

VEGETATION PATTERNS AND SOILS IN THE MAPIMI BOLSON
(CHIHUAHUAN DESERT - MEXICO)
II. POLYGONAL PATTERNS

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ABSTRACT.--Several types of patterned ground of polygonal appearance have been described, mainly in cool regions, but also in hot, arid lands where they are developed in saline and gypsic soils. In this paper, a polygonal patterned ground in the Mapimi Bolson is described. It consists of an irregular polygonus net whose edges are channels about 40 m in length, 1 m wide and 0.5 m deep. The channels are vegetated by a practically monospecific community of *Suaeda* cf. *nigrescens*, with the interchannel zone being bare ground. A gypsic horizon appears about 0.3 m deep and the soil profile is moderately saline with locally high concentrations. The genesis of the pattern seems to be due to desiccation cracks in the soil surface combined with volume diminution of gypsum by water losses in hot summers. The union of several desiccation cracks result in a polygonal pattern.

The term "patterned ground" is used to designate an organization of the surface of the ground which may take the form either of a geometric pattern more or less orderly (polygons, circles...) or of a striped or a steplike pattern (Washburn, 1950, 1956). These formations have been described in numerous regions of the globe, but more specifically in cold environments where the action of the frost is important, and in hot and arid environments (Knechtel, 1951; Bellair, 1957; Malde, 1961; Bonython, 1956; Hunt and Washburn, 1966; Ollier and Seely, 1977; Tucker, 1978; Watson, 1980).

In cold areas, the alternations between freezing and thawing account for the origin of the observed forms in the "patterned ground." In hot and arid zones, their genesis is bound to the intervention of physico-chemical processes such as the variations in volume of certain minerals or constituents under the effect of wet and drying cycles and salt action according to the dissolution-precipitation cycles. We shall describe a "polygonal patterned ground" located in the Chihuahuan Desert (Mexico) and we present a hypothesis to explain its genesis.

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 defined by Schmidt (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'.

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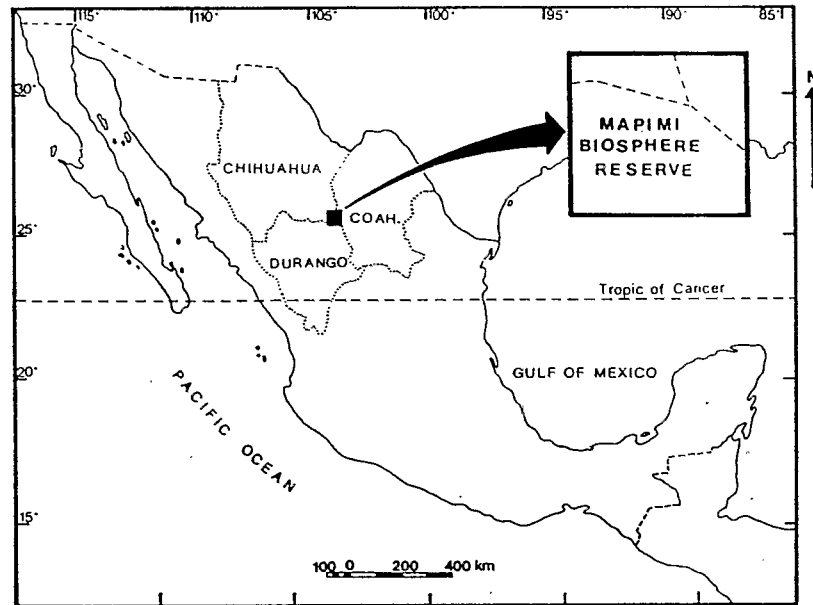


Fig. 1. Localization of Mapimi Biosphere Reserve (Durango, Mexico).

Figure 2, from Montaña and Breimer (1981), delimits 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 - 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.) In the northern part of the Reserve we go progressively 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.

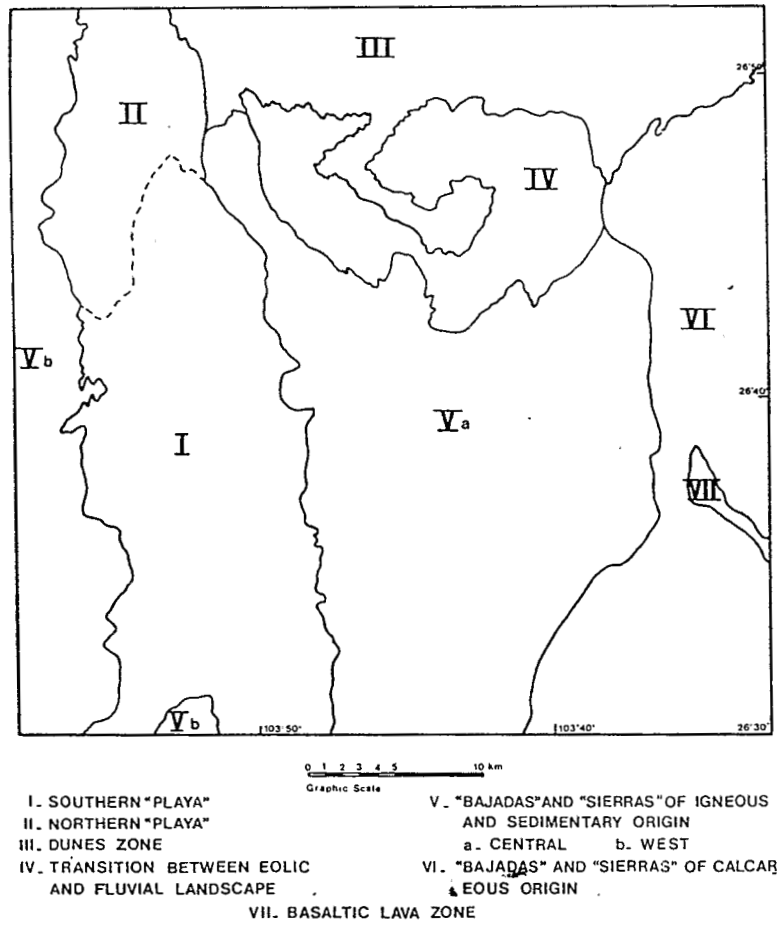


Fig. 2. Delimitation of landscape units, according to geomorphology, soil and vegetation (from Montaña and Breimer, 1981).

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 temperature is 20.2°C. The minima average for the coldest month (January) is 1.5°C and the maxima for the hottest month (June) is 37.2°C.

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

THE "POLYGONAL PATTERNED GROUND" OF THE RESERVE DESCRIPTION

The polygonal pattern clearly appears on air photographs (scale 1:25000), whereas on the ground, it is difficult to notice its existence.

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It is constituted by lines or segments cutting each other and this pattern is created by the vegetation which densely settling along the lines, brings out and amplifies the polygonal pattern, in contrast with the spaces between the lines which are almost devoid of vegetation. The zone occupied by this formation has surface area of about 5 km².

In detail (Fig. 3) the polygonal pattern appears to be very irregular, with bands oriented in all directions and sometimes interrupted. The lines are 10 - 40 m long and 5 - 8 m wide. The average general slope of the area is 0.2% with a north-north-east aspect. Microtopographic surveys (Fig. 4) show in the middle part of the bands, depressions or hollows in the surface of the ground, of a concave form, 10 - 30 cm deep and 1 - 2 m wide. These depressions are present on every band and along their length.

Vegetation. The vegetation is constituted by a quasi mono-specific community of *Suaeda* cf. *nigrescens*, having colonized the band with shrubs from 1 to 2 m high well developed and in good condition. Under this shrubby stratum we find a herbaceous stratum very poor in species and with a very low percent cover, essentially constituted of *Hilaria mutica*,

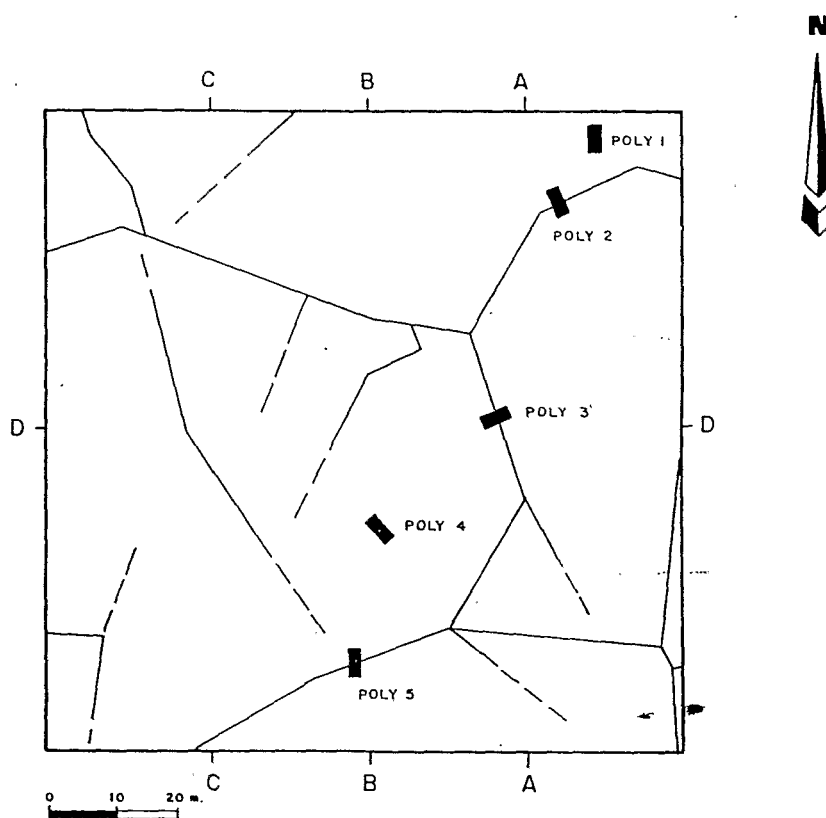


Fig. 3. Diagram of polygonal pattern (100 x 100 m); POLY 1, 2, 3, 4, 5 are soil profiles; AA, BB, CC, DD are localization of microtopographic surveys (see Fig. 4).

Sida leprosa, Heliotropium cfr. curassavicum, Euphorbia dentosa, Setaria cfr. viridis, and Bouteloua barbata. In the spaces between the bands, the ground is bare. We find only a few Suaeda in very bad condition, and dead shrubs.

Soil. On the pedologic level, the "polygonal pattern" zone is relatively homogenous and profile POLY 1 (see localization in Fig. 3) described below is representative of the soils of the whole area.

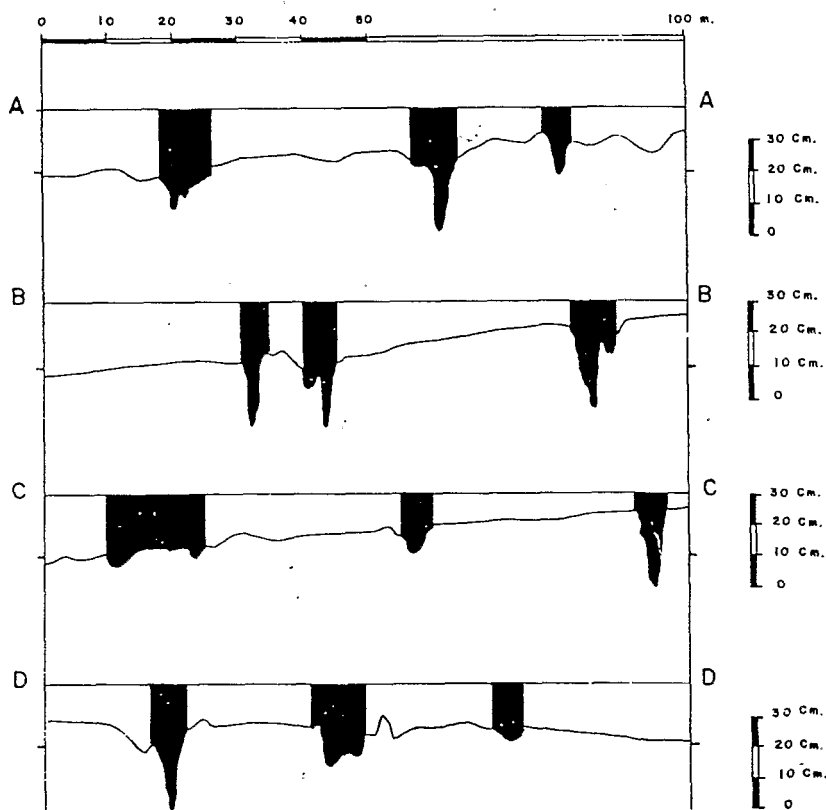


Fig. 4. Microtopographic surveys (see localization on Figure 3).

Profile POLY 1. Located in a zone without vegetation, slope less than 1%. Micro-relief on the surface.

All Horizon, 0 - 4 cm, light brownish gray (7.5 YR 8/2) dry, gray-yellowish-orange (10 YR 6/3) moist, high effervescence with acid, no coarse elements, sandy loam, granular structure, few very fine pores, tubular and inter-granular, few very fine and fine roots, firm, clear and smooth

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boundary. Al2 Horizon, 4 - 30 cm, gray-orange (7.5 YR6/3) dry, gray-brown (7.5 YR 5/3) moist, high effervescence with acid, no coarse elements, clay loam, weak fine angular blocky structure, few very fine pores, intergranular and tubular, very firm, few very fine and fine roots, abrupt and smooth boundary. B21Cs Horizon, 30 - 55 cm, gray-orange (7.5 YR 6/3) dry and moist-high effervescence with acid, numerous crystals of gypsum, from 1 to 4 mm, spread out in the horizon, juxtaposed with fine earth, sandy, clay loam, no coarse elements, fine angular blocky structure, very fragile structure, friable, few pores, intergranular porosity, very fine and fine roots, gradual and smooth boundary. B22t Horizon, 55 - 140 cm observed, gray-orange (7.5 YR 6/3) dry, gray-brown (7.5 YR 5/3) moist, high effervescence with acid, crystals of gypsum especially in the upper part of the horizon and with a content decreasing with depth, no coarse elements, clay, very fine angular blocky structure from 55 to 90 cm, then fine angular blocky structure from 90 to 140 cm, very firm, hard, very few pores, few sticken sides, not well developed, not shiny, in the upper part of the horizon. Classification, "Yermosol gypsique" (FAO); Gypsiorthid (not typic), (Soil-Taxonomy).

The main analytic characteristics of this profile are the following (Table 1): the texture, from sandy-silty on the surface, becomes very rapidly clayed-silty then clayed. Organic matter, in small quantity (less than 1%), is well developed with low rates in C/N. The pH is superior to eight and increases slightly with depth. The content in calcium carbonate goes from 16% on the surface to 22% in depth. It is primary limestone of lithologic origin, and no form of secondary redistribution (pseudo-mycelium, stains...) is visible in the profile. Gypsum, on the other hand, has a secondary origin, in horizon B21Cs, where it is present in the form of crystals of the gypsum flower ("rose des sables") type. The electric conductivity becomes noticeable in the gypsum horizon and is maintained further on. Salinity is essentially due to sodium chloride.

This type of profile is representative of the soils in the area with a "polygonal pattern." However, on the vegetation bands, variations appear in the morphology of the pedologic profile. As we have indicated above, the surface of the ground at the median part of the bands is in a hollow, reaching a depth 10 - 30 cm and 1 - 2 m wide.

Vertically from this concave median zone we find, in the soil profile, a subsidence of the horizons, particularly in the gypsum level (Fig. 5, 6). This peculiar disposition of the horizons allows us to suppose that there has been a collapse of the gypsum level in a space of the subjacent clayed horizon, correlated with a subsidence of the surface horizons and lowering of the level of the ground surface, which gives the present aspect of this surface a depression.

The various soil profiles, perpendicularly to the lines of vegetation, which we have realized in the study area (POLY 2, POLY 3, and POLY 5) show the same peculiar morphology of the horizons at the level of the median axis of the bands. On the analytic level [III and IV of profile POLY 2, (Fig. 5 and Table 2) and II, III, and IV of profile POLY 3 (Fig. 6 and Table 3)], we find the same soil characteristics at the level of the vegetation bands as in the typical profile above. At most, we may note a finer texture of the surface horizon: silty-clayed to clayed-silty instead of sandy silty.

TABLE 1. Analytical data of the profile POLY 1.

Depth (cm)	Horizon	Coarse Fragments (>2 mm)*	Texture (<2 mm fraction) %			pH in water	Organic carbon (%)	Nitrogen (%)	C/N
			Clay (<0.0002)	Silt (0.002-0.050)	Sand (0.050)				
0-4	A11	0.8	18.3	26.3	55.4	8.2	0.36	0.042	8.6
6-12	A12>	0.2	40.3	14.3	45.4	8.1	0.40	0.033	12.1
18-25	A12<	2.0	38.0	16.7	45.4	8.2	0.35	0.039	9.0
32-45	B21 cs	8.0	24.3	28.3	47.4	8.1	0.30		
58-68	B 22t	6.5	44.0	18.7	37.3	8.9	0.19		
75-85	B 22t	8.0	48.3	30.3	21.4	8.7	0.13		
110-120	B 22t	7.6	60.3	20.3	19.4	8.7	0.14		

* weight percentage =

Depth	CaCO ₃ (%)	Gypsum (%)	Electrical Conductivity (mmho/cm)	Water extract from Saturated paste (meq/liter)			CEC (cation exchange capacity) (meq/100 g)
				Ca	Mg	Na	
0-4	16.3	0	1.5	5.70	0.58	7.57	18.6
6-12	15.3	0	3.0	7.75	0.83	12.13	23.6
18-25	18.4	0	4.0	11.00	1.08	13.48	25.5
32-45	21.4	28.1	12.5	32.50	4.16	15.39	23.2
58-68	19.4	16.3	25.0	19.50	9.33	15.69	23.0
75-85	21.4	12.0	20.0	15.90	6.41	15.56	23.5
110-120	22.4	10.0	20.0	17.50	5.75	15.52	25.9

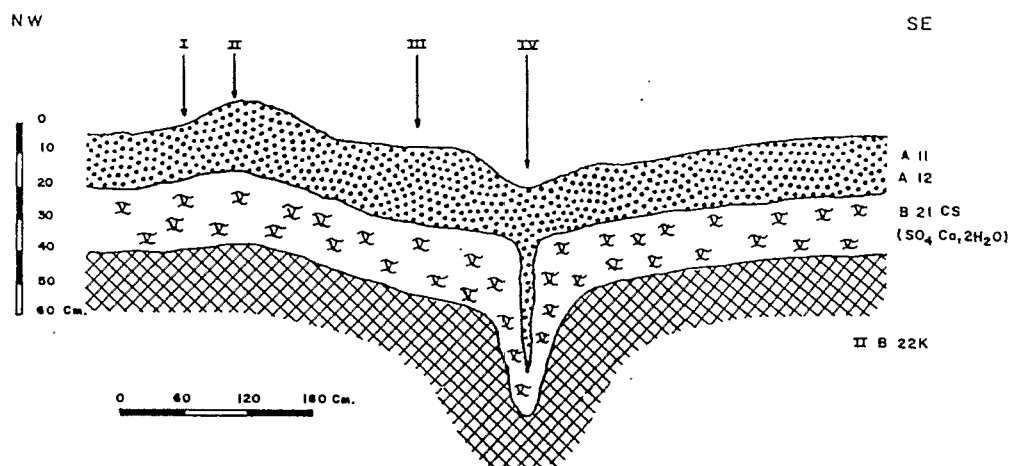


Fig. 5. Profile POLY 2.

The gypsum in horizon B21Cs presents, in the subsided zone, the same aspect and a similar content in gypsum as in the undisturbed equivalent horizon.

Along the lines, at about 2 m of their median axis, we find outgrowths with a circular appearance, without vegetation, on the ground surface. These micro-mounds, about 1.2 m in diameter and 10 cm high in their center, are located along the edge of the vegetation bands, but with an irregular distribution.

The cuts transversal to the bands of vegetation of the studied pedologic profiles cut these micro-mounds in POLY 2 (I and II, Fig. 5) and POLY 3 (I, Fig. 6). They are areas with a high salt concentration: the conductivity reaches 40 - 50 mmhos/cm (Table 2, 3) in the upper 50 - 60 cm of the ground, where there are numerous whitish efflorescences in the form of fine stains uniformly distributed, and which correspond to secondary salt deposits (likely sodium chloride). Correlatively, the structure is very degraded, taking a characteristic aspect, "puffed," particularly with high porosity, resulting in the spreading of the clays in an environment where pH 9 is reached and exceeded. The other analytical characteristics are similar to those of the typical profile.

These areas of saltiness, with their circular form, evoke a concentration of runoff water, which, after a particular obstacle (micro-relief, presence of a bedding...), could not leak out normally when it came in contact with the vegetation bands. This water, which turned into salts during its drainage, has stayed this way locally, on the surface of the ground where it has infiltrated. Following desiccation, the salty solutions have a tendency to be lifted up towards the surface and little by little the salts have deposited in the upper part of the profile in the form of efflorescences. This salt concentration has provoked the degradation of the structure by spreading the clays, in a phenomena accompanied by a bulge of the ground surface (this process being probably emphasized by the crystallization of the salts), and by the thermic expansion of the salts

TABLE 2. Analytical data of the profile POLY 2.

Depth (cm)	Texture % (fraction 0-2 mm)			pH water	Organic carbon (%)	CaCO ₃ (%)	Gypsum (%)	E.C. (mmho/cm)	CEC (meq/100g)	Water extract from Saturated paste (meq/liter)			
	Clay	Silt	Sand							Ca	Mg	Na	
I	0-2	40.3	4.3	55.4	8.1	0.31	22.4	0.0	6.5	23.0	10.2	1.1	14.9
	8-16	58.6	10.0	31.4	8.5	0.37	18.4	2.9	50.0	27.0	21.5	3.7	16.5
	28-40	46.7	10.7	42.6	9.2	0.22	18.4	26.3	50.0	25.1	3.5	8.2	16.3
	48-52	54.3	12.7	33.0	9.0	0.16	22.4	13.0	30.0	28.5	9.0	7.3	15.7
	63-67	65.0	16.0	19.0	9.1	0.16	19.4	11.9	30.0	27.6	10.3	10.4	16.3
II	0-3	11.4	30.4	52.2	8.0	0.28	20.4	0.0	4.5	24.1	22.8	2.1	13.7
	10-15	29.4	36.4	34.2	8.5	0.27		3.2	25.0	25.4	4.3	3.2	16.2
	22-30	23.4	20.4	42.2	8.9	0.16	18.4	27.4	45.0	26.1	5.9	10.5	16.4
	35-40	45.4	18.4	36.2	9.0	0.19	18.4	14.0	45.0	25.0	6.2	7.9	16.3
	60-67	57.4	18.4	24.4	9.2	0.10	22.4		40.0	26.6	9.3	10.9	16.5
III	0-3	40.7	18.0	41.3	8.4	0.40	20.4	0.0	31.5	24.9	2.8	0.3	14.1
	12-18	34.7	40.0	41.3	8.1	0.33	22.4	0.0	22.5	25.9	4.7	0.4	11.3
	30-38	52.7	16.0	31.3	8.0	0.18	20.4	27.0	3.0	23.8	18.7	2.5	8.0
	57-62	32.7	38.3	29.0	8.1	0.14	22.4		10.0	25.2	18.7	5.9	15.5
IV	0-6	36.7	30.0	33.3	8.5	1.04	20.4	0.0	3.0	25.9			
	16-26	38.7	32.0	29.3	8.1	0.38	20.4	3.0	4.0	22.7	22.9	1.6	12.8
	38-48	54.7	14.0	31.3	8.2	0.37	19.4	0.0	3.5	24.7	22.5	1.8	12.0

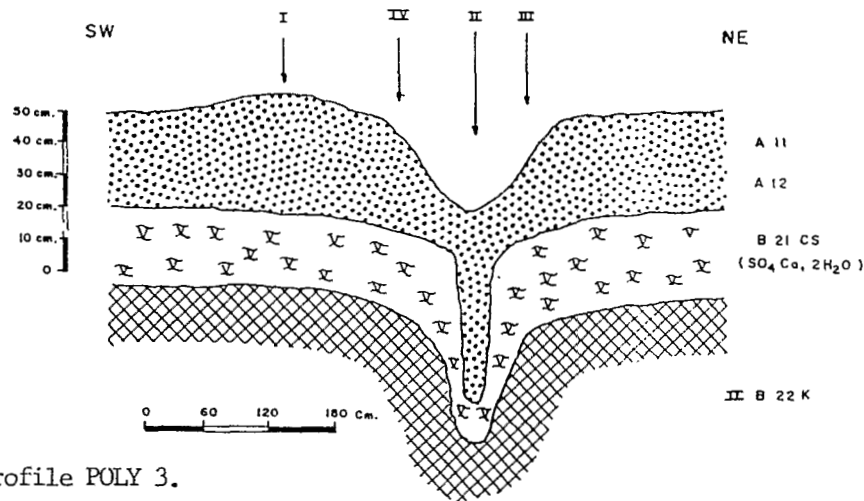


Fig 6. Profile POLY 3.

and/or their increase in volume during the phases of remoistening of the soil (Cooke and Smalley, 1968; Goudie, 1974, 1977; Evans, 1970; Chapman, 1980; McGreevy and Smith, 1982).

HYPOTHESES OF THE POLYGONAL PATTERN GENESIS

Organizations of the ground in a pattern similar to the polygonal pattern have been described, in hot and arid areas, in numerous regions of the globe: in Irak (Tucker, 1978), in Namibia (Ollier Seely, 1977; Goudie, 1972, Watson, 1980), in North Africa (Tunisia, Algeria, Lybia), in the Middle East, in the United States, in Mexico (survey and critical review in Hunt and Washburn, 1966 and Watson, 1979; Washburn, 1950, 1956). This type of formation is essentially developed either in gypseous or calcareous environments or in environments rich in salts.

In a gypseous environment, we find soil with secondary gypsum accumulation of the encrusting and crust type, with a surface organized according to two types of pattern (Watson, 1980): either small polygons less than 1 m in diameter, or in greater polygons from 2 to 6 meters in diameter. In the first case, the vegetation is quasi-non-existent. In the second case, it develops along the sides of the polygons in a herbaceous form, whereas the rest of the ground is bare. The polygonal pattern would be (Tucker, 1978; Watson, 1980) caused by the physical and mineralogical modifications of certain minerals following the daily and seasonal variations in temperature, or the alternations of desiccation and moistening of the ground.

Goudie (1972) and Watson (1980) have reported the presence in Namibia of a network of polygons from about 5 to 20 m in diameter, on the surface of a soil with a limestone crust, whose sides are occupied by a herbaceous vegetation based on Stipagrostis gonatostachys.

TABLE 3. Analytical data of the profile POLY 3.

Depth (cm)	Clay	Silt	Sand	pH water	Organic carbon (%)	CaCO ₃ (%)	Gypsum (%)	E.C. (mmho/cm)	Water extract from Saturated paste (meq/liter)		
									Ca	Mg	Na
	10.7	24.0	65.3	9.3	0.75	22.4	0.0	12.5	14.1	9.3	16.0
	19.0	36.4	44.6	8.6	0.35	15.3	1.5	20.0	16.4	5.6	16.0
	20.6	24.4	55.0	8.9	0.28	17.3	4.0	50.0	23.1	7.8	15.7
I 45-53	29.0	20.4	50.6	8.7	0.14	18.4	25.8	25.0	22.6	7.7	16.1
65-75	49.0	16.7	34.3	8.9	0.12	19.4	12.0	15.0	16.4	5.8	10.0
85-95	59.0	20.7	20.3	8.9		21.4	8.2	30.0	13.7	9.4	16.6
124-130	59.0	24.4	16.6	9.0		25.5		25.0	15.3	8.2	16.1
	19.0	38.4	42.6	8.8	0.43	17.3	0.0	42.5	2.6	0.3	12.1
II 32-42	23.4	40.0	36.6	8.1	0.37	19.4	0.0	2.5	11.9	1.5	10.1
62-72	29.4	16.4	54.2	8.1	0.25	20.4	25.5	5.0	26.2	4.2	14.3
95-102	53.4	24.4	22.2	8.3	0.18	22.4	14.0	9.0	20.3	4.7	15.6
	35.4	32.7	31.9	8.2	0.31	22.4	0.0	3.0	8.5	0.8	12.4
III 32-44	43.4	18.4	38.2	8.2	0.19	21.4	27.5	5.0	24.6	4.7	14.6
55-65	58.7	10.0	31.3	8.6	0.18	21.4	10.5	10.0	15.0	3.9	15.8
105-115	58.7	22.0	19.3	8.7	0.12	23.5		15.0	20.0	4.9	16.0
	44.7	26.0	29.3	9.0	0.35	18.4	0.0	6.5	6.0	0.4	15.5
IV 38-52	40.7	18.0	41.3	8.0	0.15	19.4	26.6	4.0	21.2	3.8	14.2
78-88	56.3	24.3	19.4	8.9	0.12	22.4	11.3	15.0	19.8	5.6	16.0
112-122	63.0	19.6	17.4	8.9	0.11	21.4		15.0	15.1	4.3	15.9

In the environments with a high saline concentration, the polygons have a size not exceeding 10 m in diameter and they present the peculiarity of having their edges in relief forming ramps with the interior spaces of the polygons, which gives a very characteristic aspect to those formations. They are successive saline crystallizations which thus clearly delimit the polygonal network. There too, alternations of humidity and drought and variations of temperatures have originated those formations (Hunt and Washburn, 1966).

The polygonal pattern observed in the Mapimi Reserve is similar by its morphology to the various polygonal patterns reported and described everywhere in the world, but is of a different type. Actually, it neither develops in a very saline environment nor in an environment highly enriched in limestone or gypsum. As we have seen, the conductivity stays average and the contents in gypsum and limestone are well below those of the gypseous or limestone crusts. Moreover, we must note here the relatively important size of the polygons, compared to that of the other known patterns.

The genesis of this polygonal pattern is based on the intervention of various combined physico-chemical processes. It begins, as we observed in the field, with the appearance of lines on the surface of the ground, of variable length (10 - 30m), actually corresponding to cracks of desiccation, which under the effect of the drought, gradually open to reach a width of several centimeters and a depth of several decimeters. Similar cracks, much deeper though, (1 - 3 m) have been described by White (1970, 1972) in South Dakota and Knechtel (1951) in New Mexico. This phenomenon is frequent, in dry periods, in environments rich in "bulging" clay of the smectite type. We should note that these cracks originate at the top of the clayed horizon 50/60 cm deep, where, due to the intense drought during the estival period, desiccation takes place. The upper horizons, little clayed, are less favorable to the formation of cracks and these do not necessarily reach the surface of the ground.

In this vacuums or cracks so created on the 50 - 60 cm of the upper part of the soil, the gypsum level being more friable than the other horizons shows a tendency to "flow" (leak out) towards the base of the crack, which is found in the clayed horizon, and to progressively fill it. When a rain occurs, there is a progressive closing of the crack, especially in the clayed level, following a phenomenon of bulging (moistening-absorption) of the clays. In the upper horizons, the crack "closes," from the process of filling up by materials coming from the edges of the initial crack of desiccation. It thus results in a lowering, and formation of a hollow zone on the surface of the ground, as the ones which we observed in the median zone of the vegetation bands.

It is likely that these various phenomena (lowering of the gypseous horizon to the level of the clayed horizon and collapsing of the surface of the ground), are favored and intensified on one hand by the alternations of dissolution-deposition of gypsum, and on the other by the variations of the volume in gypsum under the effect of the drought, during its change from the hydrated form to the semi-hydrated form (Chatterji and Jeffery, 1963; Cooke and Smalley, 1968).

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