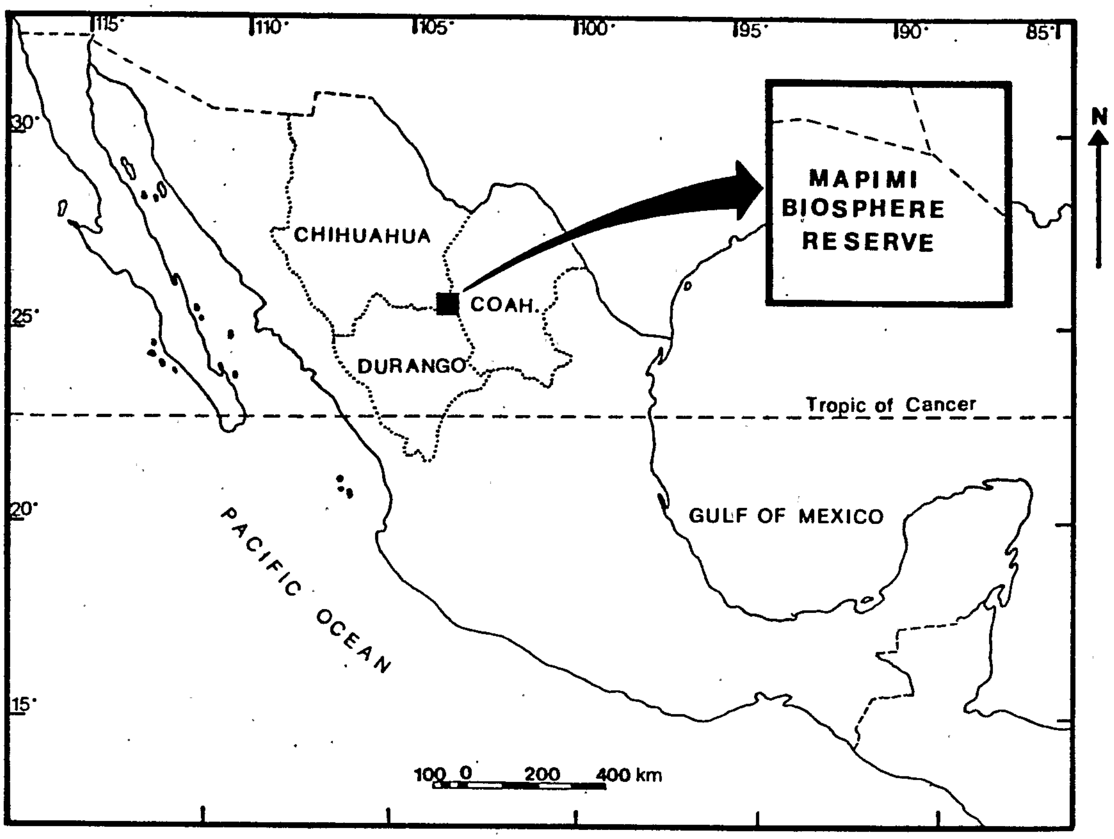

Fig. 1. Localization of Mapimi Biosphere Reserve (Durango, Mexico).

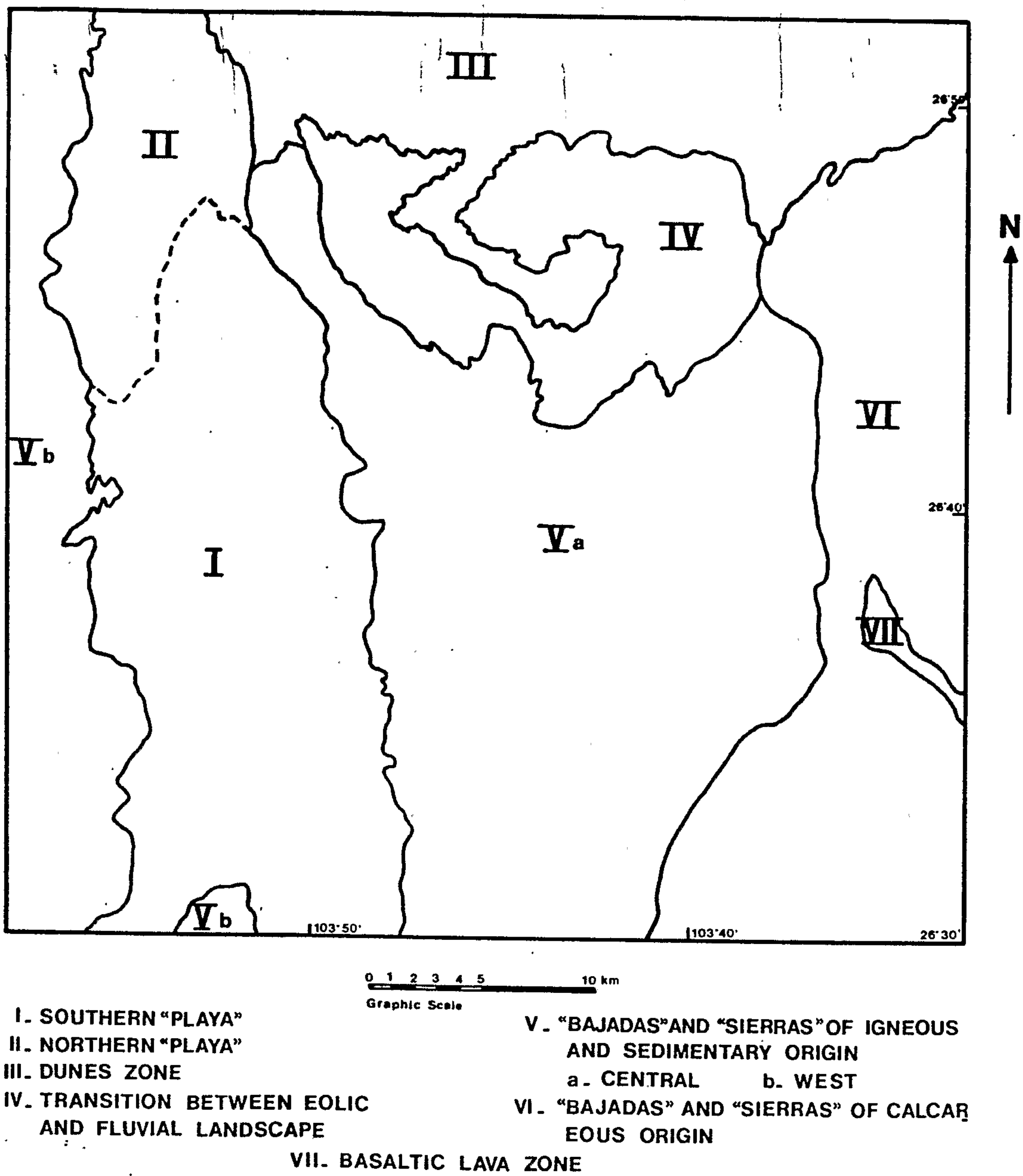

Fig. 2. Delimitation of landscape units, according to geomorphology, soils and vegetation (from MONTAÑA and BREIMER, 1981).

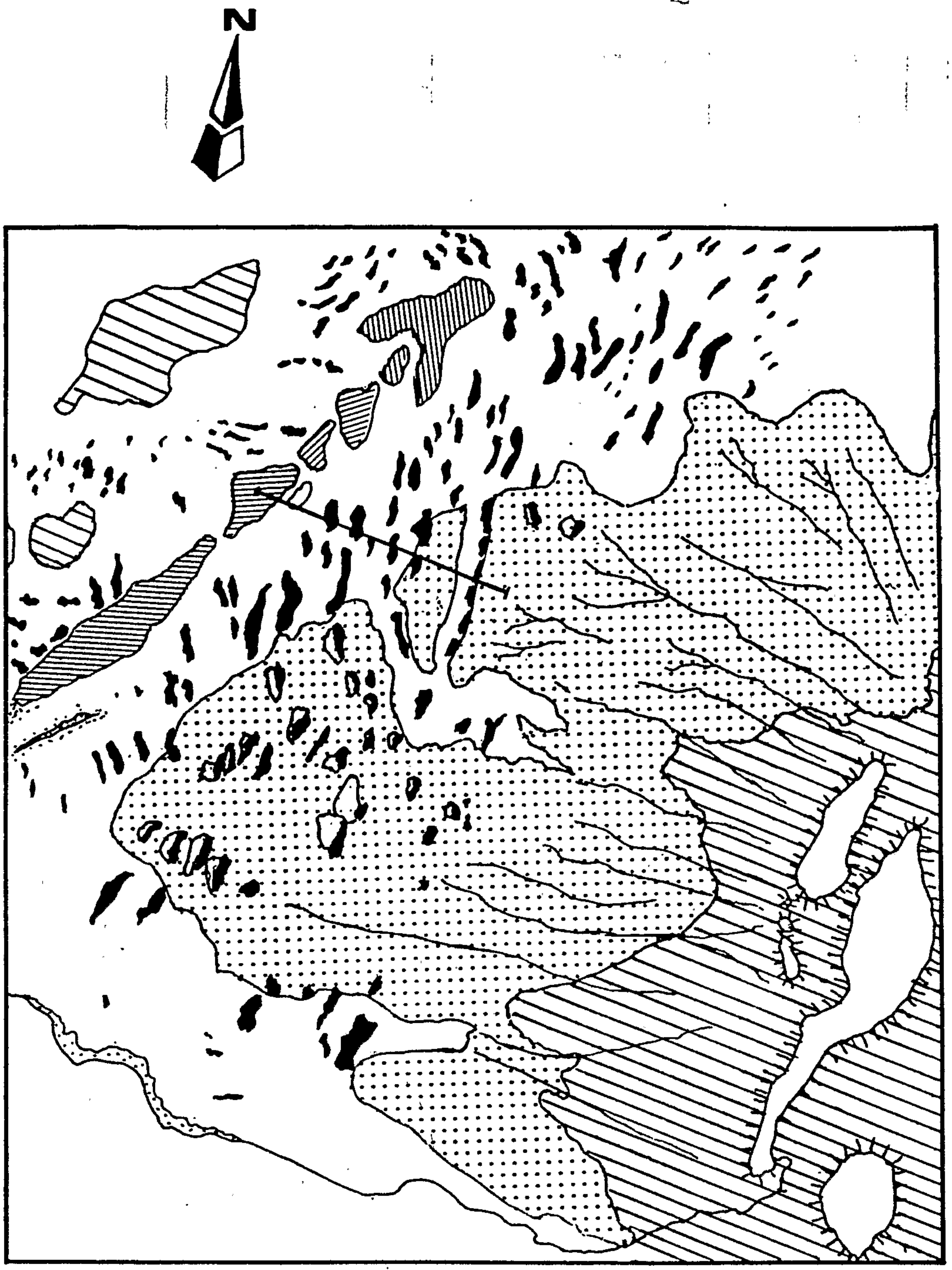

Fig. 3. Distribution of vegetation arcs in the Mapimi Biosphere Reserve.

- Vegetation arcs or "mogotes"

- Upper "bajada" with desert matorral

- Piedmont and low hills (lomas)

- Arrival zone with *Hilaria* grassland

- Transect

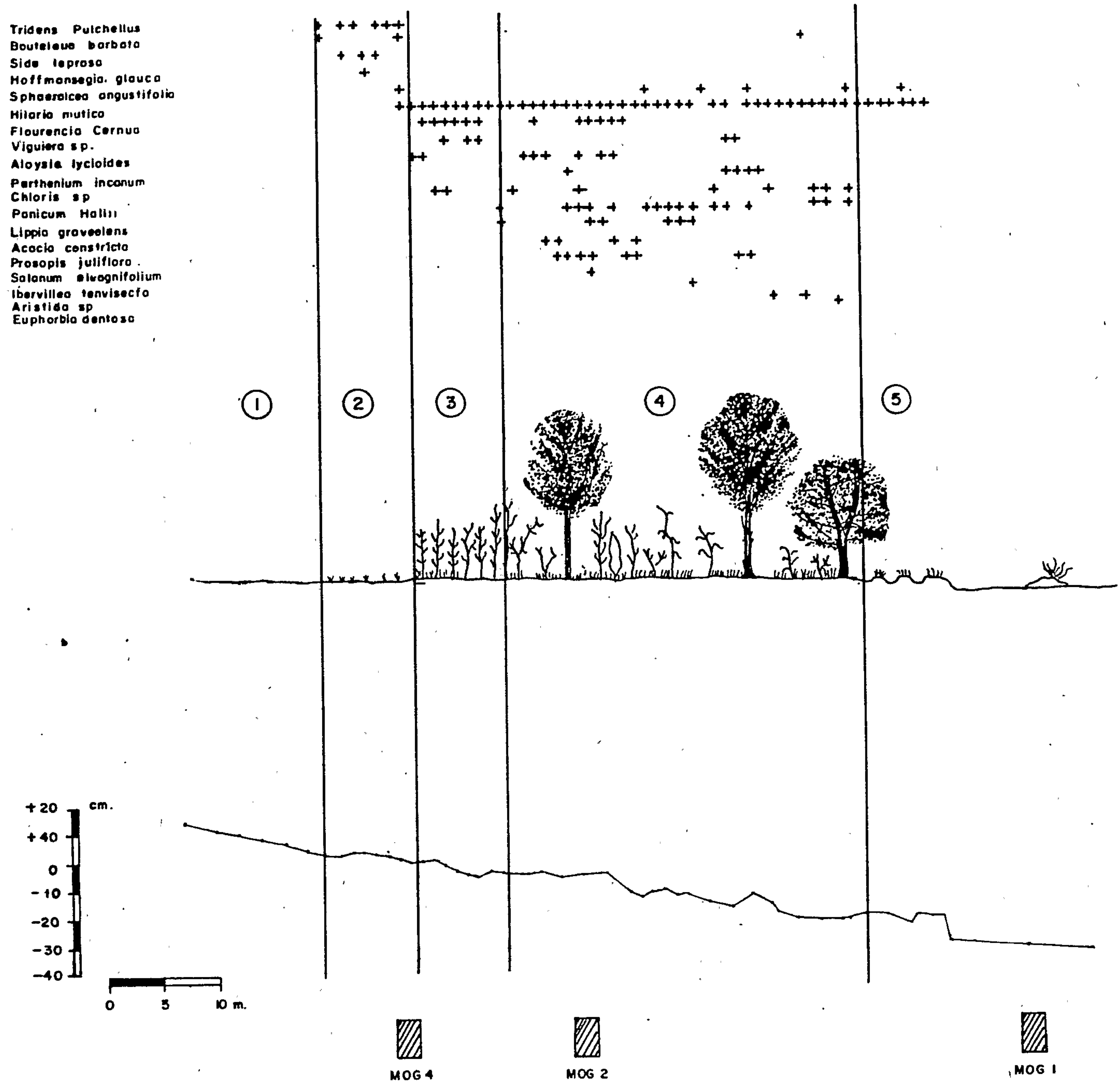

Fig. 4. Section across a vegetation stripe showing the repartition of the main species, the level profile and the location of soil profiles.

1 - Bare area with surface gravel

2 - Pioneer zone (front)

3 - Screen of *Flourensia*

4 - Body of the "mogote"

5 - Down hill area of the "mogote"