2 Soil from the Coastal Plane

Julio Moreno, Gustavo Sevillano, Omar Valverde, Verónica Loayza, Renato Haro, and Johanna Zambrano

Abstract

The coastal plain is a region with high agricultural potential, since 43% of the land is suitable for production of a wide range of tropical crops such as cocoa, coffee, banana, oil palm, sugarcane, rice, corn, soybean, cassava, and numerous tropical fruits. The existence of a very fertile plain between Quinindé and the border with Peru permits the development of a highly profitable agriculture. Within this great plain are located the only Ecuadorian soils without limitations for agriculture; soils located on the old plain with volcanic protrusions, Andisols in the humid zone and Mollisols in the drier zone, occupying 13 million ha. There are several landscape units at the Ecuadorian coastal plain characterized for having similar climate and parent material conditions over which different soil types have developed contributing to the great diversity of the country soils. The main factor of soil formation on the Ecuadorian coastal plain, in addition to geological and topographical factors, was climate, especially precipitation. In general, there exist three broad sets of conditions grouping the diversity of soils from this region. (a) Soils developed from old rocks (sedimentary, metamorphic, or igneous) comprising the majority of soils in the western part of the coastal plain, particularly those developed from sedimentary rocks; (b) Soils from the old coastal plain which received volcanic ash depositions, material over which soils of high agronomic interest were developed; and (c) Alluvial soils developed over recent sedimentary materials grouped into soils from the fluvial-marine environment located on the beaches, littoral stripes and mangroves, and soils from the river surroundings corresponding to almost all of the alluvial soils of the region.

Keywords

Coastal plain • Soils over old rocks • Soils over volcanic ash • Alluvial soils

2.1 Introduction

The coastal plain, with the exception of the extremely humid northern part, is a region with high agricultural potential. While the steep slopes of the region mountain ranges are an undeniable limitation for crop production, the existence between Quinindé and the border with Peru of a very fertile plain enables the development of highly profitable agriculture. It is important to note that within this great plain are located the only Ecuadorian soils without limitations for agriculture; soils sited on the old plain with volcanic protrusions, Andisols in

J. Moreno (✉) · G. Sevillano · R. Haro · J. Zambrano
Instituto Espacial Ecuatoriano, Quito, Ecuador
e-mail: julio.moreno@institutoespacial.gob.ec

G. Sevillano
e-mail: gusfersv@gmail.com

R. Haro
e-mail: renoharobull@gmail.com

J. Zambrano
e-mail: johana.zambrano@institutoespacial.gob.ec

O. Valverde · V. Loayza
Ministerio de Agricultura y Ganadería, Quito, Ecuador
e-mail: amarobvalarias82@hotmail.com

V. Loayza
e-mail: veronica_loayza@yahoo.es

J. Espinosa et al. (eds.), *The Soils of Ecuador*, World Soils Book Series,
https://doi.org/10.1007/978-3-319-25319-0_2

the humid zone and Mollisols in drier zone, occupying 13 million ha (20% of the region's area) (Huttel et al. 1999).

The agricultural aptitude map, scale 1:200,000, generated by the PRONAREG-ORSTOM in 1982, shows that 43% of the coastal plain land (2.8 million ha) is suitable for agricultural use. This zone is located on flat to slightly hilly areas, with favorable conditions for a wide range of tropical crops such as cocoa, coffee, banana, oil palm, sugarcane, rice, corn, soybean, cassava, and numerous tropical fruits. Twenty-two percent of the land in the region (approximately 1.4 million ha) has hilly and dissected reliefs, which makes them marginal for agricultural use, but can be used for livestock production based on cultivated pastures. Finally, 35% of the region land (2.4 million ha) corresponds to areas with steep slopes and other morphopedologic limitations, and they can only be used for forest production and/or protection (Pacheco 2009; PRONAREG-ORSTOM 1982).

There are several landscape units at the Ecuadorian coastal plain characterized for having similar climate and parent material conditions over which different soil types have developed contributing to the great diversity of the country soils (Fig. 2.1). The main factor of soil formation on the Ecuadorian coastal plain, in addition to geological and topographical factors, is climate, especially precipitation, as the temperature tends to be isohyperthermic in the entire region. In general, there exist three broad sets of conditions grouping the diversity of soils from this region.

2.1.1 Soils Developed over Old Rocks

The soils developed from old rocks (sedimentary, metamorphic, or igneous) constitute the majority of soils in the western part of the coastal plain, particularly those developed from sedimentary rocks. The variety of soils formed on these old rocks is explained by the different pedogenic conditions like climate, bedrock, and relief. From these conditions, precipitation was perhaps the most important factor in the development of these soils, for example, pH, CEC, and base saturation decrease as precipitation increases in areas of soils developed from similar sedimentary rocks, and located in comparable topographic positions (Zebrowski and Sourdat 1997). The following groups can be identified within the soils developed from old rocks (Huttel et al. 1999): (a) Shallow poorly evolved soils located in areas with steep slopes, for example, mountain ranges where erosion prevents the formation of deeper soils; (b) Vertic soils with pH > 7, characteristic of dry arid zones from the coastal plain (for example, Santa Elena Peninsula), developed mainly from old sedimentary rocks such as clays and sandstones; (c) Brown (Mollisoles) and vertic (Vertisols) soils with pH < 7, located in the humid part of Chongón Colonche mountain range: the brown soils are located on steep slopes and vertic soils on less pronounced relief; and (d) Highly desaturated red ferralitic soils from the northern more humid zones of the Esmeraldas Province, with very acid pH resulting in aluminum toxicity.

2.1.2 Soils Developed over Volcanic Ash

Sections of the old coastal plain received volcanic ash depositions, material over which soils of high agronomic interest were developed. The variety of climates under which the ashes were weathered is largely responsible for the diverse characteristics of these soils. In the northern area (Quinindé), soils developed on recent ash have a thickness of about one meter, but they are on top of another 10-m layer of soils developed over old ashes. The thickness of soils developed from recent ash decreases as the sites get away from the Andes and move southward, reaching only 30 cm in the south (Balzar). The fine ash particles were pushed away by the wind to considerable distances from the centers of emission, so the weathering was rapid, resulting in homogeneous, loamy, and brown profiles. Rainfall, especially the length of the dry season, played a major role on developing some of the characteristics of these soils, for example, in the more humid areas (<4 dry months per year), pedogenesis lead to the formation of amorphous clays (allophane and imogolite), whereas in regions with a well-marked dry season (>4 months per year) the synthesis of crystalline clay minerals (2:1 clays) was the dominant pedogenic process (Huttel et al. 1999; Zebrowski and Sourdat 1997).

2.1.3 Alluvial Soils Developed over Recent Sedimentary Materials

These are alluvial soils formed on recent sedimentary materials that are grouped into (a) soils from the fluvial-marine environment located on the beaches, littoral stripes, and mangroves; and (b) soils from the river environment corresponding to almost all of the alluvial soils of the region. The texture and the degree of base saturation from the fluvial environment allow the differentiation of groups of generally good fertility and easy to cultivate soils, but they may have the following unfavorable characteristics: (1) Sandy texture or existence of surface stones upstream of the spreading areas; (2) Water excess and the consequent presence of hydromorphic soils making farming activity difficult or even impossible, particularly in areas where the water table rises to the surface; and (3) Clayey texture, characteristic of soils of the recent plain, that limits drainage and favors flooding in the rainy season; however, these are ideal soils for patty rice (Huttel et al. 1999; Moreno 2001; Zebrowski and Sourdat 1997).

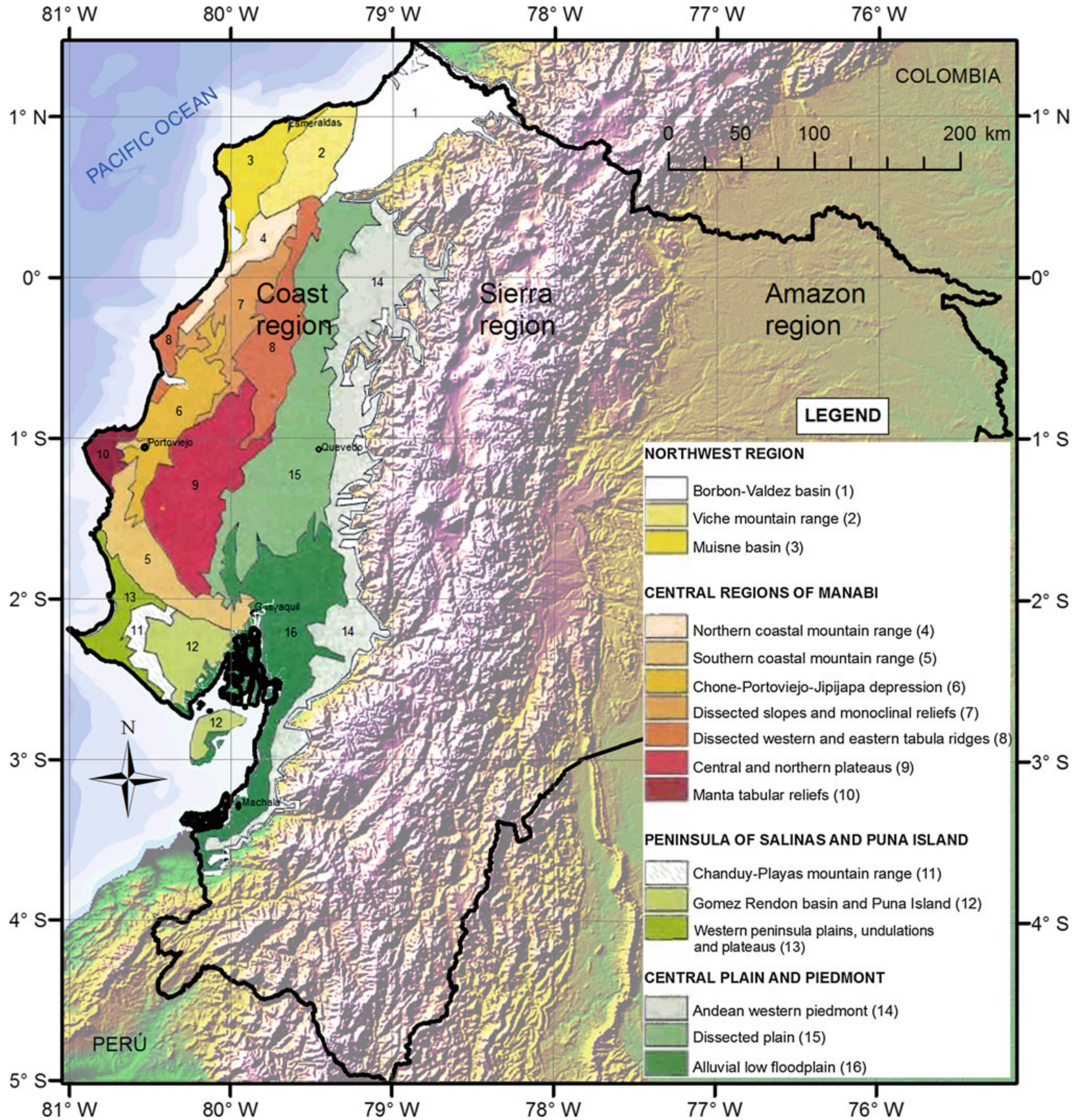

Fig. 2.1 Coastal plain landscape distribution with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

A detailed description of each landscape unit and its respective soils of the Ecuadorian coastal plain are presented below.

2.2 Tabular Cone Totally Covered with Volcanic Ash

This area is located to the east of the Borbón Valdez basin in the province of Esmeraldas (Fig. 2.2). The connection between the Andean and coastal reliefs generally occurs through a steep slope, but in this case, the slope was attenuated in the northwestern part by the existence of a tabular relief, slightly inclined to the northwest, which ends at 750 m o.s.l. at Alto Tambo, San Lorenzo. This relief was formed from ancient coalescing spreading cones established at the mouth of the Mira, Lita, and Gualpi rivers, which have a torrential regime and drain the inter-Andean valleys (Fig. 2.2). The area consists of thick dendritic and torrential deposits (≈600 m thick), which were covered by recent volcanic projections, probably coming from volcanoes located south of Colombia. These materials, exposed to a warm and hyper humid climate (4000–6000 mm rain per year and temperature >25 °C), resulted in perhydrated volcanic soils (>100% water retention), somehow sandy at the top of the cone and silty at the bottom (Zebrowski and Sourdat 1997).

2.2.1 Areas Near the Andean Slopes

This landscape integrates the crest surfaces (b) and surrounding abrupt (c) as shown in Fig. 2.3. The crest level has a very smooth surface, moderately dissected into small rounded biconvex tops that end at the village of Alto Tambo, at the gorge outlet of the Lita River. This platform reaches heights exceeding 800 m o.s.l. at the confluence of the Mira River into the Lita River. These cones then come together to the east rapidly widening the surface of the peaks. The thickness of these perhydrated Andisols steadily decreases from southeast to northeast. Soils from the abrupt slope are eroded and colluviated, so soils of volcanic originally adjacent to shallow, clayey, and often stony soils (Winckell and Zebrowski 1997).

In this zone, there are also small areas that are remainders of steeped deposits accumulated above the cones, usually perched on the flanks of the current riversides [(a) in Fig. 2.3]. Its position into the Andean flank favored the accumulation of an important volcanic ash cover on which deep perhydrated Andisols were developed (2–3 m deep).

The representative soils of this unit are Hydrudands (Soil Survey Staff 2006), with low bulk density (<0.9 g cm^{-3}), high phosphorus fixation, and silty loam texture. These soils have a very strong reaction to sodium fluoride (NaF) throughout the entire profile, due to the high content of amorphous clays. The amount of water in situ is always

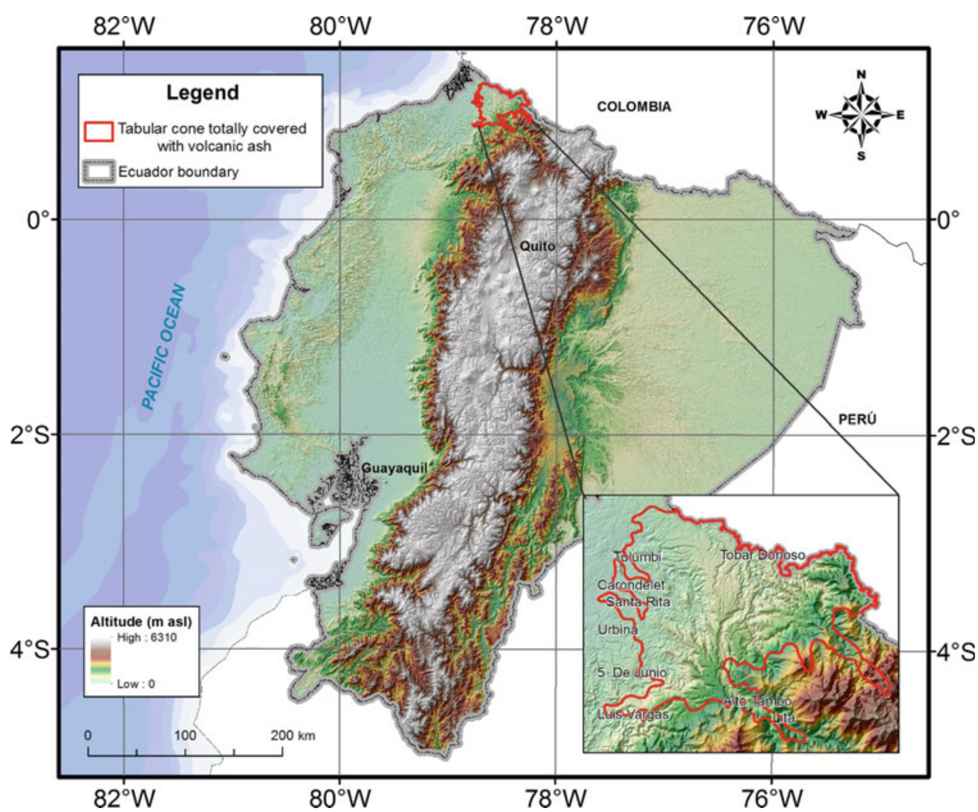

Fig. 2.2 Location with respect to continental Ecuador of the tabular cone totally covered with volcanic ash (adapted from Zebrowski and Sourdat 1997)

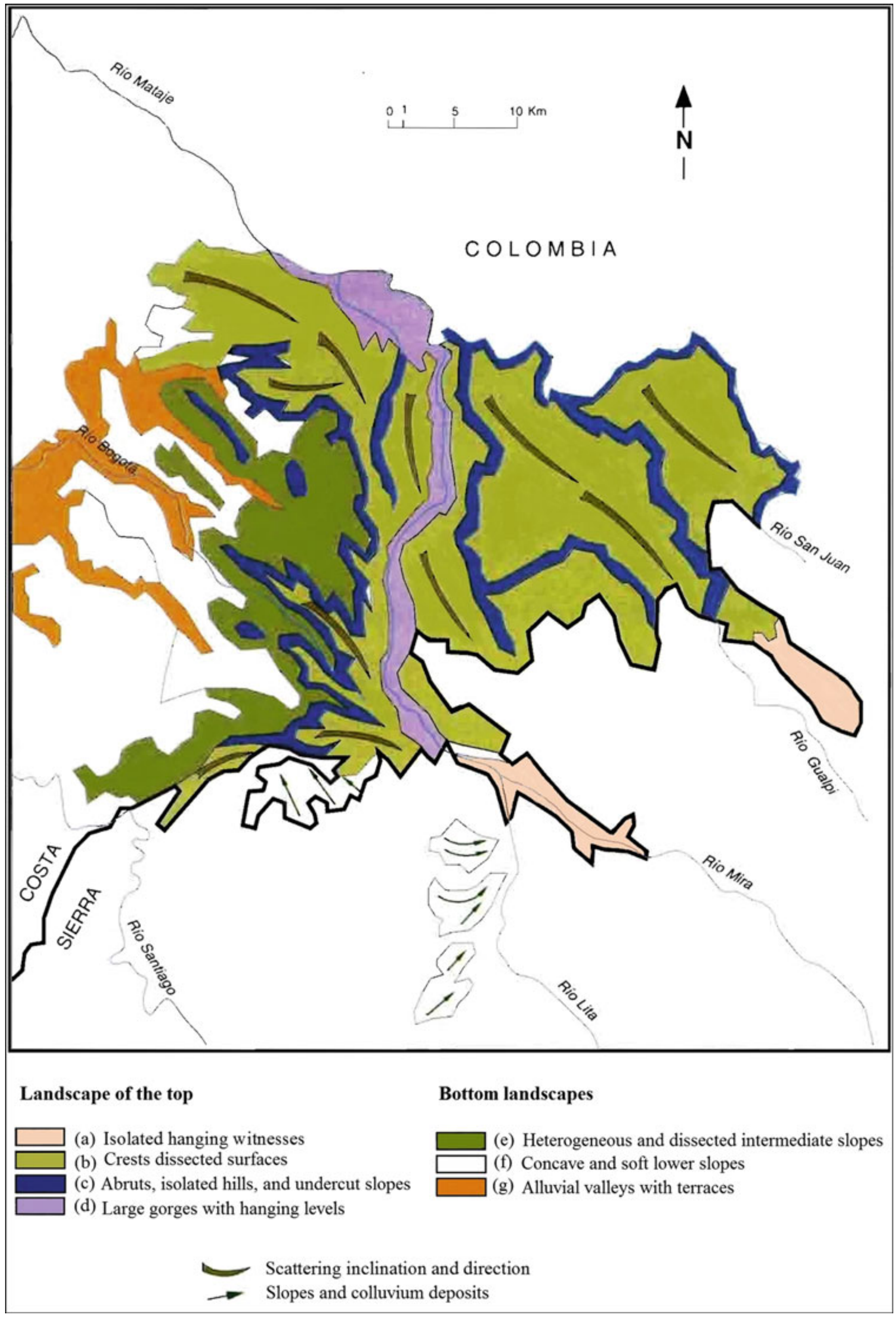

Fig. 2.3 Tabular cone of dissected relieves (adapted from Zebrowski and Sourdat 1997)

high, close to those obtained at pF3 on a wet soil, usually >200%, sometimes reaching 300%. Topsoil pH is low (4.6), but increases with depth (pH slightly lower than 6.0 in the rest of the profile). The amount of exchangeable bases is very low (≤ 0.3 cmol kg^{-1}), as well as base saturation ($\leq 1\%$) (Zebrowski and Sourdat 1997).

2.2.2 Rolling Surfaces

At the foot of abrupt, slope extends a complex set of hills and moderate slopes [(e) and (f) in Fig. 2.3)], mainly present in the western part of the cone (the most eroded), developed on relatively homogenous deposits of highly weathered sandstones and conglomerates that have formed motley clays and pebbles. These hills and slopes have less torrential facies with a state of alteration far more advanced that can only be explained by the older age of the lower deposits in relation to higher deposits, and for the more humid climate conditions. The upper part of these slopes has moderate to strong inclination (straight and convex) which are dissected by numerous parallel streams. The lower part of the slopes, or those located forward, contains concave, soft inclination slightly extended by the underlying reliefs (Winckell and Zebrowski 1997). The thin ash cover has been partially removed by erosion. Consequently, the silty perhydrated Andisols sit beside very desaturated yellow pseudoferralitic and ferralitic soils (Fig. 2.4) with clayey loam texture, low organic matter content, low CEC (<10 cmol kg^{-1}), pH strongly acid (4.6–4.1), highly desaturated and overly rich in exchangeable aluminum (Al) in a matrix of kaolinite, gibbsite traces, iron oxides, and fine quartz (Zebrowski and Sourdat 1997).

2.3 Structural Reliefs over Tertiary Deposits

The reliefs are located within the coastal plain provinces of Manabí and Esmeraldas (Fig. 2.5), but about half of this zone is located in the center and south of the province of Manabí as the characteristic landscape from this area of Ecuador. The altitude with respect to the crest tabular surfaces varies from 450 to 500 m o.s.l. in the center and from 250 to 300 m o.s.l. to the sides. All of these landscapes belong to only one type of relief developed on over an association of geological formations characterized by a hard summit layer on top of a soft bottom layer; in other words, a base of clays and siltstones (Onzole formation) topped by a set of detrital sediments of sandstones, sand, and conglomerates (Borbón formation) (Aalto and Miller Iii 1999; Ramírez 2013; Winckell and Zebrowski 1997). With regard to climate, these structural reliefs, mainly on the central and southern sections of Manabí, are characterized by receiving an average annual rainfall >1000 mm, reaching 1500 mm on the surfaces of the plateau. Average annual temperatures are >25 °C (Winckell and Zebrowski 1997).

The altitudinal distribution of the structural reliefs that is presented in Fig. 2.6 describes its components as (a) Top plateau crest surfaces with soft slopes and well-developed soils; (b) Surrounding flanks (abrupt) with steep slopes exposed to severe erosion processes and poorly developed soils; (c) Low flanks with a moderate gradient; and (d) Alluvial flat valleys with more developed soils in the higher and stable areas (middle and upper terraces) and poorly developed soils in areas close to the riverbeds (lower terraces) that are exposed to flooding originating new fluvial depositions that constantly rejuvenate these soils.

2.3.1 Sandstone Plateau

The sandstone plateau accounts for almost all of the crests surfaces. Soils from this area have mollic characters; deep epipedon, >50% base saturation and silty clay to clayey texture (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997). As an example a soil profile from a soil classified as Mollic Hapludalfs (Soil Survey Staff 2006) is presented (Fig. 2.7; Table 2.1). This soil has a 34-cm epipedon with loamy texture at the surface and clayey in the deeper horizons, the A horizon color is very dark gray and the Bt horizon is clearer with a very hard consistency which limits root growth (CLIRSEN et al. 2012a).

In addition to the plateau summit surface, a sandy abrupt contour can also be found in this unit, which sits on a cemented detrital base from the Borbón formation, surrounding the plateau and delimiting it from the adjacent

Fig. 2.4 Profile of a ferralitic soil (left) located in the area of San Lorenzo, Esmeraldas where oil palm (right) is grown

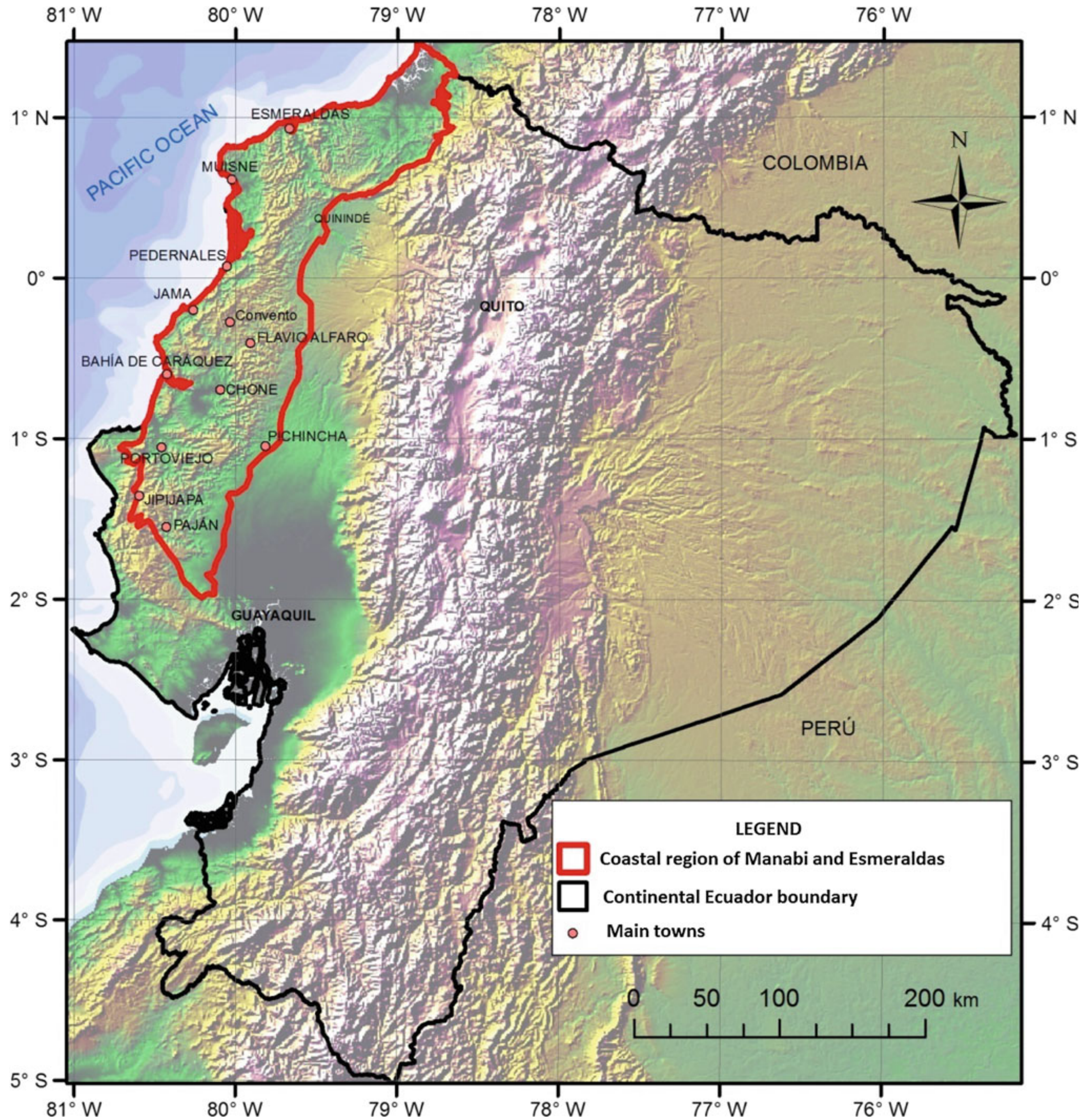

Fig. 2.5 Location of the structural reliefs over Tertiary sediments of the Manabí (central and southern) and Esmeraldas (north) Provinces with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

areas. The altitude difference of the slopes from the higher to the lower surrounding landscapes is usually around 300 m and the inclination is almost always >70% forming rocky cliffs. Due to the steep slopes, soils at these sites are subject to severe erosion that overcomes the pedogenic processes; therefore, they are characterized for having a shallow profile, often less <10 cm, due to the outcrop of rocky material from the substrate (Zebrowski and Sourdat 1997).

A typical soil profile from this zone is presented in Fig. 2.8 and Table 2.2. This soil is classified as Lithic Ustorthents (Soil Survey Staff 2006) and its profile shows little or no evidence of pedogenic horizon formation (IEE 2015).

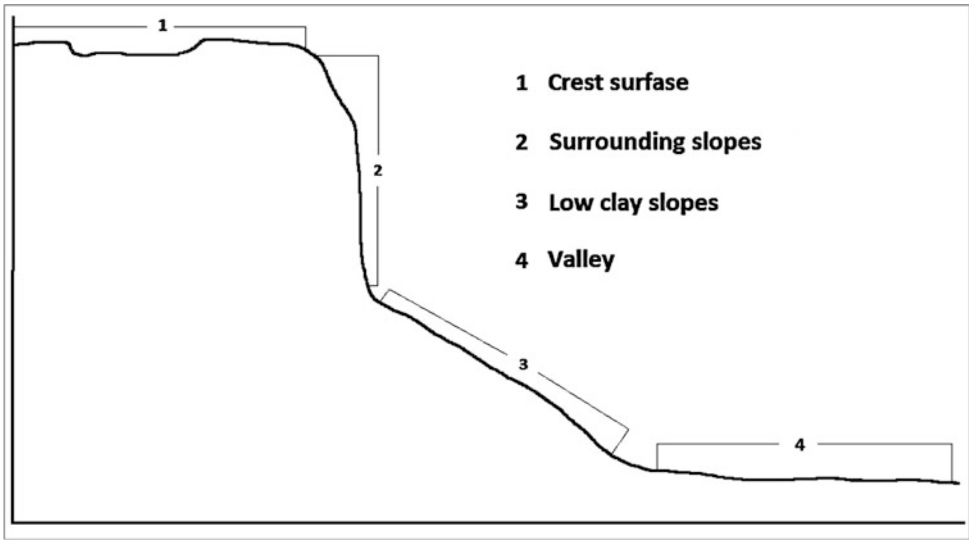

Fig. 2.6 Distribution of different landscapes developed on the structural reliefs over Tertiary sediments

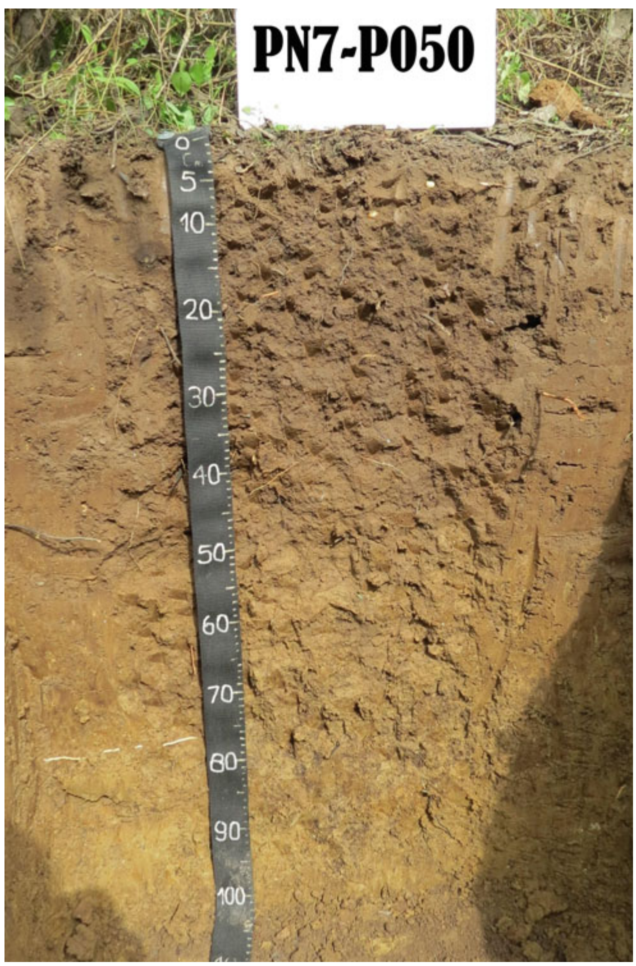

Fig. 2.7 Profile of a soil classified as Mollic Hapludalfs at Peña Alta, Santa Ana—Manabí, located on the plateau crest surface from the Borbón formation (sandstones) over a <12% slope (IEE 2015)

Table 2.1 Profile description of a soil classified as Mollic Hapludalfs from the plateau crest surface (IEE 2015)

Horizons	Depth (cm)	Description
A	0–25	Very dark gray (10YR 3/1) moist color, loamy texture, granular to subangular blocky structure, pH 6.3, organic matter 2.5%, CEC 24 cmol kg^{-1}, base saturation 91.2%
Bt	25–45	Very dark gray (10YR 3/1) moist color, clayey loam texture, subangular blocky structure, clay coating, pH 6.2, organic matter 0.7%
BC	45–70	Very dark grayish brown (2.5Y 3/2) moist color, clayey loam texture, massive to subangular blocky structure with a few coarse fragments of gravel

Fig. 2.8 Profile of a soil classified as Lithic Ustorthents located at San Vicente, Manabí (IEE 2015)

Table 2.2 Profile characteristics of a soil classified as Lithic Ustorthents (IEE 2015)

Horizons	Depth (cm)	Description
O	0–5	Very dark grayish brown (10YR 3/2) moist color, loamy texture, granular to subangular blocky structure
A	5–30	Brown (10YR 4/3) moist color, sandy-clayey loam texture, subangular blocky structure, pH 7.1, organic matter 1.7%, CEC 20 cmol kg^{-1}, base saturation 97.3%
CR	30–60	Yellowish brown (10YR 5/4) moist color, sandy clay loam texture, massive structure with coarse gravel fragments showing little weathering
R	60–90+	White (2.5Y 8/1) moist color

2.3.2 Clayey Reliefs

Beyond the steep slopes extends a set of clayey slopes with a moderate gradient (<40%) moving down to the alluvial valleys mostly located at altitudes <100 m o.s.l., in places even <50 m o.s.l. These slopes have reliefs derived from the Onzole formation made of relatively homogeneous deposition of siltstones and fine poorly cemented sandstones containing minor insertions of clays and lutites. These facies, without primary coherence, and easily alterable even under dry climate, are made of soft rocks located under the hard sandstone layers (formation Borbón) from the upper tabular reliefs that rarely exceed 200 m o.s.l. (Aalto and Miller Iii 1999; Ministerio de Transporte y Obras Públicas and INECA 2012; Winckell and Zebrowski 1997).

This unit is located beyond the influence of upper orographic precipitation regime, and for this reason has a climate characterized by a long dry season which has led to moderate changes that developed heavy clayey, vertic, and saturated soils (Zebrowski and Sourdat 1997). As an example of this unit, a profile of a soil classified as Vertic Haplustepts is presented (Soil Survey Staff 2006) in Fig. 2.9 and Table 2.3. This profile shows an incipient pedogenic development and vertic characteristics, with the consequent 2-cm-wide and up to 50-cm-deep crack formation. The B horizon shows glossy slickensides on the aggregates.

Fig. 2.9 Profile of a soil classified as Vertic Haplustepts (left) located in El Hormiguero, Portoviejo–Manabí, on a plateau developed over the Onzole formation (right) (IEE 2015)

Table 2.3 Profile characteristics of a soil classified as Vertic Haplustepts (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–10	Black (10YR 2/1) moist color, clayey texture, subangular blocky structure, pH 7.1, organic matter 3.5%, CEC 42 cmol kg^{-1}, base saturation 93.9%
Bss	10–30	Very dark brown (10YR 2/2) moist color, clayey loam texture, angular and subangular blocky structure, pH 7.5, organic matter 1.3%
BCss	30–60	Very dark gray (10YR 3/1) main moist color, dark brown (10YR 3/3) secondary moist color, clayey loam texture, massive to angular blocky structure
C	60–100	Brown (10YR 4/3) main moist color, light oil brown (2.5Y 5/3) secondary mist color, sandy clay texture, unstructured

Moisture regime is Ustic, which means that the profile is dry for 90 or more cumulative days in normal years (IEE 2015).

2.3.3 Alluvial Environment

Two of the largest coastal plain valleys are situated south of the Portoviejo River and north of the Chone River in the Chone–Portoviejo depression, both valleys having high and low flat terraces. The high terraces are 6–10 m above the present river course; soils are basic, vertic, silty clay to clayey. The lower terraces, subject to annual flooding, are located 1–5 m above the water; soils are poorly evolved of sandy to silty texture (Winckell and Zebrowski 1997). Soils from the lower terraces, adjacent to the existing river channels, are constantly rejuvenated by new contributions of sedimentary material transported by the annual river flooding during rainy periods. The middle and upper terraces, also flat (<5% slope), are not exposed to new contributions from alluvial material because they are located at higher staggered levels in relation to the riverbeds and, for this reason, these terraces had the necessary stability to develop highly fertile soils, with good physical and chemical conditions, where the region agriculture is conducted. Due to river proximity, these soils have more moisture content in the dry periods or the use of irrigations is feasible.

As an example of this type of alluvial soils, the profile of a soil classified as Fluventic Eutrudepts (Soil Survey Staff 2006) is presented in Fig. 2.10 and Table 2.4. This soil is characterized for having the following horizon sequence is A/Bw/BC/C, loamy texture, good natural drainage, and a 70-cm effective depth. The Udic moisture regime indicates that the entire profile is not dry more than three cumulative months most of the years (IEE 2015).

2.4 Tabular Cone of Santo Domingo

The Great Tabular Cone of Santo Domingo (Fig. 2.11) was formed from deposits contributed by major rivers coming from northern Highlands. The amplitudes of the sediment deposition and subsequent boxing between steep banks (400 m in Mindo) are evidence of the deposits old age, which came from rivers of larger capacity and amplitude than those of the actual river network, and are related to one or various periods of glacier melting, and with later increase of fluvial

Fig. 2.10 Profile of a soil classified as Fluventic Eutrudepts (left) located at Quiroga, Bolívar, Manabí, on a middle terrace cultivated with cocoa (*Theobroma cacao* L.) (IEE 2015)

Table 2.4 Profile characteristics of the soil classified as Fluventic Eutrudepts (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–10	Very dark gray (10YR 3/1) mist color, loamy texture, subangular blocky structure, pH 7.3, organic matter 4.5%, CEC 40 cmol kg^{-1}, base saturation 97.6%
Bw	10–30	Very dark grayish brown (10YR 3/2) mist color, loamy texture, angular blocky structure, pH 7.3, organic matter 0.9%
BC	30–70	Brown (10YR 4/3) moist color, loamy texture, massive structure
C	70–100	Dark grayish brown (10YR 4/2) moist color, loamy texture, massive structure

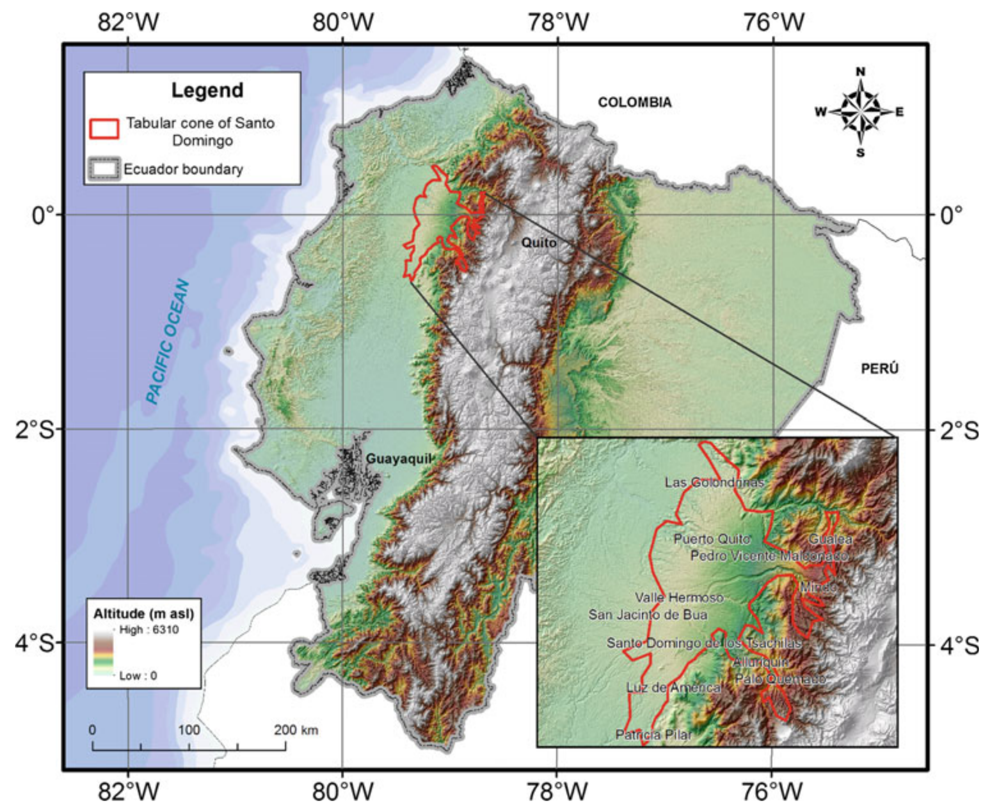

Fig. 2.11 Location of the Tabular Cone of Santo Domingo with respect to continental Ecuador (adapted from Winckell et al. 1997)

water runoff promoted by the melting of Andean glacier cap. Furthermore, it is also evident the relationship with the huge amount of deposited material (volcanic ash) product of the intense Andean volcanic activity (Winckell et al. 1997).

This large cone, situated at a humid tropical zone, receives an annual average precipitation >2500 mm, and has an annual average temperature >22 °C, generating an Udic and even Perudic moisture regime and an isohyperthermic soil temperature regime. All soils are derived from volcanic ash due to the proximity to the emission centers; ash covered all the reliefs no matter the slope. Under these climate conditions, the alteration of volcanic ash promotes the formation of low base saturation amorphous clays (allophane) (Winckell et al. 1997).

2.4.1 Areas Near the Western Andean Flanks

This zone is located at the top of the cone, along the western Andean flanks, site where the alluvial deposits have taken a perched position along the current notches formed by the boxing of the hydrographic network. These conditions have promoted the formation of an association of dissected–notched surfaces with very abrupt external flanks showing rocky conglomeratic outcrops (Winckell et al. 1997).

The modal profile of this unit corresponds to a soil classified as Thaptic Hapludands (Soil Survey Staff 2006) presented in Fig. 2.12 and Table 2.5. The profile is characterized by having very dark colors in the first horizon and strong reaction to NaF in most of the horizons.

Fig. 2.12 Profile of a soil classified as Thaptic Hapludands (left), located at La Mina, Mindo, Pichincha. The site is at the top of the cone close to the western Andes mountain range. These sites are used for silvopastoral systems to raise livestock for both milking and meet purposes (right) (IEE 2015)

Table 2.5 Profile characteristics of the soil classified as Thaptic Hapludands (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–10	Very dark grayish brown (10YR 3/2) moist color, sandy loam texture, granular to subangular blocky structure, strong reaction to NaF, pH 5.6, organic matter 6.7%, CEC 18 cmol kg^{-1}, base saturation 12.1%
C	10–25	Yellowish brown (10YR 5/6) moist color, sandy texture, massive structure, no reaction to NaF
2Ab1	25–80	Main color very dark gray (10YR 3/1) moist color, yellowish brown (10YR 5/6) moist secondary color, sandy loam texture, subangular blocky structure, strong reaction to NaF, pH 6.1, organic matter 5.1%, CEC 21 cmol kg^{-1}, base saturation 4.8%
2Ab2	80–110	Very dark grayish brown (10YR 3/2) moist color, loamy texture, subangular blocky structure, strong reaction to NaF

2.4.2 Central and Western Surfaces

These landscapes are formed by a close association of dissected surfaces located mainly at the central and western part of Great Tabular Cone. The representative profile corresponds to a soil classified as Hapludands (Soil Survey Staff 2006) (Fig. 2.13; Table 2.6). This soil has the following profile sequence: A/Bw/BC/C1/C2, a sandy loam texture in the first 50 cm; all horizons have strong reaction to NaF, horizon A has a very dark brown color and of granular to

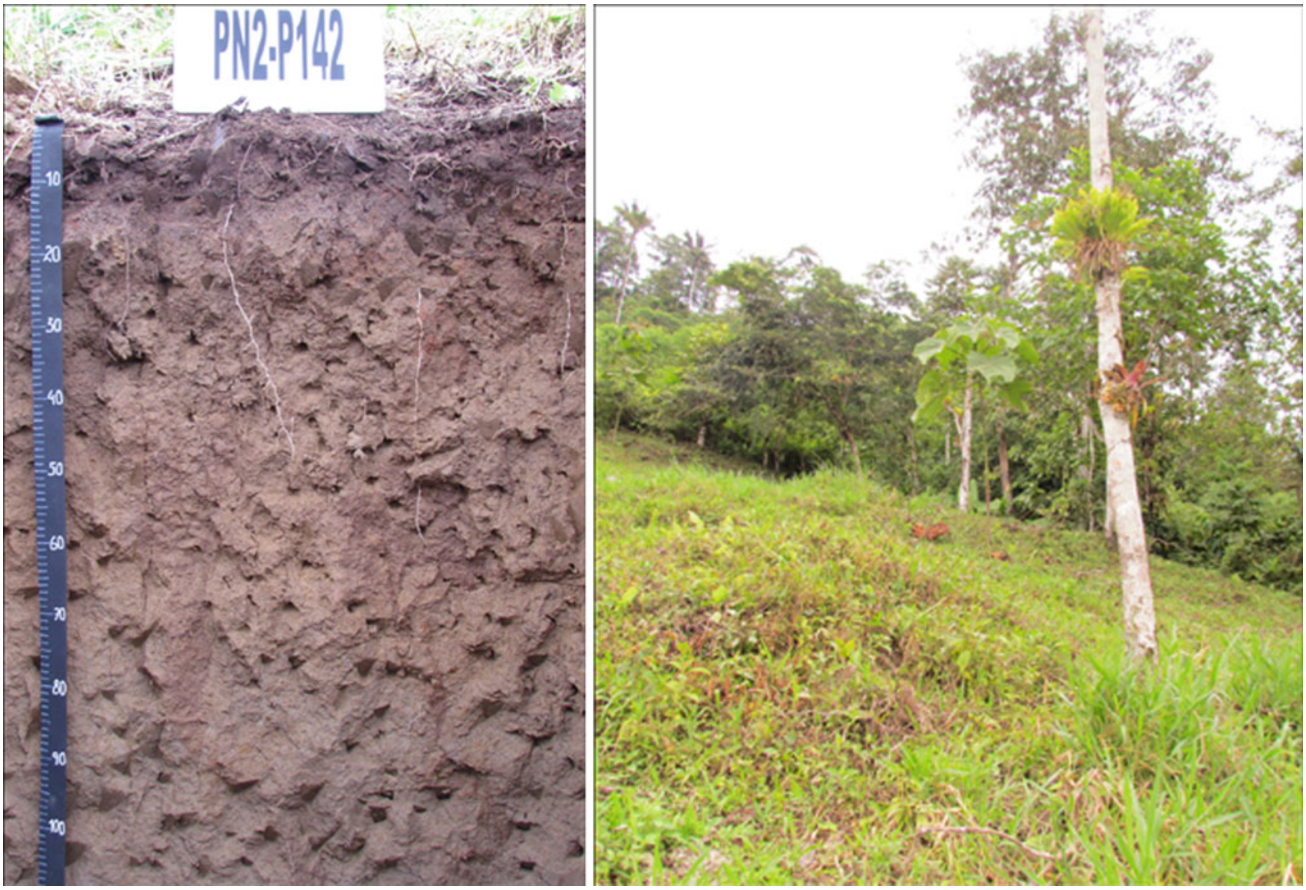

Fig. 2.13 Profile of a soil classified as Typic Hapludands (left) located at Monte Olivo, Pedro Vicente Maldonado, Pichincha, in the central part of the Great Tabular Cone. These sites are used for silvopastoral systems to raise livestock for both milking and meet purposes and for agroforestry systems with crops like guava (*Psidium guajava* L.), cocoa (*Theobroma cacao*), naranjilla (*Solanum quitoense*), and coffee (*Coffea* sp.) (right) (IEE 2015)

Table 2.6 Profile characteristics of the soil classified as Typic Hapludands (IEE 2015)

Horizons	Depth (cm)	Description
A	0–20	Very dark brown (10YR 2/2) moist color, sandy loam texture, granular to subangular blocky structure, strong reaction to NaF, pH 5.7, organic matter 6.4%, CEC 16 cmol kg^{-1}, base saturation 21.4%, bulk density of 0.9 g cm^{-3}
Bw	20–50	Dark yellowish brown (10YR 4/4) moist color, sandy loam texture, subangular blocky structure, strong reaction to NaF, pH 6.1, organic matter 2.41%
BC	50–85	Dark yellowish brown (10YR 4/6) main moist color, yellowish brown (10YR 5/6) secondary color, massive to subangular blocky structure, strong reaction to NaF
C1	85–110	Yellowish brown (10YR 5/4) moist color, sandy loam texture, massive structure, strong reaction to NaF
C2	110–130+	Dark gray (10YR 4/1) main moist color, dark yellowish brown (10YR 4/4) secondary color. Sandy loamy texture, massive structure, strong reaction to NaF

subangular blocky structure. Underlying the horizon A is a Bw horizon of dark yellow brown color, angular blocky structure. The BC horizon is dark yellowish brown, sandy loam texture, and of massive to subangular blocky structure. The two C horizons have yellowish brown to dark gray colors with massive structure.

2.5 Old Deposition Plain

The old deposition plain is made of dissected and undulating reliefs that start at Quinindé at its northern part and move south as far as the line between Daule and Puebloviejo where it spreads into the recent alluvial plain. The plain

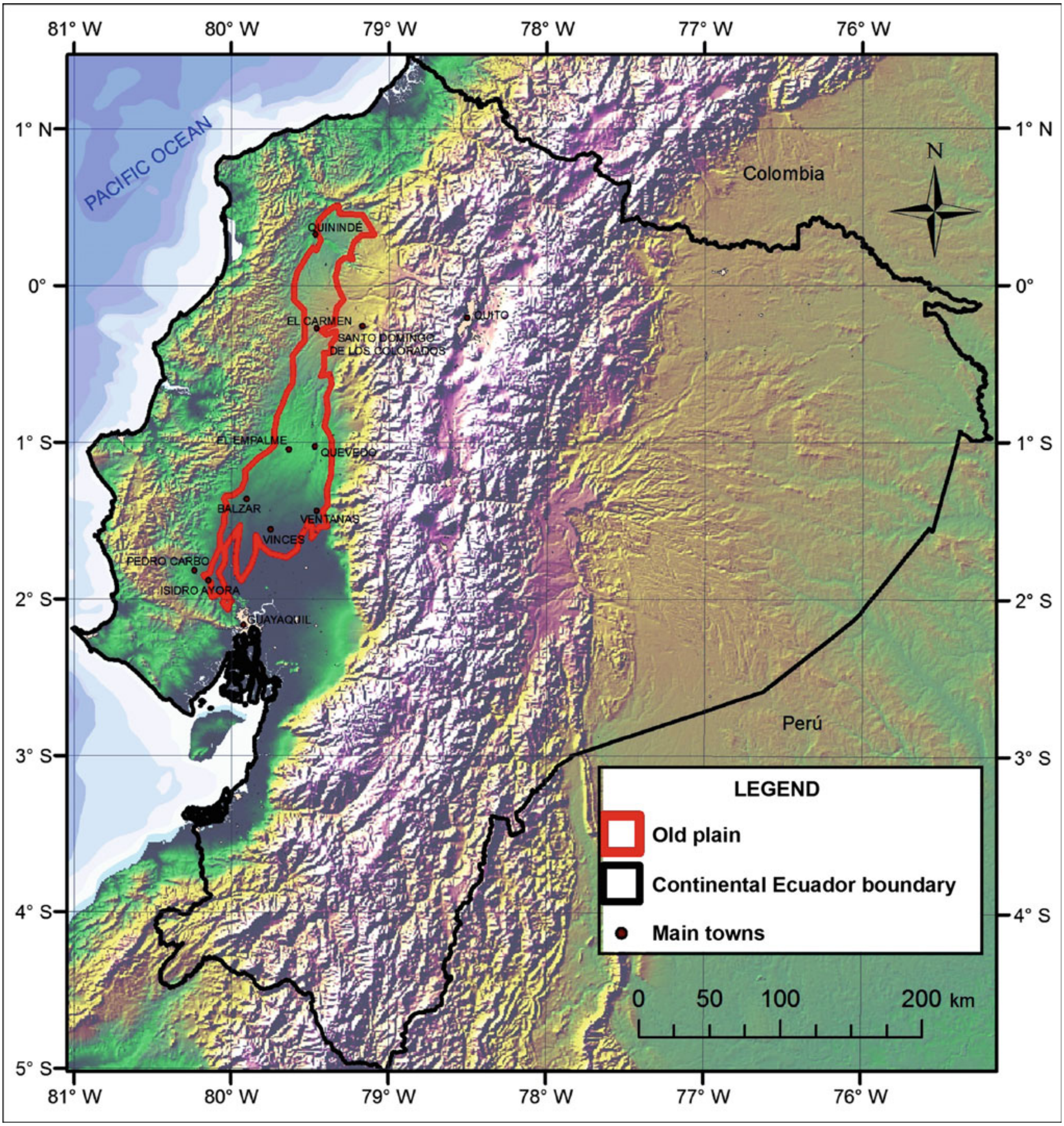

Fig. 2.14 Location of old alluvial plain with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

borders to the east with the western Andes piedmont and to the west with the coastal sedimentary reliefs (Fig. 2.14). This zone is characterized for having dissected surfaces with wide or narrow round tops, slopes range from 2 to 40% with a maximum altitude of 15 m, but typically not exceeding 5 m (Winckell and Zebrowski 1997).

Genetically, this plain sits on old sediment deposits that were accumulated by the abundant contribution of the major rivers of the northern Highlands, the pyroclastic deposits of Andean volcanic material transported by the wind, and the subsequent boxing caused by the increased water runoff promoted by the melting of the Andean ice cap and the former hydrographic network that had more volume and strength that the current one due to one or more periods of glacial melting. The old plain, also known as dissected plain, has then been influenced by three sets of forming factors:

(a) dissection of deposited river sediments, (b) fluvial and pyroclastic surface shaping; and (c) climatic gradient, wet at the north and dry at the south. On account of the above-described conditions, the plain is divided into three homogeneous zones in terms of climate and pedogenesis: (a) surfaces fully covered by volcanic ash at the north; (b) zones with partial coverage of volcanic ash at the center; and (c) surfaces without pyroclastic ash cover to the south (León 2010; Winckell and Zebrowski 1997).

In climate terms, the old plain is located at very humid and humid megathermic tropical zone. The northern section and the strip that runs along the Andes piedmont receive an annual average rainfall ranging from 3,000 to 4,000 mm over a 195-day period with an annual deficit of <150 mm (<4 dry months), and with an average daily temperature ranging from 24 to 25 °C (CLIRSEN et al. 2009a). At the center (Vinces), the average annual rainfall reaches 1,500 mm and at the south (Isidro Ayora) only 970 mm products of 100 and 75 days of actual rain, respectively, which at the south represents an annual water deficit of 800 mm during the dry season (8–9 months) (Huttel 1997; Winckell and Zebrowski 1997). Recent survey data from Vinces ratifies that the average annual rainfall in that zone fluctuates from 1,400 to 1,650 mm and the average daily temperatures range from 25 to 27 °C (IEE 2015). A large segment of the central old plain has intermediate climate conditions characterized by an average annual rainfall of 2,000 mm, and an annual water deficit of 500 mm (5–7 dry months) (Winckell and Zebrowski 1997).

The old plain has the highest agricultural potential of the country which favors the production of major crops for domestic consumption and export. The crops that stand out are banana (*Musa* sp. div.), oil palm (*Elaeis guineensis*), cocoa (*Theobroma* cacao L.), mango (*Mangifera indica* L.), abaca (*Musa textiles* N.), plantain (*Musa paradisiaca*), corn (*Zea mays* L.), and rice (Oriza sativa) (Huttel 1997; INEC 2013; Pacheco 2009).

2.5.1 Northern Surfaces Fully Covered with Volcanic Ash

This zone corresponds to the northern old plain, which is the more humid section (>2500 mm annual rainfall), a condition that has promoted the formation of amorphous clays (allophane and imogolite) as a result of volcanic ash alteration and the marked loss of exchange bases (Winckell and Zebrowski 1997). Two general soils types are distinguished in this zone: (a) Slightly hydromorphic desaturated Andisols at the surface developed from recent ashes in an Udic and even Perudic moisture regime, but having slightly perhydrated fine-textured soils developed from old ashes deeper in the profile; and (b) soils fully covered by volcanic ash developed over red Paleosols in an Udic moisture regime.

Classification studies indicate that Andisols are the predominant soils in this zone (Fig. 2.15; Table 2.7). These soils have an effective depth >50 cm, loam, clayey loam, silty loam, or sandy loam surface texture, characteristic inherited from the ash coverage. Texture in deeper horizons continues in the loam range, except when they have underlaying Paleosols characterized by heavy clayey texture. Generally, soil drainage is good, and soil pH concentrates in the range from 6.0 to 7.0 in the upper horizons, very few profiles have a pH slightly higher than 7.0 (IEE 2015).

2.5.2 Zones with Partial Volcanic Ash Cover

This zone is located at the central part of the old plain, between El Empalme–Quevedo at the north and Balzar–Ventanas at the south. The ash coverage of this zone is thinner, relief is more pronounced, and there are outcrops of initially buried soils. The climate is drier compared to the areas fully covered by volcanic from the north, receiving <1,500 mm of annual rainfall. The soils are slightly more clayey than humid north and the content of amorphous clays decreases. The underlying buried soils are always saturated ferralitic soils (Winckell and Zebrowski 1997). The most important crops of this zone are banana (*Musa*sp div), plantain (*Musa paradisiaca*), cocoa (*Theobroma cacao*), and corn (*Zea mays* L.).The modal profile for this zone belongs to a soil classified as Typic Hapludolls (Soil Survey Staff 2006) (Fig. 2.16; Table 2.8).

2.5.3 Zones Without Ash Cover

This zone, which gradually diffuses into the low flood plain, has an Ustic moisture regime and, in consequence, is the driest of old plain. The soils developed exclusively from ancient alluvial sediments, since recent ash did not reach these areas because they are far away from the emission centers. Soils from the northeastern section located in more humid area, near the Andean western flank, are ferralitic; however, with the westward rainfall reduction as sites get away from Andean mountain range, soils become fersiallitic and then vertic (Winckell and Zebrowski 1997). Dominant soils in this region are Inceptisols and Alfisols (Table 2.9). The modal profile of this zone corresponds to a soil classified as Inceptic Haplustalfs (Soil Survey Staff 2006) (Fig. 2.17; Table 2.10).

Also in this zone, and generally throughout the old plain, there are valleys characterized for having alluvial deposits as substrate and flat slopes (0–2%) which tend to flood in the

Fig. 2.15 Profile of a soil classified as Typic Hapludands (left) at El Pital, Quevedo, Los Rios, with an A/Bw1/Bw2/C horizon sequence, located in a banana plantation on a dissected 3% slope surface (IEE 2015)

Table 2.7 Profile characteristics of the soil profile classified as Typic Hapludands (IEE 2015)

Horizons	Depth (cm)	Description
A	0–40	Very dark brown (10YR 2/2) moist color, loamy texture, granular structure, strong reaction to NaF, pH 6.6, organic matter 3.6%, CEC 23 cmol kg^{-1}, base saturation 43.9%, bulk density 0.68 g cm^{-3}
Bw1	40–60	Dark yellowish brown (10YR 4/6) moist color, loamy texture, subangular blocky structure, strong reaction to NaF, pH 6.8, organic matter 2.4%, CEC 22 cmol kg^{-1}, base saturation 33.1%
Bw2	60–105	Brown (10YR 5/3) moist color, loamy texture, subangular blocky structure, strong reaction to NaF, pH 6.4, organic matter 2.0%
C	105–110	Brown (7.5YR 4/3) moist color, clay loam texture, massive structure, strong reaction to NaF

rainy season, and then they are used to grow crops like upland rice and corn in dry periods (IEE 2012b). An example of the soils located in these valleys is the Typic Endoaquerts soil (Soil Survey Staff 2006) presented in Fig. 2.18 and Table 2.11 located at Mocache, Los Ríos, characterized by cracks, slickensides, high of 2:1 clay content (montmorillonite), aquic moisture regime and a water table located at 65 cm in the dry season, a condition that limits the effective depth. In addition, the soil has a clayey loam texture at the surface, a clayey texture in the lower horizons, and poor natural drainage (IEE 2015).

2.6 Recent Alluvial Plain

The recent alluvial plain lies between the Andean piedmont to the east, the old alluvial plain to the north, and the sedimentary reliefs of Manabí to the west, but it narrows

Fig. 2.16 Profile of a soil classified as Typic Hapludolls (left), located at Peñafiel, Mocache, Los Rios, on a 12% slope dissected area, on which cocoa has been planted (right) (IEE 2015)

Table 2.8 Profile characteristics of a soil profile classified as Typic Hapludolls (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–15	Very dark brown (10YR 2/2) moist color, silty loamy texture, grain structure, pH 6.9, organic matter 3%, CEC 33 cmol kg^{-1}, base saturation 93.4%
A	15–49	Very dark brown (10YR 2/2) moist color, silty loam texture, subangular blocky structure, pH 6.8, organic matter 0.6%
2AB	49–70	Very dark brown (10YR 2/2) main moist color, clayey loam texture, angular blocky structure, iron–manganese concretions, pH 6.3, organic matter 0.6%
2Bt1	70–93	Very dark brown (7.5YR 2.5/3) moist color, clayey texture, angular blocky structure, clay coatings, iron–manganese concretions, pH 6.6, organic matter 0.4%, CEC 14 cmol kg^{-1}, base saturation 93.1%
2Bt2	93–108+	Dark brown (7.5YR 3/4) moist color, clayey texture, massive to angular blocky structure, clay liners, pH 6.5, organic matter 0.3%

considerably between Guayaquil and the Masvale hills, and continues south forming only a narrow strip of about 10 km wide that extends as far as the border with Peru (Winckell and Zebrowski 1997) (Fig. 2.19). This is in one of the dry zones of the country; however, mean annual precipitation increases from west to east (1180–2215 mm), but it also decreases from north to south (1555–500 mm), presenting a dry period which lasts 8–9 months. Average annual temperatures are above 23 °C and annual temperature variations do not exceed 4 °C. This is a transition zone which tends to be a semi-humid environment when it approaches the Andean piedmont (Moreno 2001; Winckell and Zebrowski 1997).

These areas originated from quaternary detrital sediments of continental, alluvial, fluvial lacustrine, or fluvial-marine origin that filled a topographic depression created by the

Table 2.9 Percentage distribution of different soils at the subgroup level (Soil Survey Staff 2006), at the areas corresponding to Balzar, Colimes, Daule, Palestine, Santa Lucia, Puebloviejo, and Vinces, cantons located in the southern part of the old plain, characterized by the absence of a volcanic ash cover (IEE 2012b)

Subgroup	%
Vertic Haplustepts	42.95
Vertic Haplustalfs	15.91
Inceptic Haplustalfs	9.21
Typic Haplustalfs	8.19
Vertic Paleustalfs	6.71
Oxyaquic Vertic Haplustalfs	3.59
Typic Haplusterts	2.08
Typic Haplustepts	1.27
Dystric Haplustepts	1.22
Others	8.88

Fig. 2.17 Profile of a soil classified as Inceptic Haplustalfs located at Guayaca Puga, Puebloviejo, Los Rios, with an A/Bt/C horizon sequence (left). The site is located in a <12% slope dissected surface (right) (IEE 2015)

presence of a geological meridian trench. The landscape altitude is always <20 m a.s.l., but in most zones it only reaches 5 m, with a slight increase in altitude toward the piedmont. These are flat and monotonous areas, and the existent ondulations never are over 2 or 3 m in altitude; they are not easily perceptible (Winckell and Zebrowski 1997).

The formation of this alluvial plain started with the severe erosion processes in the Highlands that generated abundant

Table 2.10 Profile characteristics of the soil classified as Inceptic Haplustalfs (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–35	Very dark gray (10YR 3/1) moist color, with speckled reddish yellow (7.5YR 7/8) color, clayey loam texture, subangular blocky structure, pH 5.8, organic matter 4.1%, CEC 28 cmol kg^{-1}, base saturation 40.1%
Bt	35–53	Light yellowish brown (2.5Y 6/4) moist color, with speckled brownish yellow (10YR 6/8) color, clayey texture, massive structure, pH 6.7, organic matter 0.7%
C	53–125+	Light olive brown (2.5Y 5/4) main moist color, dark grayish brown (2.5Y 4/2) secondary color, with speckled reddish yellow (7.5YR 7/8) color, clayey texture, massive structure

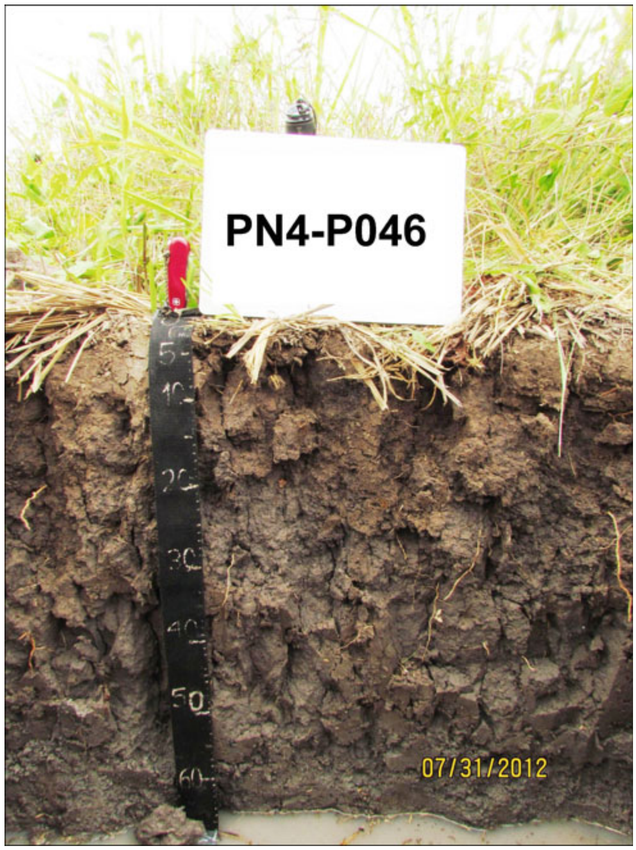

Fig. 2.18 Profile of a soil classified as Typic Endoaquerts (left) located at Garza Grande, Mocache, Los Ríos, with an Apss/ACssg horizon sequence. The photograph was taken in the dry season (IEE 2015)

Table 2.11 Profile characteristics of the soil profile classified as Typic Endoaquerts (IEE 2015)

Horizons	Depth (cm)	Description
Apss	0–15	Dark gray (5Y 4/1) moist color, with speckled red (2.5YR 4/6) color, clayey loam texture, blocky structure, pH 5.5, organic matter 5.2%, CEC 29 cmol kg^{-1}, base saturation 69.5%
ACssg	15–55	Gray (5Y 5/1) moist color, clayey texture, massive to angular blocky structure, pH 6.4, organic matter 2.7%

sediments which were washed by rivers that finally reached the old alluvial plain or the dissected cones. These rivers spilled over this great plain generating clay and silt particle settling. The sediment accumulation affects the Gulf of Guayaquil where the fluvio-marine environment of the Guayas River estuary loses ground because the sediment contributions are higher than the spaces generated by the continuous sinking of actual subsidence structure.

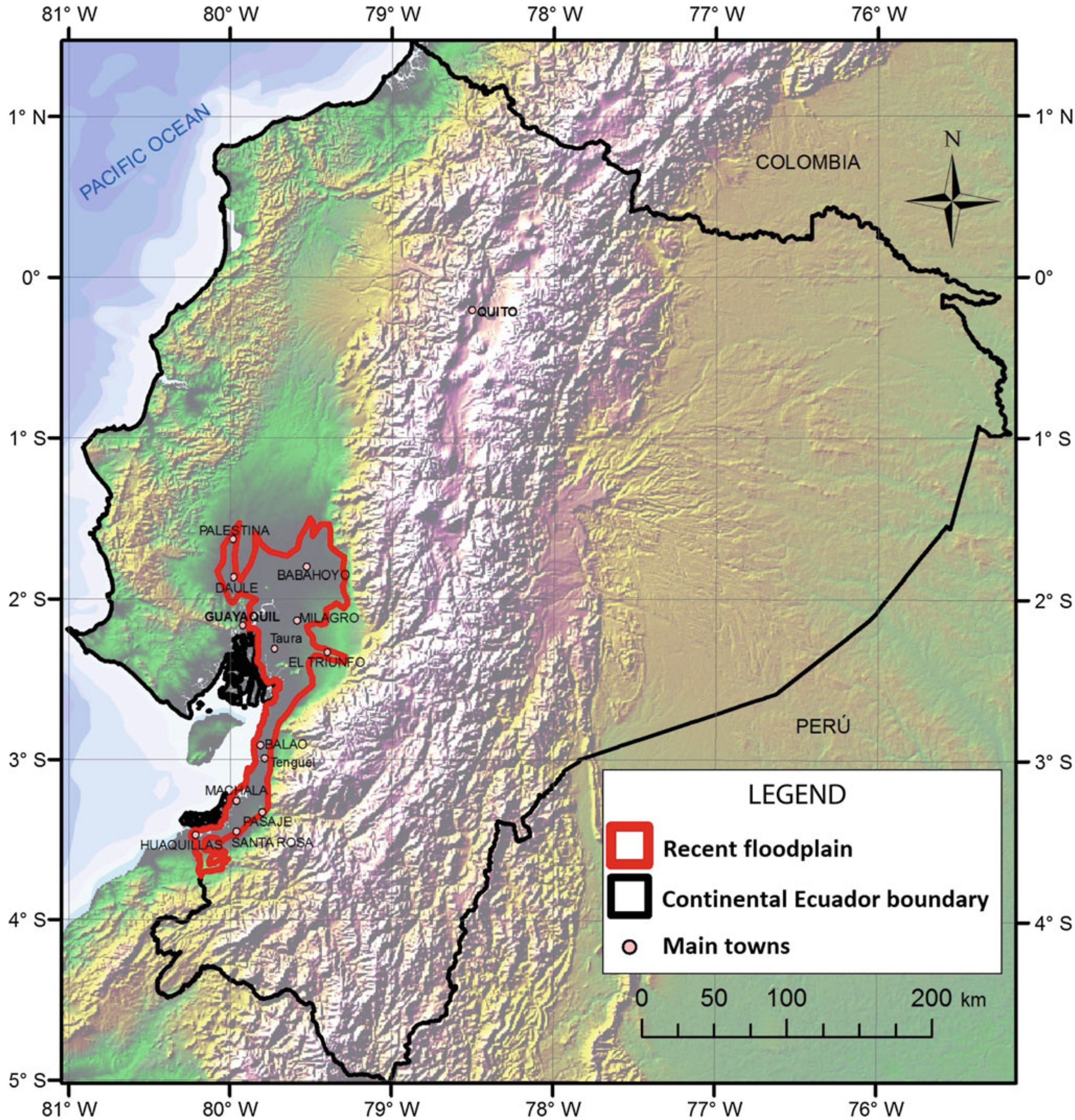

Fig. 2.19 Location of the recent alluvial plain with respect to the continental Ecuador (adapted from Winckell and Zebrowsky 1997)

Consequently, the soils of the recent alluvial plain are remodeled by periodic floods that come with the rainy seasons (Tapia 2012; Winckell and Zebrowski 1997). It is important to note that the lower Guayas River basin is immersed within this plain, which is the most important agricultural zone of the country. This basin is formed by the lower sub-basins of the Daule, Vinces, Babahoyo, Chimbo, Bulubulu, Taura, and Churute rivers (Lasso et al. 2010; Sevillano 2010).

As a result of recent formation factors, the low alluvial plain is subject to flooding, and in general, soils are characterized by a homogeneous clayey texture to an appreciable depth. Those soils with shallow water table show horizons of very sharp colors marked by hydromorphism. Areas near the fluvio-marine environment can have saline and totally flooded soils. The heavy clayey soils (>60% clay) located at the bottom of plain are black when they are not submerged part of the year, but soils at lower sites are flooded much of the year and present olive gray color, usually, slightly acidic pH (6.0–7.0), and a base saturation >50% (Moreno 2001; Winckell and Zebrowski 1997).

The low alluvial plain is characterized by the intensive agricultural use. The floodplain at the lower levels has important areas for patty rice production inundated by natural flooding in the rainy season and by pumped irrigation in the dry season. The highest areas, with less flooding risk, are used for sugarcane or banana plantations (IEE 2012b; Winckell and Zebrowski 1997).

2.6.1 Flat Plain

The flat plain is characterized by gradients that do not exceed 2%, and with no relative incline, reason why these are areas frequently flooded. Predominant soils are Vertisols (Soil Survey Staff 2006) (Table 2.12) which are characterized by heavy texture with the presence of expansive-type clays that form cracks in the dry season and expand in the rainy season. Due to the low relative inclination, soils are poorly drained and show a massive structure (CLIRSEN et al. 2009a).

The main limitation of this type of soils is the poor physical characteristics that generate conditions of poor drainage, low water and air conductivity, heavy textures, poor structural development and porosity, water saturation, and high water tables (Table 2.13). These are very difficult tillage soils with severe limitations to grow crops, except patty rice (Fig. 2.20). The cost of corrective drainage to habilitate these soils for other crops is very high (Mejía 1997).

The stratification and insertion processes of the fluvial and marine deposits promote salinity, condition which is evident in the profile presented in Fig. 2.21 and Table 2.14, showing changes in electrical conductivity ranging from 0.17 to 11.0 dS m^{-1} below 55 cm in the profile.

2.6.2 Banks and Alluvial Dams

The banks and alluvial dams area is located primarily at the Daule and Babahoyo river banks, but also along the sinuous border of the hydrographic system of the flat plain (Fig. 2.22). These are depositional areas, with a 0–5% dominant slope, and a relative gradient that varies from 0 to 5 m (CLIRSEN et al. 2009d). Banks and dikes play the important environmental role of protecting riverbanks with a tropical tree vegetation cover like mango which provides shade to coffee, and cocoa. Banana, citrus, and other subsistence crops are also grown in these areas. Banks and alluvial dams also protect adjacent land against river flooding (Winckell and Zebrowski 1997). Soils classified as Mollisols are predominant in the banks and alluvial dams (Figs. 2.22 and 2.23), followed by Entisols and Inceptisols (Table 2.15).

A good portion of the alluvial banks has been altered to meet the requirements for patty rice and sugarcane production. At the agricultural area of Milagro, between 1983 and 2010, soils classified as Fluventic Hapludolls, developed over banks and alluvial dams, were altered and degraded to Fluventic Eutrudepts, mainly by human intervention in response to the price decline of crops such as cacao and coffee, and the increment of patty rice and sugarcane. Farmers literally eliminated the mollic epipedon in order to find clayey layers that allow production of crops such as patty rice. It is estimated that the disturbed soils cover an area of 5,970 ha (Montúfar et al. 2010).

These soils are characterized by having, in general, a loamy texture within the first 50 cm, soils are friable and have good drainage, and therefore easy to manage. Similarly, chemical properties are favorable for agricultural

Table 2.12 Percentage distribution of different soil types, at the subgroup level (Soil Taxonomy 2006) at the flat plain (IEE 2012a)

Subgroup	%
Typic Hapluderts	58.26
Entic Haplusterts	10.70
Aquic Hapluderts	10.67
Fluventic Hapludolls	5.76
Typic Haplusterts	5.17
Typic Udifluvents	5.05
Aquic Haplustepts	3.25
Aeric Endoaquepts	0.67
Udic Haplusterts	0.35
Vertic Eutrudepts	0.07

Table 2.13 Profile characteristics of a soil classified as Typic Hapluderts (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–30	Dark gray (10YR 4/1) and black (10YR 2/1) moist color, clayey texture, wedge-shaped mixed with massive structure, pH 6.7, organic matter 1.5%, CEC 27.6 cmol kg^{-1}, base saturation 98.7%
Css1	30–80	Very dark gray (5Y 3/1) moist color, clayey texture, wedge-shaped structure mixed with massive structure, many friction faces, pH 7.2, organic matter 0.7%, CEC 31.8 cmol kg^{-1}, base saturation 97.9%
Css2	80–130	Main color Dark gray (5Y 4/1) main moist color and olive gray (5Y 5/2) secondary moist color, clayey texture, massive structure, pH 7.3, organic matter 0.4%, CEC 42.3 cmol kg^{-1}, base saturation 98.1%

Fig. 2.20 Profile of a soil classified as Typic Hapluderts (left) located at Balsa, Colimes, Guayas, in a flat area where rice was grown (right). All horizons have >40% clay (IEE 2015)

production, pH is not far from neutrality, organic content is >2%, and base saturation is >50% (CLIRSEN et al. 2009d). The modal profile for this type of soils is presented in Fig. 2.23 and Table 2.16.

2.6.3 Slightly Wavy Areas with the Presence of Water

This zone is located in the area of influence of the Babahoyo and Daule rivers, water bodies that deposit sediments generating an association of very smooth ondulations (maximum 3–5 m), and permanently flooded depressions slightly perceptible to the eye. This is the typical manifestation of an undulating molding which only shows the peaks emerging from the water. Sites within this zone are characterized by 2–5% slopes if they are natural and 0–2% if they have been mechanized. Vegetation cover consists of patty rice, pastures, and natural vegetation (Fig. 2.24) (CLIRSEN et al. 2009c; Moreno 2001; Winckell and Zebrowski 1997). Semidetailed soil surveys conducted in this zone demonstrated that the dominant soils are Vertisols and Inceptisols, but they also reported the presence of Entisols and Mollisols in lesser extent (Table 2.17) (IEE 2012a).

In general, soils from this landscape are clayey and shallow. These soils are represented in associations due to the difficulty to separate them cartographically, for example, soils that remain flooded most of the year (depressions) have gley colors (olive green) and they have been classified as Vertic Endoaquepts, because they have an aquic moisture regime; in contrast, soils at the emerged tops have black colors and they have been classified as Udic Haplusterts

Fig. 2.21 Profile of a soil profile classified as Aeric Endoaquents (left) located at La Esperanza, Montalvo, Los Rios, in a flat area where patty rice was grown (right). The water table at this site is at a depth of 70 cm, and a layer of dark greenish gray color shows at 10 cm (IEE 2015)

Table 2.14 Profile characteristics of a soil classified as Aeric Endoaquents (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–10	Olive brown (2.5Y 4/3), and yellowish red mottled (5YR 4/6) moist colors, silty clay texture, subangular blocky structure, pH 6.6, organic matter 2%, CEC 18 cmol kg^{-1}, base saturation 69.9%, electrical conductivity 0.28 dS m^{-1}
C1	10–30	Dark greenish gray (GLEY 1 5GY 4/1) moist color, clayey texture, crumbly structure, pH 7.1, organic matter 1.9%, CEC 19 cmol kg^{-1}, base saturation 73%, electrical conductivity 0.2 dS m^{-1}
2C2	30–40	Yellowish brown (10YR 5/4), and dark greenish gray (GLEY 1 5GY 4/1) mottled moist colors, loamy texture, pH 7.4, CEC 14 cmol kg^{-1}, base saturation 78.9%, electrical conductivity 0.16 dS m^{-1}
2C3	40–55	Yellowish brown (10YR 5/4), dark greenish gray mottled (GLEY 1 5GY 4/1) moist colors, sandy loam texture, crumbly structure, pH 6.8, organic matter 0.05%, electrical conductivity 0.17 dS m^{-1}
3C4	55–70	Light olive brown (2.5Y 5/3), and strong brown mottled (7.5YR 5/8) moist colors, loamy texture, pH 7, organic matter 0.4%, electrical conductivity 11.0 dS m^{-1}

(Fig. 2.25). There are also poorly drained, heavy textured soils that remain saturated part of the year (usually from January to May) (Fig. 2.26; Table 2.18). These soils tend to be slightly acid (pH 6.0–6.5), slight saline (electrical conductivity >2.0 and <4.0 dS m^{-1}), and have a base saturation >50% (CLIRSEN et al. 2009c; Moreno 2001; Winckell and Zebrowski 1997).

2.7 Piedmont of the Western Andean Mountain Range

This unit is located between the western Andean flanks to the east and the alluvial plain to the west (Fig. 2.27). Its position immediately at the foot of the Andean flanks originates the name. The unit was formed by the sweeping of

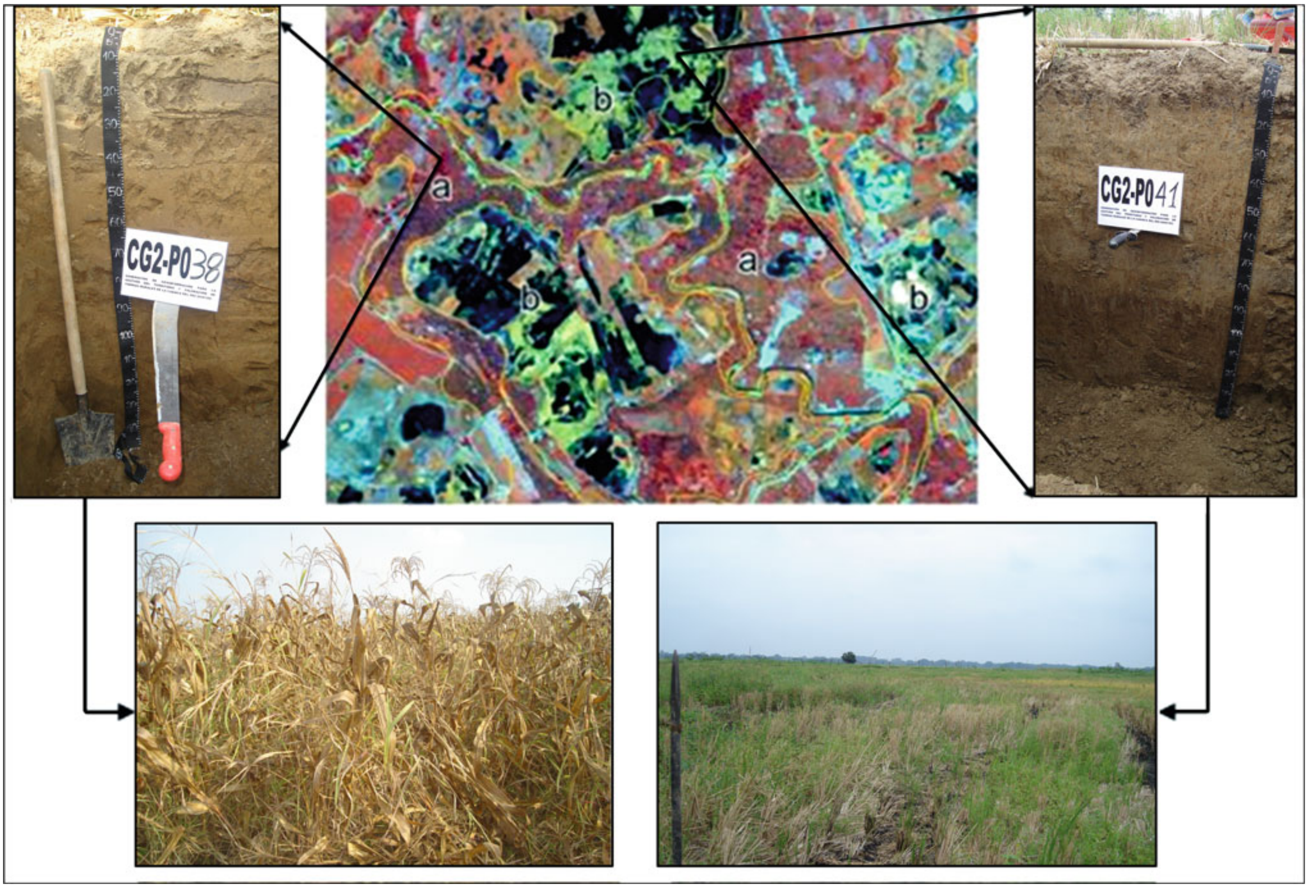

Fig. 2.22 Soil vegetation relationship in the recent alluvial plain. At the center, a 2009 KOMPSAT image (4,2,1—RGB band combination). On the left, a profile of a soil classified as Fluventic Hapludolls located at El Hacha, Vinces, Los Ríos developed over either a bank or an alluvial dam (**a** in the image) used for perennials such as cocoa and tropical fruits or crops like corn. On the right, a profile of a soil classified as Vertic Haplustepts located at Junquillo, Vinces, Los Ríos in an area slightly dissected area (**b** in the image) covered with cultivated pastures (Sevillano 2010)

Table 2.15 Percentage distribution of different soil types, at a subgroup level (Soil Taxonomy 2006), from the banks and alluvial dams (IEE 2012a)

Subgroup	%
Fluventic Hapludolls	65.20
Fluventic Eutrudepts	15.30
Mollic Udifluvents	12.90
Typic Hapludolls	3.02
Typic Udifluvents	1.76
Vertic Eutrudepts	0.59
Typic Ustipsamments	0.43
Udic Ustifluvents	0.37
Other	0.43

colluvial–alluvial deposits provoked by the melting of Quaternary glaciers which moved at high-speed drawing conical figures on the surface of the plain; thus, minerals are varied both in composition and in size and shape. The diagram presented in Fig. 2.28 describes the direction and force of sediment deposits (MIDENA et al. 2013b; Winckell and Zebrowski 1997).

There is a marked difference between the Piedmont northern landscapes and those located at the center and south. The northern area is completely covered with

Fig. 2.23 Profile of a soil profile classified as Fluventic Hapludolls (left) located at Recinto San Ramón, Vinces, Los Rios, developed over several layers of loose friable deposits in an alluvial bank with an A/Bw/C1/C2/2Ab/2C1/2C2 horizon sequence. The site is cultivated with cocoa (right) (IEE 2015)

Table 2.16 Profile characteristics of a soil classified as Fluventic Hapludolls (IEE 2015)

Horizons	Depth (cm)	Description
A	0–30	Dark brown (10YR 3/3) moist color, loamy texture, granular structure, pH 6.4, organic matter 2.9%, CEC 17.3 cmol kg^{-1}, base saturation 98.7%
Bw	30–58	Light olive brown (2.5Y 5/6) moist color, loamy texture, granular structure, pH 7.0, organic matter 1.9%, CEC 19.9 cmol kg^{-1}, base saturation 98.4%
C1	58–76	Light olive brown (2.5Y 5/4) dry color brown mottled (7.5YR 4/4) when moist, silty clay loam texture, pH 7.3, organic matter 1.8%
C2	76–90	Light olive brown (2.5Y 5/4) dry color with dark brown mottled (7.5YR 3/4) moist color, silty clay texture, pH 7.2, organic matter 1.6%
2Ab	90–97	Main color Dark grayish brown (10YR 4/2) main moist color, light olive brown (2.5Y 5/3) secondary color when moist, dark brown (7.5YR 3/4) mottled dry color, clayey texture, granular structure, pH 7.3, organic matter 1.5%
2C1	97–120	Light olive brown (2.5Y 5/4) moist color, dark yellowish brown (10YR 4/6) mottled moist color, clayey texture
2C2	120–153	Light olive brown (2.5Y 5/4) dry and moist color, yellowish brown mottled (10YR 5/8) dry and moist color, clayey texture

pyroclastic material, condition that smooths out the geoforms and provides particular physical and chemical characteristics to the soils. The altitude decreases as the unit moves southward, from around 1000 m o.s.l. in Alluriquín at the north to 20 m o.s.l. where the Piedmont enters in contact with the alluvial plain at the south. Similarly, there is a reduction in the amount of average annual precipitation that varies from 2660 mm at the north to 500 mm at the south. In addition, there is also a secondary precipitation gradient from east to west due to orographic blocking of air circulation; the highest average annual precipitation occurs close to the Andean flanks (2290 mm at Bucay) and the lowest at the western edge of the Piedmont (1440 mm at San Carlos) (Winckell and Zebrowski 1997). There are two clearly defined subunits within the Piedmont: (a) Dejection cones and (b) scattered cones.

2.7.1 Dejected Cones

The dejected or alluvial cones are located in direct contact with the Andean flank (Fig. 2.28) on slopes ranging from 12 to 25% characterized by dissected surfaces due to the long time under the action of remodeling processes. This zone was formed by glacial melting which broth detrital, alluvial, and torrential deposit of pebbles, blocks, and gravel in a sandy-clayey matrix that extended radially downslope as a result of the sharp gradient decline from the point where the

Fig. 2.24 Overview of a slightly ondulating area with vertic soils located at the Cooperativa Vista Alegre, Samborondón, Guayas. At the bottom, the flooded soil covered with hydrophilic plants (*Eichhornia* sp.), and on the top the non-flooded soil with trees (CLIRSEN et al. 2009c)

Table 2.17 Percentage distribution of different soil types, at subgroup level in the slightly ondulating area (IEE 2012a)

Subgroup	%
Typic Haplusterts	24.92
Typic Hapluderts	19.40
Vertic Eutrudepts	9.12
Vertic Endoaquepts	9.11
Udic Haplusterts	5.57
Others	31.88

flow of water leaves the rugged area (MIDENA et al. 2013b). Dominant soils in this area are Andisols and Alfisoles (Table 2.19).

The soils in the northern part of this unit are covered by a thick layer of volcanic ash which is 6 m deep at the northern part (areas close to the emission centers) and can be only 10 cm deep at the northern central part. The predominant soils of this area are Andisols characterized by low bulk density (<0.9 g cm^{-3}) and high moisture retention (Table 2.20). Rainfall differences within the dejected cone are responsible for the unit particular soil characteristics. At the more humid zone, closer to the ash emission centers, desaturated Andisols (<50% base saturation) have been developed. At the same humid zone, but far away from the emission centers, perhydrated Andisols (water retention >100%) were developed, and at the drier zones saturated Andisols (>50% base saturation) are evident (IEE 2015; Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

The soils in the central and southern parts of the dejected cones are characterized by having clayey-stony texture, because they were originally developed from stony deposits. These soils have been leached by high rainfall, conditions which have promoted the development of ferralitic soils at the more humid zones and fersiallitic at the drier zones. This area is dominated by soils classified as Alfisols (Table 2.20).

An example of the soils from the northern area is the soil classified as Typic Hapludands (Soil Survey Staff 2006) (Fig. 2.29; Table 2.21) characterized by having moderate depth (<100 cm), sandy loam texture, slightly acid (pH 6.2), high organic matter content (4.3%), and low base saturation (31.1%) (MIDENA et al. 2013b).

An example of a soil from the central and southern part of the dejected cones is presented in Fig. 2.30 and Table 2.22. This soil, classified as Mollic Paleudalfs (Soil Survey Staff 2006), has a shallow effective depth (<50 cm) due to the heavy texture (>50% clay) of the deeper horizons which prevents root penetration. Weighted-average pH, organic matter content, and base saturation in the first 47 cm are 6.7, 2.2, and 54.7%, respectively, conditions of a soil with high natural fertility (IEE 2015).

2.7.2 Dispersion Cones

This zone is located immediately below the dejected cones. The alluvial deposits were dispersed over larger areas and modeled a lower gradient relief with mostly flat surfaces of

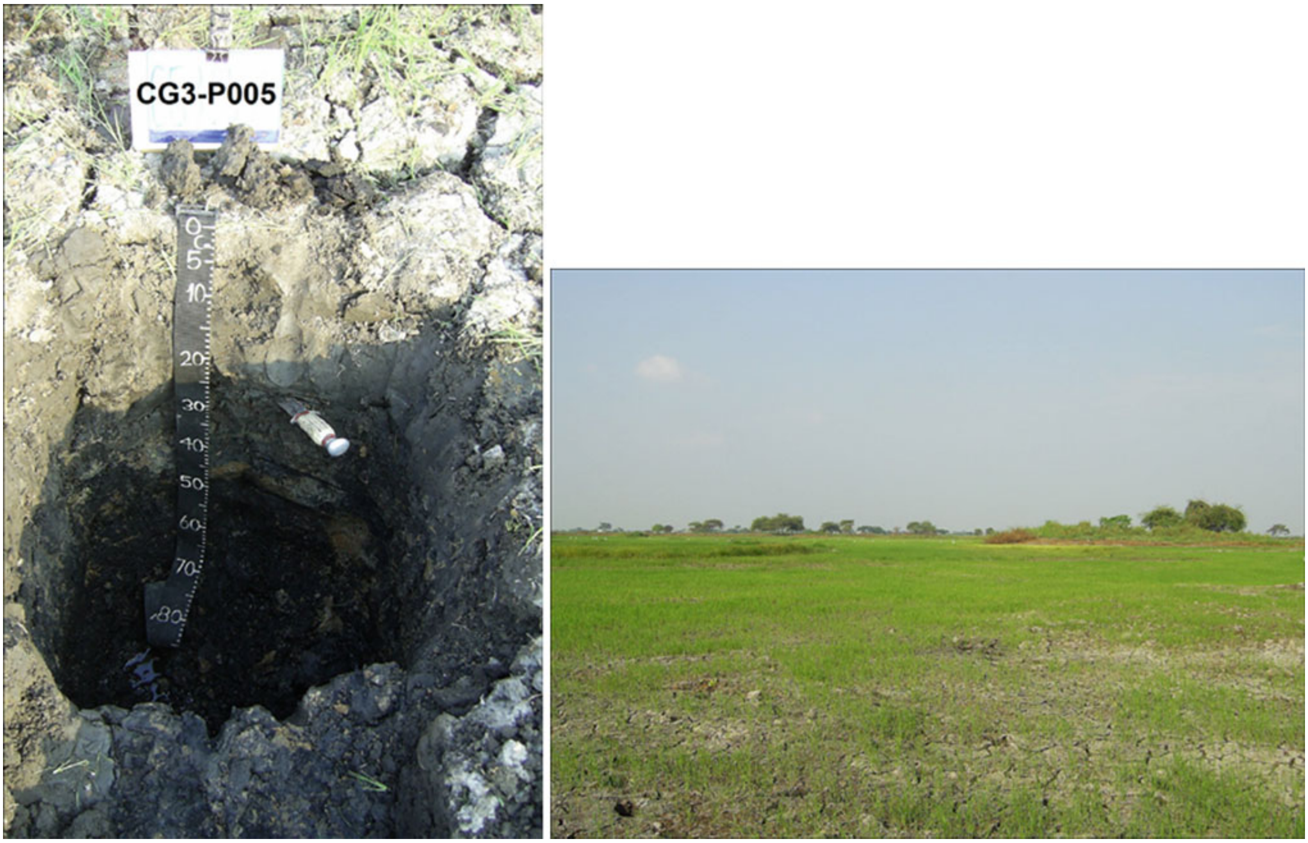

Fig. 2.25 Profile of a soil classified as Udic Haplusterts (left) located at El Hormiguero, Samborondón, Guayas, where the characteristic blocks of a Vertisol are evident. Patty rice is the main crop grown in these soils (right) (IEE 2015)

Fig. 2.26 Profile of a soil profile classified as Aquertic Hapludolls (left) located at El Mango Morado, Babahoyo, Los Rios, cultivated with patty rice (right) (IEE 2015)

Table 2.18 Profile characteristics of a soil classified as Aquertic Hapludolls (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–18	Black (10YR 2/1) moist color with strong presence brown mottling (7.5YR 5/8), clayey texture, granular structure, pH 5.5, organic matter content 3.2%, CEC 21.8 cmol kg^{-1}, of base saturation 97.2%, of electric conductivity 1.5 dS m^{-1}
Ag	18–40	Dark greenish gray (Gley 1 4/5GY) moist color with red mottling (2.5YR 4/8), olive yellow (2.5Y 6/8) secondary moist color, silty loam texture, pH 6.9, organic matter 0.7%, CEC 32.8 cmol kg^{-1}, base saturation 98.8%, electric conductivity 4.84 dS m^{-1}
Bg	40–90	Olive gray (5Y 4/2) moist color with light olive brown mottling (2.5Y 5/6), clayey texture, pH 7.7, organic matter 1.2%, CEC 41.1 cmol kg^{-1}, base saturation 98.8%, electric conductivity 3.2 dS m^{-1}
Cg	90–100+	Gray (2.5Y 4/1) moist color, silty loam texture, massive structure

large undulating slopes that do not exceed 12%. Deposits are sandy-rocky at the top and sandy-silty at lower part as the relief gradually reaches the recent alluvial plain.

At the north side of this unit, covered with volcanic ash, the humid climate has promoted the development of desaturated Andisols; however, in the less humid climate, soils are saturated Andisols. The southern zone of this unit, drier and without volcanic ash cover, presents sandy-silty soils with gravel at the higher part, and silty clay soils at the lower part which gradually merges with the recent alluvial plain. Deposits in this unit have not completely aged due to the deposits younger age and the drier environment; this condition has promoted the development of 2:1 clays (Winckell and Zebrowski 1997).

A typical soil of the northern part of the dispersed cones is presented in Fig. 2.31 and Table 2.23. This soil, classified as Typic Hapludands (Soil Survey Staff 2006), has good physical characteristics (loamy within the profile first 40 cm) which can be tilled for agricultural use. Weighted averages of the chemical characteristics for the first 40 cm are 5.3, 4.1, and 23.8% for pH, organic matter content, and base saturation, respectively (MIDENA et al. 2013b).

The soil profile presented in Fig. 2.32 and Table 2.24 represents the southern part of the dispersed cones with no volcanic ash cover. This soil, located near Naranjito, classified as Mollic Ustifluvents (Soil Survey Staff 2006) has >100 cm effective depth; texture of the first 40 cm of the profile varies from loam to clayey loam, but texture is sandy loam from 40 to 100 cm. Because soils are in an Ustic moisture regime, base saturation is >50% (CLIRSEN et al. 2009b; Zebrowski and Sourdat 1997).

2.8 Sedimentary and Fluvio-Marine Reliefs

The sedimentary and fluvio-marines reliefs are located in the central littoral regions of the Manabí and Santa Elena Provinces. The development of these reliefs is consequence of the direct action of the sea and the various marine processes related with the transgression–regression marine events, and the old and new deposits, which formed the littoral plains, beach ridges, and different levels of marine plateaus. These landscapes include medium and low seasides, with minor cliffs and large front straight beaches in sectors near Manta and the entire periphery of the Santa Elena Peninsula where different quaternary transgressions were deposited (Fig. 2.33) (Collot et al. 2009; Winckell and Zebrowski 1997). The presence of herbaceous and shrub vegetation is typical of the desert thorny scrub of the dry tropical areas. The average annual temperature is >23 °C (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

2.8.1 Sandstone Calcareous Plateaus

The calcareous plateaus correspond to areas of dry tropical to subdesert climate that receives directly the drying effects of the Humboldt cold current; the average annual precipitation varies from 240 mm near the coast to 400 mm inland, reaching 800 mm on the plateau summits. This zone covers mainly the uneven coastal perched, rolling, and dissected plateaus located over recent sediments. These calcareous sandstone plateaus extend in an inclined plane from 80–100 to 320–360 m o.s.l. from the coastal line as far as Montecristi inland. The continuity of all of these surfaces is due to the existence of recent marine transgressions that deposited a succession of detrital sediments, probably of Pleistocene age, that were affected by Quaternary tectonic activity. They are located exactly where the Carnegie submarine ridge collides with the continent, condition which allowed that deposits of these transgressions arise above 350 m o.s.l. Plateau composition is defined by alternating layers of moderately cemented sands and sandstones and fossiliferous calcareous sandstone having in the middle a well-cemented basal conglomerate, corresponding to the Tablazo formation. On the slopes of ravines, formations conformed by rocky

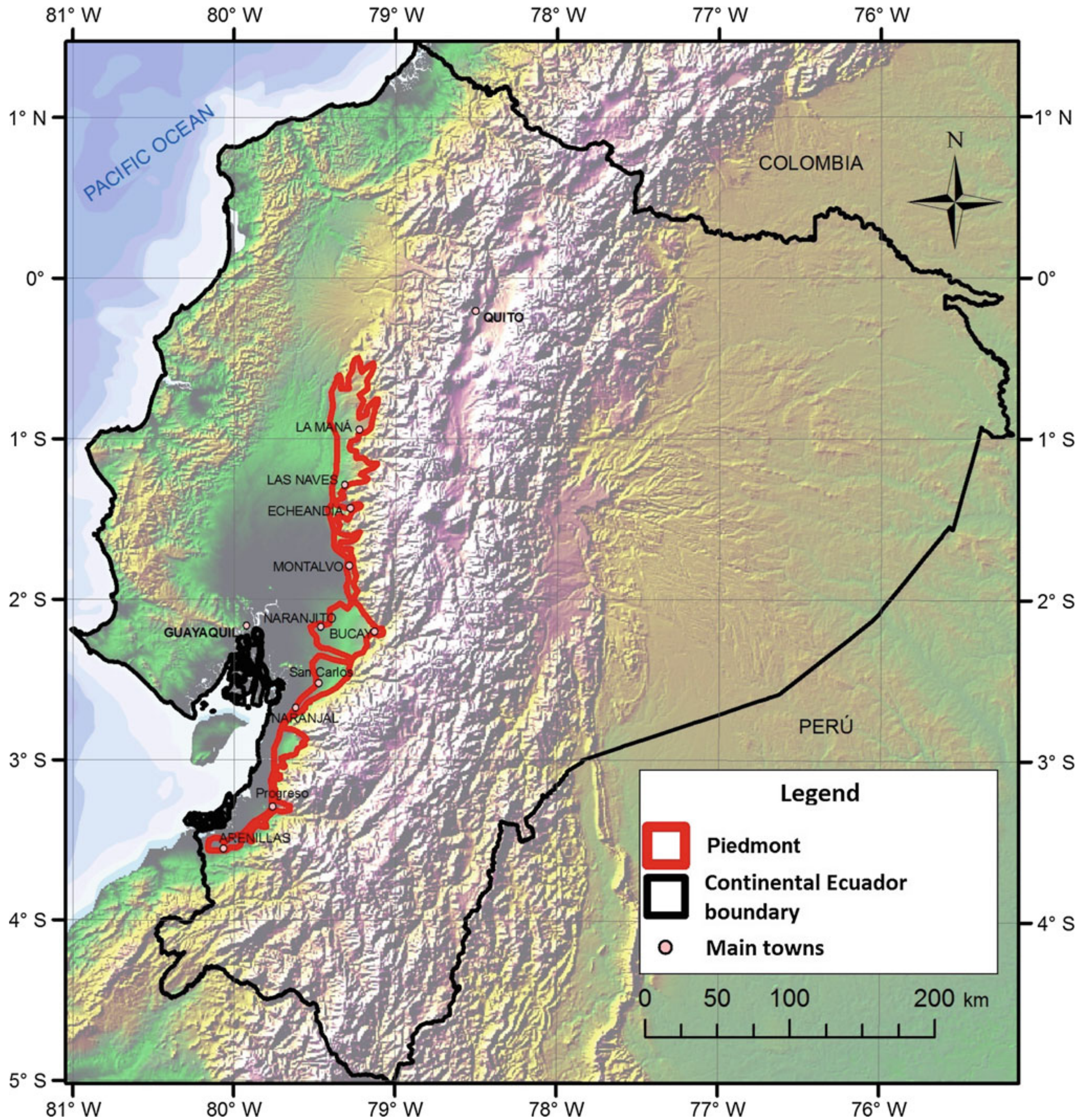

Fig. 2.27 Location of the western Andean Piedmont with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

outcrops are alternated over more consolidated banks of fine to medium grain compacted calcareous sandstones, lumaquels and, in many cases, recent sand deposits (Collot et al. 2009; Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

The soils in this zone are clayey, vertic, moderately profound, with a textural discontinuity between 10 and 50 cm (top horizon poor in clay and the subjacent more clayey) which often have accumulations of calcium carbonate and even gypsum, due to pedoclimate changing from dry to very dry (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

The modal profile of this zone corresponds to a soil classified as a Typic Haplustalfs (Soil Survey Staff 2006) (Fig. 2.34; Table 2.25). Morphologically, this soil presents the following horizon sequence: A/AE/Bt/C with evident

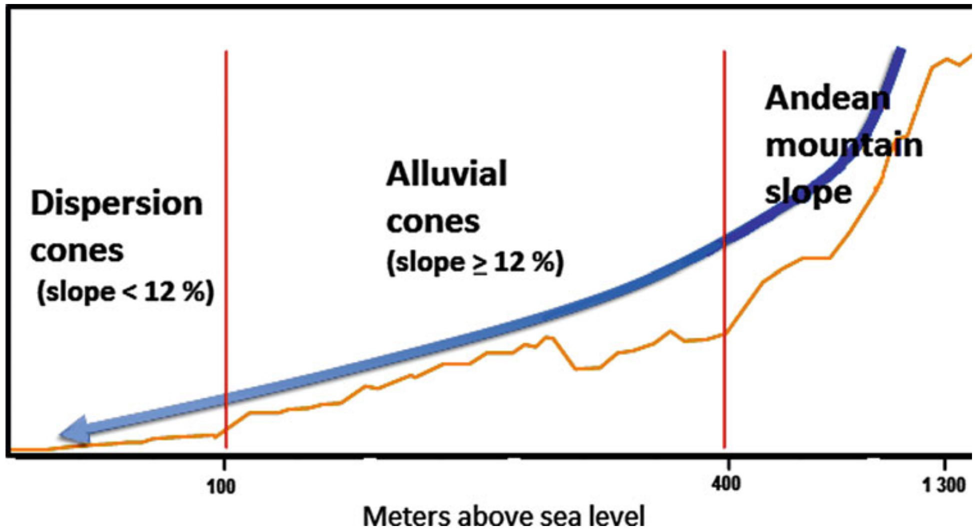

Fig. 2.28 Surface contour of Western Andean Piedmont. The brown line represents the ground surface and the blue arrow represents the direction and strength of the deposits, a darker line indicates a greater force (MIDENA et al. 2013b)

Table 2.19 Percentage distribution of the different soil types at the order level in the dejected cones (IEE 2012a)

Order	%
Andisols	44.04
Alfisols	45.28
Inceptisols	7.56
Entisols	2.97
Mollisols	1.15

Table 2.20 Percentage distribution of the different soil types, at subgroup level, at the northern and central southern sectors of the dejection cones (IEE 2012a)

Subgroup	%
Northern sector	
Typic Hapludands	89.73
Thaptic Hapludands	10.27
Central and southern sectors	
Typic Hapludalfs	42.97
Typic Hapludands	18.42
Inceptic Hapludalfs	13.49
Humic Dystrudepts	5.39
Typic Udorthents	4.32
Ultic Hapludalfs	3.67
Typic Dystrudepts	3.39
Mollic Paleudalfs	3.35
Andic Paleudalfs	2.53
Humic Eutrudepts	1.53

albic and argillic horizons. This type of soil is found at the <5% slopes landforms of the marine plateau surfaces characterized by an Ustic moisture regime and an isohyperthermic temperature regime (CLIRSEN et al. 2011a).

2.8.2 Littoral Strip

This zone is located at the western part of the Santa Elena peninsula, as plains and undulations characterized by nearly

Fig. 2.29 Profile of a soil classified as Typic Hapludands (left) located at Manguila, Valencia, Los Ríos, on a 25–40% slope. These soils are suitable for tree plantations such as rubber (right) (IEE 2015)

Table 2.21 Profile characteristics of a soil classified as Typic Hapludands (IEE 2015)

Horizons	Depth (cm)	Description
Oe	0–5	Black (10YR 2/1) moist color, loamy sand texture, granular structure
A	5–15	Main color Very dark gray (10YR 3/1) main moist color, very dark gray brown (10YR 3/2) secondary moist color, sandy loam texture, granular to subangular blocky structure, slight reaction to NaF, pH 6.2, organic matter 4.3%, CEC 20 cmol kg^{-1}, base saturation 31.1%
Bw	15–35	Very dark grayish brown (10YR 3/2) main moist color, dark brown (10YR 3/3) secondary moist color, loamy texture, subangular blocky structure, strong reaction to NaF
C1	35–60	Dark brown (10YR 3/3) moist color, sandy clay loam texture, massive structure, strong reaction to NaF
C2	60–90	Dark brown (10YR 3/3) main moist color, dark grayish brown (10YR 4/2) secondary moist color, sandy clay loam texture, massive structure, strong reaction to NaF

flat reliefs of clayey sedimentary to sandy hills. This peninsula is fully exposed to the drying effects of the Humboldt cold current to the point that the tip of Salinas could be considered the final part of the Peruvian coastal desert; therefore, rainfall is very scarce. Average annual rainfall is <100 mm at Salinas and up to 400 mm at Playas. This littoral landscape of desert like climates is divided into three sub-landscapes: (a) Eroded hills of sedimentary base, (b) recent low undulations, and (c) littoral deposits.

Eroded Hills from Sedimentary Base

This type of landscape is located in two well-defined distinct sectors of the Ecuadorian littoral, behind the Santa Elena coast to the north, and at either side of Ancon to the south. This zone is characterized by reliefs <50 m o.s.l., with flat plateaus truncated by Quaternary marine abrasion, covered or not by marine deposits. In general, this is an area with steep slopes (>40%), with variable dissection where the poor

Fig. 2.30 Profile of a soil profile classified as Mollic Paleudalfs (left) located at hacienda La Independencia, Ventanas, Los Rios, with an A/Bt/BC/C horizon sequence planted with cocoa (right) (IEE 2015)

Table 2.22 Profile characteristics of a soil classified as Mollic Paleudalfs (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–25	Very dark grayish brown (10YR 3/2) dry color, clayey texture, granular to subangular blocky structure, pH 6.7, organic matter 3.1%, CEC 24 cmol kg^{-1}, base saturation 60.7%
Bt	25–47	Very dark grayish brown (10YR 3/2) dry color, clayey texture, massive to subangular blocky structure with clay liners, pH 6.8, organic matter 1.3%, CEC 28 cmol kg^{-1}, of base saturation 48.0%
BC	47–62	Dark brown (7.5YR 3/3) moist color, clayey texture, massive to subangular blocky structure, pH 6.5, organic matter 0.5%
C	62–80+	Dark brown (7.5YR 3/4) moist color, clayey texture, massive structure, presence of fine gravel

xerophytic vegetation does not cover and stabilizes the soil, which is easily eroded by the infrequent rainfall events forming gullies (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

A characteristic soil of this zone, classified as Calcic Petrocalcids (Soil Survey Staff 2006), is presented in Fig. 2.35 and Table 2.26. These incipiently developed soils present excess of carbonates, gypsum, or salts that drastically limit crop production. The main feature of these soils is the presence of a calcic horizon over a petrocalcic horizon where carbonates have accumulated forming a hard horizon. The reference profile (Fig. 2.35) is found on steep slopes (40–70%), has sandy-clayey loam texture on the surface, and clayey loam in depth, and has the following horizon

Fig. 2.31 Profile of a soil classified as Typic Hapludands (left), located at La Experiencia de Chipe, Valencia, Los Ríos. The soil horizon sequence is Ap/Bw/C/2Ab/2C, showing evidence of two events of volcanic ash deposition. This <12% slope relief is cultivated with soybeans (right) (IEE 2015)

Table 2.23 Profile characteristics of a soil classified as Typic Hapludands (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–20	Main color Very dark gray (10YR 3/2) main moist color, yellowish brown mottling (10YR 5/8) moist color, loamy texture, granular to subangular blocky structure, strong reaction to NaF, pH 5.8, organic matter 5.3%, CEC 21 cmol kg^{-1}, base saturation 25.4%
Bw	20–40	Very dark grayish brown (10YR 3/2) moist color, sandy loam texture, subangular blocky structure, strong reaction to NaF, pH 6.5, organic matter 3.81%, CEC 19 cmol kg^{-1}, base saturation 29.2%
C	40–65	Dark yellowish brown (10YR 3/4) moist color, silty loam texture, porous massive structure, strong reaction to NaF
2Ab	65–90	Very dark brown (10YR 2/2) moist color, silty clay loam texture, massive to subangular blocky structure, strong reaction to NaF
2C	90–100	Dark yellowish brown (10YR 3/6) moist color, silty clay loam texture, massive structure, strong reaction to NaF

Fig. 2.32 Profile of a soil classified as Mollic Ustifluvents (left), located at the San Carlos sugar plantation, Naranjito, Guayas, with the following horizon sequence: Ap/A/AC/CA/C. This zone holds the largest sugarcane area of the country (right) (IEE 2015)

Table 2.24 Profile characteristics of a soil classified as Mollic Ustifluvents (IEE 2015)

Horizons	Depth(cm)	Description
Ap	0–20	Very dark brown (10YR 2/2) moist color, clayey loam texture, subangular blocky structures, pH 6.7, organic matter 2.5%
A	20–40	Dark brown (10YR 3/3) moist color, yellowish brown (10YR 5/6) mottling moist color, loam texture, subangular blocky structure, pH 7.5, organic matter 1.9%
AC	40–65	Dark grayish brown (10YR 4/2) moist color, yellowish red (5YR 4/6) mottling moist color, sandy loam texture, subangular blocky to porous massive structure, pH 7.9, organic matter 1.5%
CA	65–100	Primary color grayish brown (10YR 5/2) primary moist color, olive brown (2.5Y 4/3) secondary moist color, strong brown (7.5YR 4/6) mottling primary moist color, olive (5Y 4/3) mottling secondary moist color, sandy loam texture, porous massive to subangular blocky structure, pH 8.5, organic matter 0.5%
C	100–130	Dark yellowish brown (10YR 3/6) moist color, sandy texture, single grain massive structure, pH 8, organic matter 0.2%

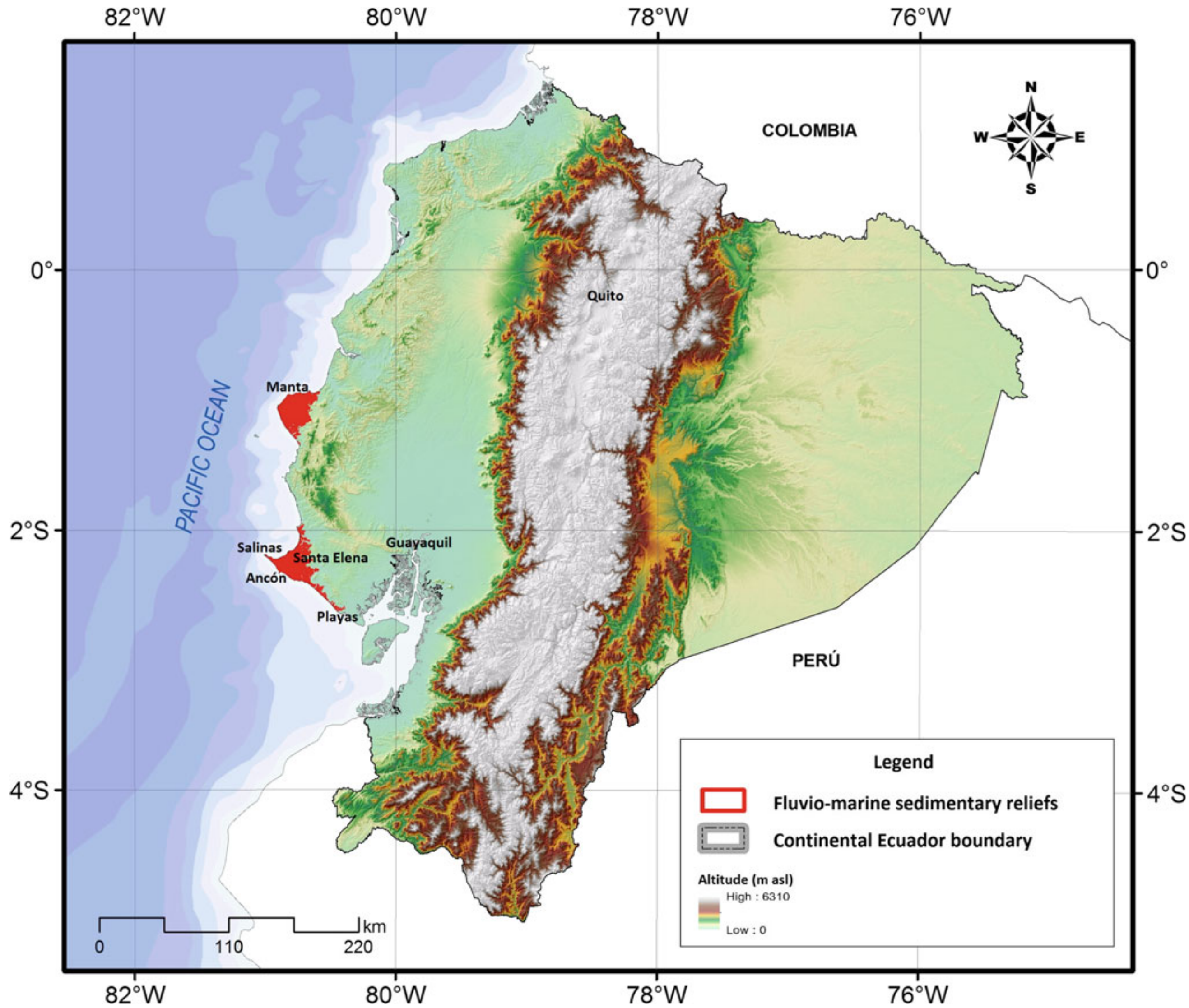

Fig. 2.33 Location of sedimentary and fluvio-marine reliefs with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

sequence: A/BAk/Bkk/Ckm. Colors of the upper horizons are very dark grayish brown to very pale brown, while the Ckm horizon is white (IEE 2015).

Low Undulations from the More Recent Plains

This zone consists of reliefs formed by not consolidated Quaternary marine deposits of fine and coarse limestone sands containing a high percentage of gravel and shells fragments. These deposits are alternated with clayey sands and clays layers of cream to greenish color and conglomeratic sandstone beds rich in shells. These landscapes also belong to the Tablazo formation and cover almost totally the Salinas Peninsula and continue down to Playas (Collot et al. 2009; Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

The profile of a representative soil from this zone is shown in Fig. 2.36 and Table 2.27. This soil, located on gentle slopes (<12%) and classified as Typic Calciargids (Soil Survey Staff 2006), has a salt excess throughout the

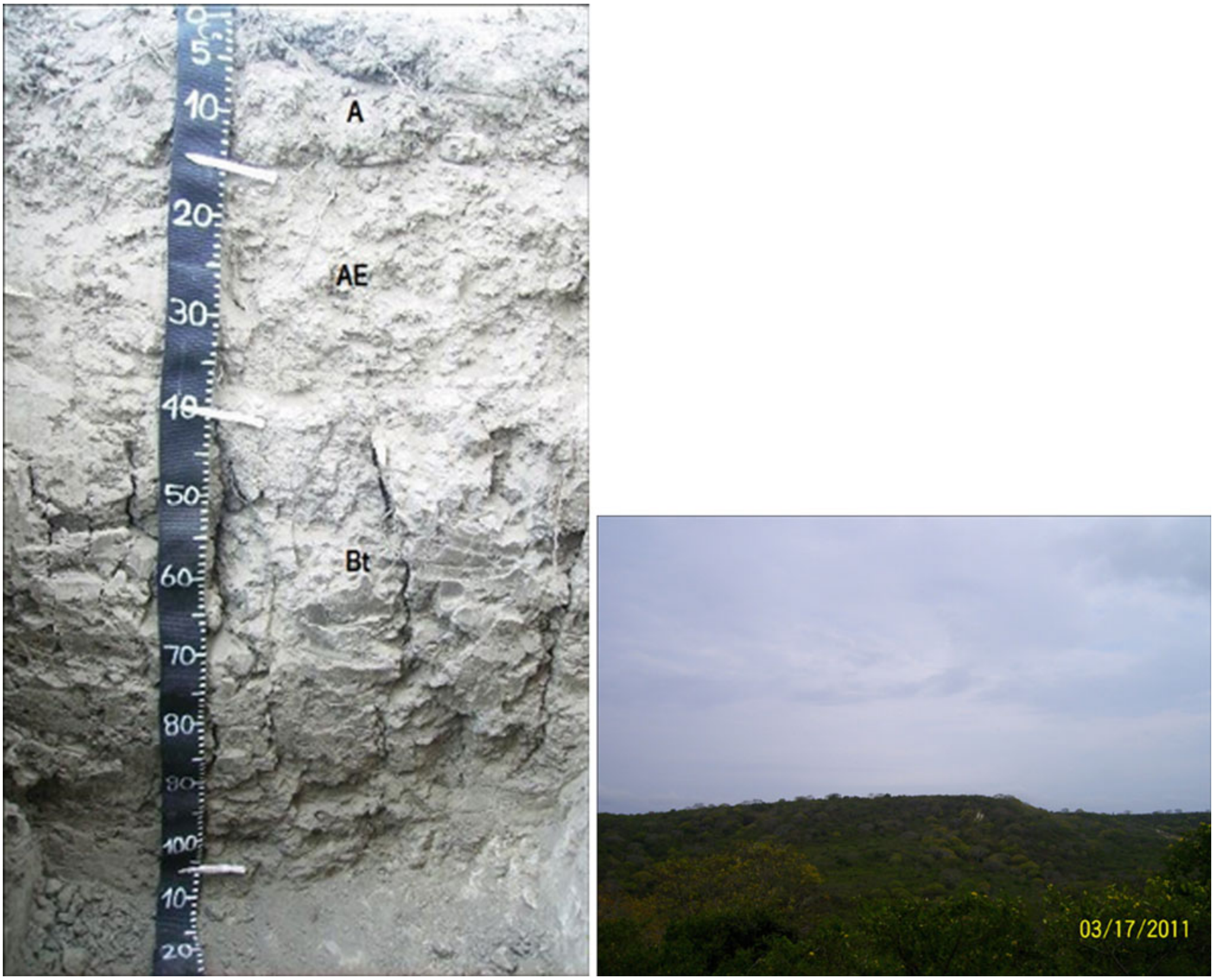

Fig. 2.34 Typic Haplustalfs soil profile (left) located at Las Palmas, Montecristi, Manabí, in a Marine Plateau (right) (IEE 2015)

Table 2.25 Profile characteristics of a soil classified as Typic Haplustalfs (IEE 2015)

Horizons	Depth (cm)	Description
A	0–15	Main color grayish brown (10YR 5/2) main dry color, loamy texture, subangular blocky structure, pH 7.1, organic matter 4.6%, CEC 24 cmol kg^{-1}, base saturation 93.6%
AE	15–40	Light brownish gray (10YR 6/2) dry color, silty loam texture, subangular blocky structure, pH 7, organic matter 1.3%, CEC 24 cmol kg^{-1}, base saturation 94.8%
Bt	40–106	Dark grayish brown (10YR 4/2) main dry color, clayey texture, prismatic structure, pH 7, organic matter 0.9%, CEC 30 cmol kg^{-1}, base saturation 90.77%
C	106–115+	Very pale brown (10YR 7/4) dry color, clayey loam texture, massive structure

Fig. 2.35 Modal profile of a soil classified as Calcic Petrocalcids (left) located at Cerro Barbasco, Santa Elena, at hills of tertiary origin (right) (IEE 2015)

Table 2.26 Profile characteristics of a soil classified as Calcic Petrocalcids (IEE 2015)

Horizons	Depth (cm)	Description
A	0–20	Grayish brown (10YR 5/2) dry color, very dark grayish brown (10YR 3/2) moist color, sandy-clayey loam texture, subangular blocky structure, light reaction to HCl, presence of secondary carbonates in the form of dispersed powdery lime, pH 8.2, organic matter 2.2%, CEC 30 cmol kg^{-1}, base saturation 95.3%
BAk	15–40	Very pale brown (10YR 8/2) main dry color, light brownish gray (10YR 6/2) secondary dry color, very pale brown (10YR 7/3) main moist color, dark grayish brown (10YR 4/2) secondary moist color, clayey loam texture, massive to subangular blocky structure, moderate reaction to HCl, presence of secondary carbonates as dispersed powdery lime
Bkk	40–106	Very pale brown (10YR 8/3) dry color, very pale brown (10YR 7/3) moist color, sandy loam texture, extremely strong reaction to HCl, presence of secondary carbonates as dispersed powdery lime
Ckm	106–115+	White (10YR 8/1) dry color, loamy sand texture, massive structure, extremely strong reaction to HCl, cemented layer by carbonates compaction in more than 90% of the horizon

profile, condition which limits crop production. Morphologically, the horizon sequence is A/Bt/Ck (IEE 2015).

Littoral Deposits

This zone corresponds to quaternary sandy marine deposits and calcareous saline deposits of silts and clays that also contain abundant shell residues that are located on beaches, beach ridges, and filled lagoons behind these strings. Beaches and coastal strings are composed of fine and very fine sand, often mobilized by wind. The interior lagoons are commonly composed by clayey to silty clayey deposits. The eolian process acting upon the littoral outline, especially on the south coast, promoted by the strong ocean winds, remobilize the current and old sand deposits forming dunes (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

The soils of these emerged beaches and coast strings are classified as Typic Ustipsamments (Fig. 2.37; Table 2.28) (Soil Survey Staff 2006). They show little or no evidence of

Fig. 2.36 Profile of a soil profile classified as Typic Calciargids (left) located at the Fuerte Militar, Salinas, Santa Elena, in a low undulation from the more recent plains. Note the very dry vegetation (right) (IEE 2015)

Table 2.27 Profile characteristics of a soil classified as Typic Calciargids (IEE 2015)

Horizons	Depth (cm)	Description
A	0–30	Pale yellow (2.5Y 7/3) dry color, brown (10YR 4/3) moist color, sandy loam texture, pH 7.8, organic matter 1.6%, CEC 18 cmol kg^{-1}, base saturation 91.3%
Bt	30–60	Dark yellowish brown (10YR 4/6) dry color, dark yellowish (10YR 4/4) moist color, sandy-clayey loam texture, prismatic structure with many clay liners, pH 8, organic matter 0.4%, CEC of 20 cmol kg^{-1}, base saturation 98.1%
Ck	60–110	White (10YR 8/1) dry color, pale yellow (2.5Y 8/2) moist color, sandy loam texture, porous massive structure, extremely strong reaction to HCl, pH 8.7, organic matter 0.4%, CEC of 30 cmol kg^{-1}, of base saturation 96.5%

pedogenic development, have an Ustic moisture regime (dry soil 90 or more cumulative days annually), and are located on gentle slopes (5–12%). Also, these soils have sandy texture, and consequently the excessive drainage (IEE 2015).

2.9 El Progreso Basin

This is a zone of subsidence located in the triangle formed by the Chanduy–Playas mountain range to the west and southwest and coastal Chongón and Colonche mountain range to the north. This unit occupies the eastern half of the Salinas Peninsula, including the Puna Island located immediately southeast of the peninsula, at the axis of the Guayas River delta, an island that maintains the continuity of the major structural features from the basin (Fig. 2.38). Overall, this basin is formed by reliefs of sedimentary-structural origin from the Tertiary period around a northwest southeast axis that has been filled by recent Oligo-Miocene sediments as it moves eastward into the basin. Altitude varies from 50 to 200 m o.s.l. Landscape ranges from flat to slightly wavy at the eastern boundary, and vigorous reliefs and traces of monocline reliefs

Fig. 2.37 Profile of a soil classified as Typic Ustipsamments located at Los Arenales, Crucita, Manabí (IEE 2015)

Table 2.28 Profile characteristics of a soil classified as Typic Ustipsamments (IEE 2015)

Horizons	Depth (cm)	Description
AC	0–20	Light brownish gray (10YR 6/2) dry color, dark grayish brown (10YR 4/2) moist color, sandy texture, unstructured, pH 9.0, organic matter 0.29%, CEC 30 cmol kg^{-1}, of base saturations 94.7%, moderate reaction to HCl
C1	20–50	Light brownish gray (10YR 6/2) dry color, grayish brown (10YR 5/2) moist color, sandy texture, unstructured, moderate reaction to HCl
C2	50–100	Light brownish gray (10YR 6/2) dry color, brown (10YR 5/3) moist color, sandy texture, unstructured, moderate reaction to HCl

(slopes and plateaus) of clusters of sandstone and clays, as well as clay-gravel depressions, all located to the west (MAG and ORSTOM 1978; Winckell and Zebrowski 1997).

The climate of El Progreso Basin is characterized by average annual rainfall ranging from 400 mm at the west to 1000 mm at the east. Similarly, rainy days change from 20 to 80, the number of dry months from 12 to 9, and the annual water deficit from 1000 to 750 mm in west to east direction. The mean annual temperature is around 22 °C. Considering the above, the following climatic regimes can be differentiated in this zone: (a) arid west and southwest; (b) very dry inner crown; (c) dry northeast; and (d) wet high reliefs covered by drizzle clouds. The Puna island climate is very dry (CLIRSEN et al. 2011a; IEE 2015; MAG and ORSTOM 1978; Winckell and Zebrowski 1997).

The soils in this unit are influenced by three formation factors: (a) Dry climate, predominant factor that affected physical and chemical pedogenic reactions favoring the synthesis of 2:1 clays, base accumulation, and frequent presence of carbonates and gypsum deposits; (b) Parental material that influenced the type of minerals inherited by soil, for example, the high K^+ level in these soils is due to

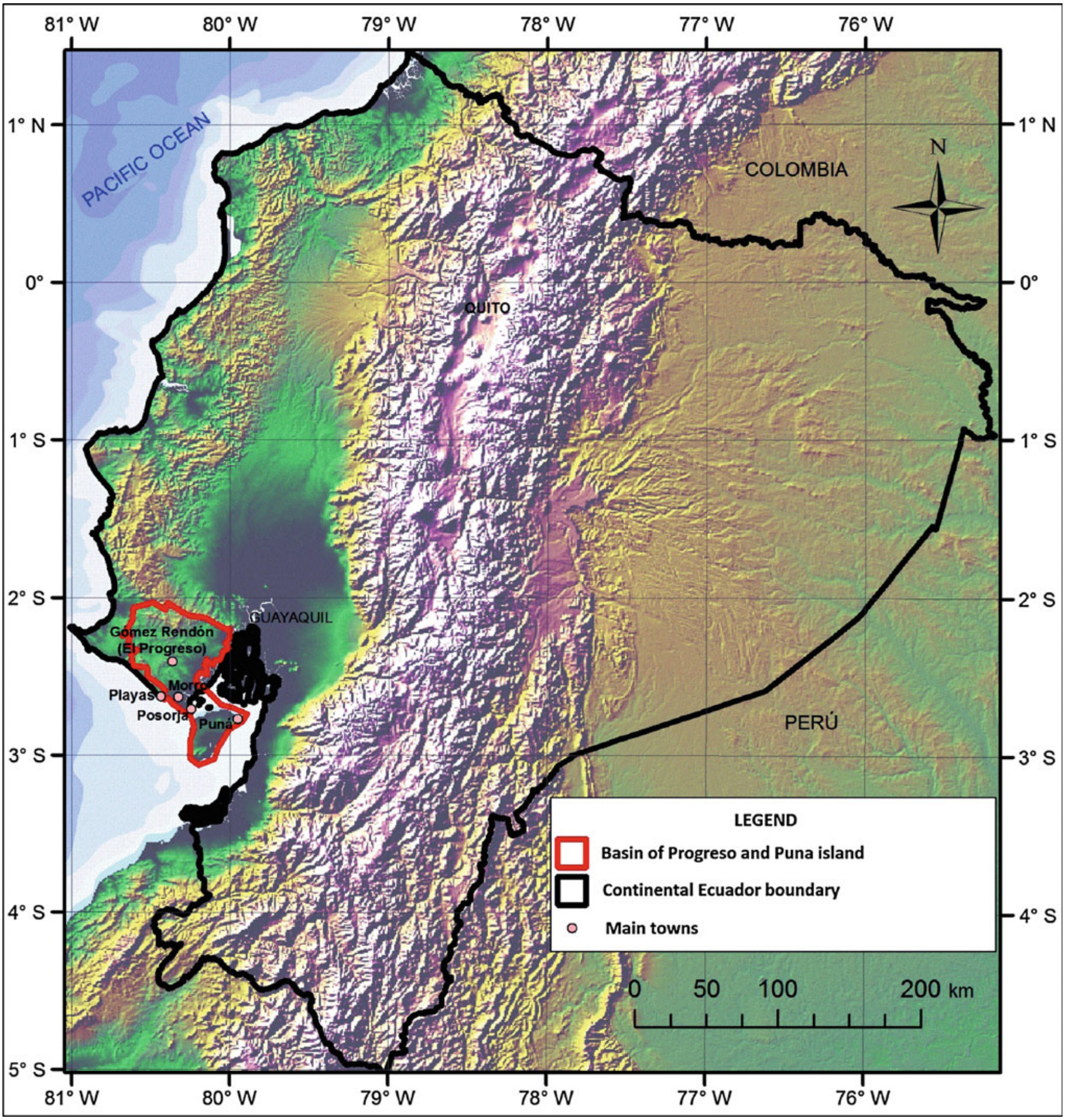

Fig. 2.38 Location of El Progreso Basin in relation to continental Ecuador (adapted from Winckell and Zebrowski 1997)

the presence of feldspars and micaceous primary rocks; and (c) Relief, soils are younger as more rugged is the relief because these areas are exposed to constant erosion (MAG and ORSTOM 1978; Mejía 1997).

Historically, El Progreso basin, also known as Gómez Rendón basin, has not been an area of significant agricultural exploitation due to climate constraints, particularly low rainfall. Common food crops like corn and peanuts were grown around the villages, and extensive livestock, especially goats, used the areas of natural vegetation for grazing purposes (Winckell and Zebrowski 1997). However, with the building of the hydraulic structure Chongón–San Vicente to transfer water to this dry area, associated small farmers are producing crops like corn, melon, watermelon, beans, and pepper on areas >4000 ha (MAGAP 2014). This unit is divided into three major areas: (a) low reliefs; (b) high reliefs; and (c) large dispersed glacis.

2.9.1 Low Reliefs

This is a zone of monotonous to gently wavy plains reliefs with wide slightly marked round plateaus sitting over clayey silty and clayey materials which formed soils classified as Vertisols (MAG and ORSTOM 1978; Winckell and Zebrowski 1997).

The modal profile of this soil, classified as Aridic Haplusterts (Soil Survey Staff 2006) (Fig. 2.39; Table 2.29), is characterized by cracks, slickensides, and high 2:1 clay content. The effective depth is only 35 cm. The pH is slightly <7.0 in the first horizon, but increases with depth. The presence of gypsum in the profile is inherited from the original parent materials (IEE 2015; MAG and ORSTOM 1978; Mejía 1997; Winckell et al. 1997).

These are fertile soils, but the lack of water has been the major constraint for agriculture which can be developed with the use of irrigation (Mejía 1997). Currently, the availability of water delivered by the Chongón–San Vicente hydraulic structure has allowed the use of this zone with high-production agriculture.

2.9.2 High Reliefs

The high reliefs zone was constituted over sandstones and conglomerates with altitudes not exceeding 275 m o.s.l. (Winckell and Zebrowski 1997). Soils are poorly developed, since the erosion processes are superior to the pedogenic processes and, therefore, they are characterized by a shallow profile which leaves little space for root development as observed in the modal profile presented in Fig. 2.40 and Table 2.30. This soil, classified as Lithic Ustorthents (Soil Survey Staff 2006), has slightly weathered rock strata within the first 50 cm of the profile. In all horizons, there is medium

Fig. 2.39 Profile of a soil classified as Aridic Haplusterts (left), located at El Ayalán, El Morro, Guayas, with a the following horizon sequence: A/CAy/Cy over an undulating relief (slope < 12%). The site is at a depopulated dry area (right) (IEE 2015)

Table 2.29 Profile characteristics of a soil classified as Aridic Haplusterts (IEE 2015)

Horizons	Depth (cm)	Description
A	0–35	Very dark gray (10YR 3/1) dry color, very dark gray (2.5Y 3/1) moist color, clayey loam texture, subangular prismatic structure, presence of coarse fragments of gravel, pH 6.4, organic matter 0.4%, CEC 37 cmol kg^{-1}, base saturation 98.1%
CAy	35–75	Clear yellowish brown (2.5Y 6/3) main moist color, light olive brown (2.5Y 5/6) secondary moist color, clayey texture, massive structure, presence of coarse fragments of gravel
Cy	75–85	Light olive brown (2.5Y 5/4) moist color, clayey texture, massive structure, presence of gypsum crystals

Fig. 2.40 Profile of a soil classified as Lithic Ustorthents (left) with the following horizon sequence: Ak/Crk1/Crk2/R, located at Pampas de Calicante, Santa Elena. The site is located in a medium wavy undulating relief (right) (IEE 2015)

Table 2.30 Profile characteristics of a soil classified as Lithic Ustorthents (IEE 2015)

Horizons	Depth (cm)	Description
Ak	0–5	Light olive brown (2.5Y 5/4) dry color, light olive brown (2.5Y 5/4) moist color, loamy texture, angular blocky structure, moderate reaction to HCl, abundant coarse fragments of fine gravel, many coatings of calcium carbonate, pH 8.5, organic matter 0.3%, CEC 29 cmol kg^{-1}, base saturation 97.2%
Crk1	5–10	Light olive brown (2.5Y 5/4) main dry color, yellowish brown (10YR 5/6) secondary dry color; light olive brown (2.5Y 5/4) main moist color, yellowish brown (10YR 5/6) secondary moist color, silty clay texture, massive structure, abundant coarse gravel fragments, moderate reaction to HCl, powdery lime, many coatings of calcium carbonate
Crk2	10–45	Pale yellow (2.5Y 7/3) dry color, light olive brown (2.5Y 5/4) moist color, loamy sand texture, massive structure, dominant presence of coarse fragments of coarse gravel, strong reaction to HCl, powdery lime, few calcium carbonate coatings
R	45+	Rock

to strong reaction to HCl due to the presence of calcium carbonate (MIDENA et al. 2012a). These soils with a shallow rocky horizon are located on steep slopes susceptible to erosion; for these reasons, these soils are not used for agriculture.

2.9.3 Large Dispersed Glacis

This zone corresponds to very dissected glacis located mainly around the large Chanduy–Playas hill, site that presents a fairly regular and continuous crown which progressively descends from around 100 m o.s.l. down to the point it gets in contact with Low Reliefs. These glacis come from scattered colluvial-alluvial materials on which stony fersiallitic soils have developed over sandy-clayey reddish matrix having a strong secondary ferruginous cementation that should have been developed in different weather conditions that those prevalent today, conditions which are not conductive for movement and crystallization of the metal oxides (MAG and ORSTOM 1978; Winckell and Zebrowski 1997).

The representative profile of the soils of this zone is presented in Fig. 2.41 and Table 2.31. This soil is classified as Arenic Paleargids (Soil Survey Staff 2006) and is considered a Paleosol because its current characteristics do not

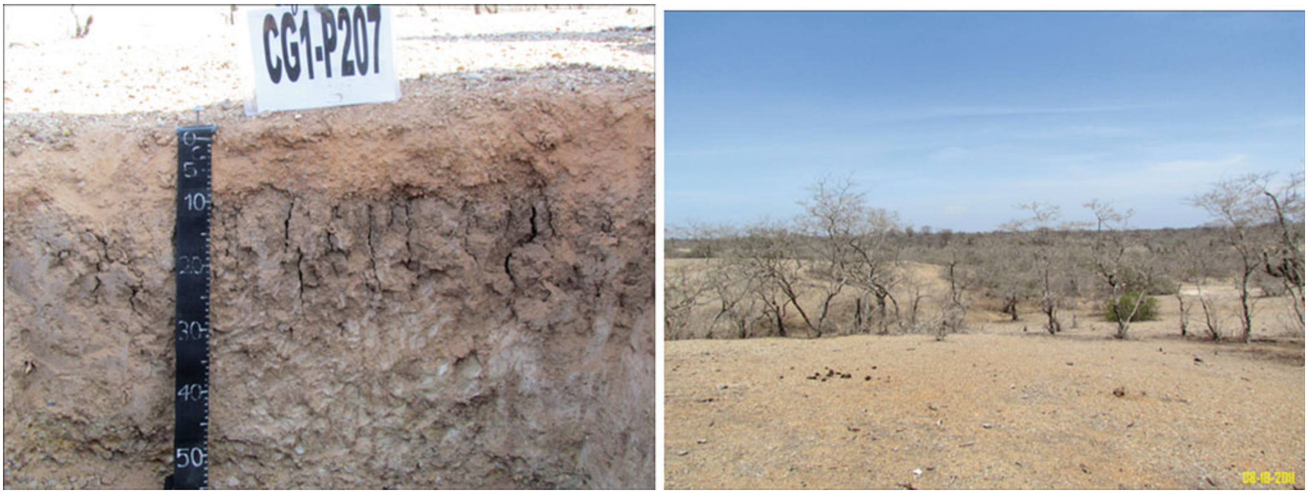

Fig. 2.41 Profile of a soil classified as Arenic Paleargids (left), located at Cerro El Morro, Guayas with the following horizon sequence: A/Bt/C. The site at a dispersed glacis landscape (right) has surface gravel sandstone and cherts (IEE 2015)

Table 2.31 Characteristics of a soil profile classified as Arenic Paleargids (IEE 2015)

Horizons	Depth (cm)	Description
A	0–10	Yellowish red (5YR 5/6) main dry color, pale brown (10YR 6/3) secondary dry color, reddish brown (5YR 4/4) main moist color, brown (10YR 5/3) secondary moist color, sandy loam texture, subangular blocky structure, many coarse gravel fragments, pH 5.1, organic matter 1%, CEC 9.0 cmol kg^{-1}, base saturation 90%
Bt	10–25	Brown (10YR 5/3) dry color, pale brown (10YR 6/3) moist color, sandy clay loam texture, prismatic structure, many coarse gravel fragments, pH 5.5, organic matter 0.4%, CEC 21 cmol kg^{-1}, base saturation 94.4%
C1	25–45	Pale brown (10YR 6/3) main dry color, brown (10YR 5/3) secondary dry color, very pale brown (10YR 7/3) main moist color, light gray (10YR 7/2) secondary moist color, sandy loam texture, massive structure, with coarse gravel fragments
C2	45–60	Pale yellow (2.5Y 8/4) dry color, pale yellow (2.5Y 7/3) moist color, loamy sand texture, massive structure, many coarse gravel fragments

correspond to the present-day climate. The effective depth is only 10 cm. According to the weighted average of the first two horizons, there is a medium level of exchangeable acidity (1.23 cmol kg^{-1}), low organic matter (0.64%), medium CIC (16.2 cmol kg^{-1}), and a high percentage base saturation (92.6%) (IEE 2015). Agricultural production is almost impossible in these soils due to the very dry climate and the presence of abundant coarse gravel (2–2.5 cm) on the surface which prevents mechanization.

2.10 Chongón Colonche Mountain Range

The Chongón Colonche mountain range, with an arch structure that extends from El Membrillal to Guayaquil (Fig. 2.42), is the most important and imposing massif of the coastal plain. The highest point reaches an altitude of 830 m o.s.l. The highest reliefs (dissected massifs) are sited over volcanic and volcano-sedimentary outcrops, while monoclines reliefs, more or less upright, developed over sedimentary strata associated with steep and highly dissected areas. This explains the marked asymmetry of this cordillera; the southern flank is quite dissected and has a steep slope, while the northeast side has a succession of gently sloping monocline reliefs (Winckell and Zebrowski 1997).

The altitudinal gradient strongly influences the climate of this unit. The annual rainfall in the lowlands is <500 mm (10–12 dry months); while in the highlands rainfall is around 1000 mm (4–8 dry months). There is also a strong contrast between the two ends of the cordillera; in northern horn, closer to the seashore, conditions are drier (400 mm annual rainfall), while in the southern horn, precipitation is close to 1000 mm. The zone has an average annual temperature of 25 °C, with a difference of 3 °C among extreme monthly mean temperatures (Winckell and Zebrowski 1997).

There is no significant agricultural production in this unit mainly due to steep reliefs, compact shaping, the presence of shallow soils, and severe drought conditions. Dry zones are

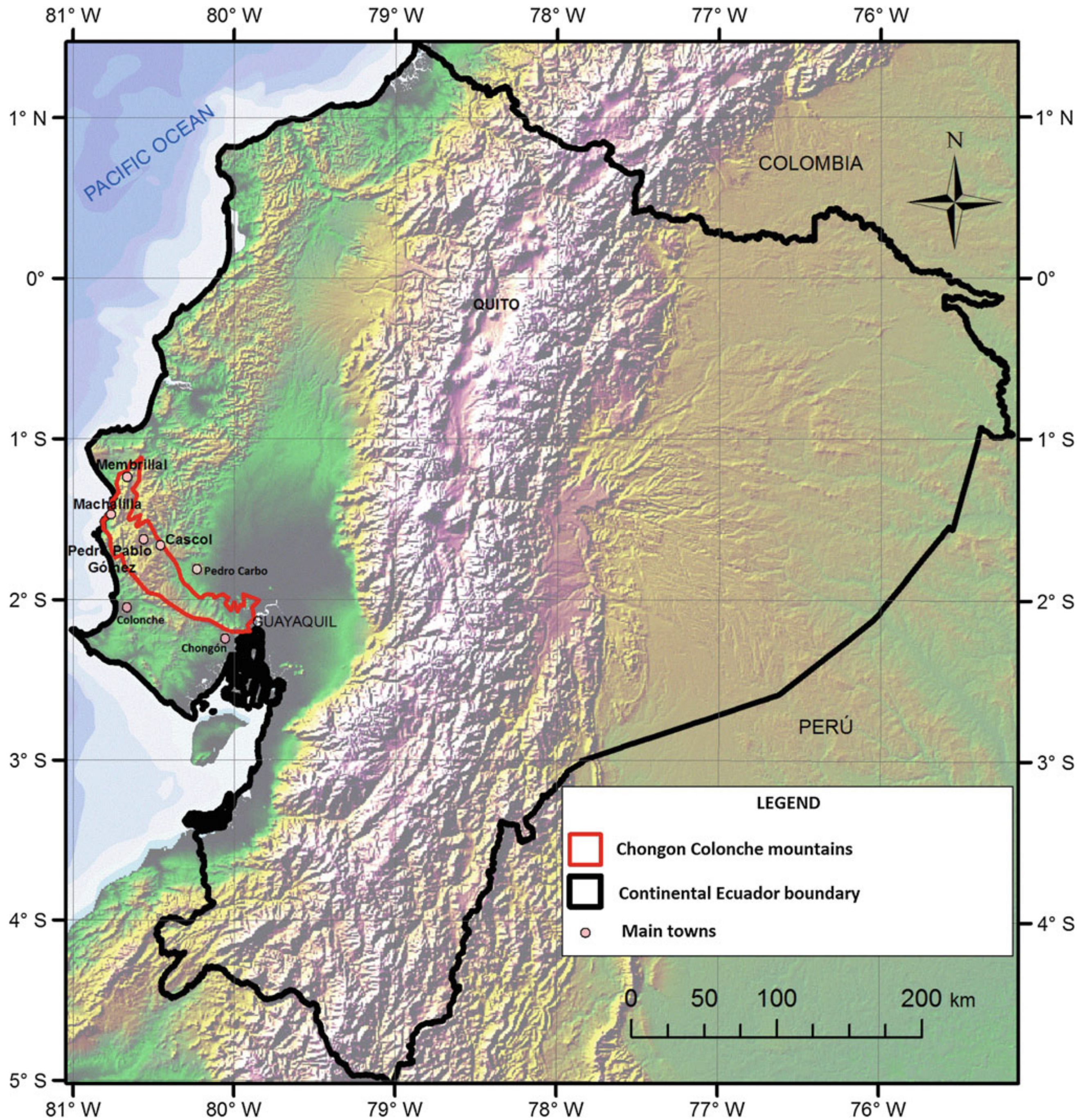

Fig. 2.42 Location of the Chongón Colonche mountain range with respect to continental Ecuador (adapted from Winckell and Zebrowski 1997)

used for itinerant cattle, goats, and sheep grazing. The highest and more humid areas are used for marginal citrus and coffee production. Agricultural activity on the flat and moderately shaped areas runs around crops such as coffee, banana, cocoa, and citrus, in many cases associated with cattle production (Winckell and Zebrowski 1997). However, more intense production of cocoa and coffee, through communal farmers association, has developed in this zone (ACBIO 2012; Bonifaz et al. 2004).

This diversity of reliefs and the particular arrangement of the different landscapes have shaped four major sets of conditions for soil development in this unit: (a) shallow reliefs, usually on rock; (b) high reliefs; (c) low reliefs; and (d) alluvial environments.

2.10.1 Shallow Reliefs with Rock Outcroppings

The soils in this zone were developed over ancient volcanic rocks (basic lavas, tuffs, breccias) which reappeared as a consequence of major tectonic movements that caused significant flaws in the relief at the heart of the cordillera. These rocks have high resistance to weathering, and are located in dry and very dry areas; for these reasons, only shallow alterations were developed forming clayey–stony soils with numerous boulder outcroppings on the surface (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997).

A characteristic profile belongs to a soil classified as Lithic Haplusterts (Soil Survey Staff 2006) which is shown in Fig. 2.43 and Table 2.32. The soil is located at an area with general 40–70% slope with Ustic and isohyperthermic moisture and soil temperature regimes, respectively. Morphologically, the profile has the following horizon sequence: A/AC/R. The surface texture is clayey loam with the presence of bedrock at 39 cm down the surface. The soil is characterized by deep cracks and slickensides related to the high content of 2:1 clay (montmorillonite) (IEE 2015).

2.10.2 High Reliefs

These are the most impressive and highest reliefs of the cordillera, derived from a sedimentary-volcanic sandstone complex, graywacke, and interbedded siliceous facies of lava and pillow lava (Cayo formation), ending at the top with a series of silicified rocks and cherts (Guayaquil formation). The central massifs, having the highest points of the cordillera (between 500 and 800 m o.s.l.), are characterized by large rectilinear flanks, steep to very steep slopes (>70%) at the north, while the full southwestern flank consists of vigorous reliefs with altitudes rising from 200 to 830 m o.s.l. These reliefs are the mountain front which blocks atmospheric circulation causing orographic precipitations that have altered the rock forming soils with mollic

Fig. 2.43 Profile of a soil profile classified as Lithic Haplusterts, located at Estero Verde, Isidro Ayora, Guayas (IEE 2015)

characteristics adjoining rocky and stony outcroppings (Winckell and Zebrowski 1997; Zebrowski and Sourdat 1997). Due to the described climatic conditions, the modal profile of this zone corresponds to a soil classified as Entic Hapludolls (Soil Survey Staff 2006) (Fig. 2.44; Table 2.33). This shallow soil, located on a steep slope, presents the following horizon sequence: Ap/A/BC/C/Cr (IEE 2015).

2.10.3 Low Reliefs

The reliefs are made of very soft hills with relative gradient from 15 to 25 m, formed from more or less cemented siltstone and limonite, extending in a halo of reliefs from 40 to 80 m o.s.l. in the site adjoin the alluvial plain and then gradually rising up to 80–100 m o.s.l. north of Pedro Carbo

Table 2.32 Profile characteristics of a soil classified as Lithic Haplusterts (IEE 2015)

Horizons	Depth (cm)	Description
A	0–28	Very dark gray (2.5Y 3/1) dry color, very dark gray (10YR 3/1) with red yellowish mottling (5YR 5/8) moist color, clayey loam texture, angular blocky structure, abundant coarse fragments of gravel, pH 6.6, organic matter 3.5%, CEC 37.0 cmol kg^{-1}, base saturation 94.1%
AC	28–39	Very dark grayish brown (10YR 3/2) dry color, dark reddish brown mottling (5YR 3/4) moist color, clayey texture, angular blocky structure, many coarse gravel fragments, pH 6.6, organic matter 0.7%, CEC 47.0 cmol kg^{-1}, base saturation 79.2%
R	29–60+	Rock (lutite)

Fig. 2.44 Profile of a soil classified as Entic Hapludolls (left) located at Río Blanco, Puerto Lopez, Manabí. The site shows a high relief with steep slopes (right) (IEE 2015)

Table 2.33 Profile characteristics of a soil classified as Entic Hapludolls (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–10	Very dark grayish brown (10YR 3/2) moist color, loamy texture, granular structure, pH 6.9, organic matter 2.9%, CEC 56 cmol kg^{-1}, base saturation 97.1%
A	10–35	Brown (10YR 4/3) dry color, very dark grayish brown (10YR 3/2) moist color, loamy texture, angular and subangular blocky structure, pH 6.9, organic matter 2%, CEC of 57 cmol kg^{-1}, base saturation 97.5%
BC	35–50	Main color brown (10YR 4/3) main dry color, dark grayish brown (10YR 4/2) secondary dry color, very dark grayish brown (10YR 3/2) moist color, clayey loam texture, massive to subangular blocky structure, pH 7.1, organic matter 0.6%
C	50–75	Yellowish brown (10YR 5/4) dry color, brown (10YR 4/3) moist color, sandy clay texture, massive structure, common presence of coarse gravel fragments
Cr	75–115	Light olive brown (2.5Y 5/6) main dry color, light olive brown (2.5Y 5/4) secondary dry color, olive brown (25Y 4/4) main moist color, olive brown (2.5Y 4/3) secondary moist color, sandy clay texture, massive structure

Fig. 2.45 Profile of a soil classified as Typic Haplusterts (left), located at La Providencia, Pedro Carbo, Guayas, in low hill relief (slope <12%) (right) (IEE 2015)

and 200 m o.s.l. at Cascol. These landscapes of depressed hills and ondulating landscapes, located beneath the Tertiary sedimentary reliefs of sandy slopes and conglomerates of the cordillera, have convex–concave smooth flanks and wide flat recessed tops with slopes ranging from 12 to 25%. Rock alterations on these soft monotonous reliefs with a relatively dry climate have allowed the development of clayey to silty clay soils of moderate depth (IEE 2015). The modal profile is from a soil classified as Typic Haplusterts (Soil Survey Staff 2006) (Fig. 2.45; Table 2.34), developed in an Ustic moisture and isohyperthermic temperature regimes. The horizon sequence is as follows: A1/A2/AC/C (IEE 2015).

Table 2.34 Profile characteristics of a soil classified as Typic Haplusterts (IEE 2015)

Horizons	Depth (cm)	Description
Ap	0–19	Gray (2.5Y 5/1) dry color, dark gray (10YR 4/1) with yellowish red mottling (5YR 5/8) moist color, sandy-clayey loam texture, angular blocky structure, coarse gravel fragments, pH 6.1, organic matter content 0.3%, CEC 24 cmol kg^{-1}, base saturation 96.8%
A	19–42	Gray (10YR 5/1) dry color, very dark gray (2.5Y 3/1) with yellowish brown mottling (10YR 5/8) moist color, sandy-clayey loam texture, angular blocky structure, many coarse gravel fragments, pH 6.2, organic matter 0.4%, CEC 27 cmol kg^{-1}, base saturation 95.8%
AC	42–61	Gray (7.5YR 5/1) dry color, brownish yellow (10YR 6/6) moist color, sandy-clayey loam texture, massive to angular blocky structure, pH 6.2, organic matter 0.7%, CEC 25 cmol kg^{-1}, base saturation 95.4%
C	61–95+	Light yellowish brown (2.5Y 6/4) moist color, sandy-clayey texture, massive structure

Fig. 2.46 Profile of a soil classified as Vertic Ustifluvents, located at El Paraiso, Pedro Carbo, Guayas (IEE 2015)

2.10.4 Alluvial Environments

The alluvial areas correspond to the fluvial valleys with complexes of terraces (low, medium, and high), located mainly between the bottom of the cordillera and the contact with the recent alluvial plain southeast of Pedro Carbo. Soils from this area have variable texture, usually silty upstream, and more clayey downstream, utilized for pasture, plantain, maize, and cassava, but later used for cocoa and coffee cultivation by the farmer communities of the region. A modal profile belongs to a soil classified as Vertic Ustifluvents (Soil Survey Staff 2006) (Fig. 2.46; Table 2.35), located at a medium terrace of alluvial deposits with slopes from 2 to 5%. This soil has Ustic and isohyperthermic moisture and temperature regimes, respectively. Morphologically, this soil presents a profile with the following horizon sequence: A/C1/2C2/2C3/3C4 (IEE 2015).

Table 2.35 Profile characteristics of a soil classified as Vertic Ustifluvents (IEE 2015)

Horizons	Depth (cm)	Description
A	0–43	Dark gray (10YR 4/1) dry color, black (10YR 2/1) moist color, clayey loam texture, subangular blocky structure, pH 7.3, organic matter 2.5%, CEC 28 cmol kg^{-1}, base saturation 95.3%
C1	43–78	Light olive brown (2.5Y 5/4) moist color, sandy loam texture, massive structure, pH 7.6, organic matter 0.7%
2C2	78–95	Olive brown (2.5Y 4/4) main moist color, very dark gray (2.5Y 3/1) secondary moist color, loamy texture, pH 7.3, organic matter 1%
2C3	95–107	Very dark gray (2.5Y 3/1) moist color, light olive brown (2.5Y 5/4) secondary moist color, clayey loam texture, pH 7.6, organic matter 0.9%
3C4	107–145+	Light yellowish brown (2.5Y 6/3) moist color, sandy loam texture, massive structure, pH 7.3, organic matter 0.3%

References

Aalto KR, Miller Iii W (1999) Sedimentology of the Pliocene Upper Onzole Formation, an inner-trench slope succession in northwestern Ecuador. J S Am Earth Sci 12(1):69–85

ACBIO (2012) Plan de acción del biocorredor Chongón Colonche. Biocorredores para el Buen Vivir. FIDES, SGP, GEF, UNDP, Guayaquil, Ecuador

Bonifaz C, Elao R, Santos M, Avilés J, Cornejo X (2004) Plan general de manejo del bosque protector de la cordillera Chongón Colonche. Universidad de Guayaquil, Guayaquil, Ecuador

CLIRSEN, SENACYT, MAGAP, SIGAGRO (2009a) Memoria técnica de suelos del cantón Colimes. Proyecto: Generación de geoinformación para la gestión del territorio y valoración de tierras rurales en la cuenca del río Guayas escala 1: 25 000. CLIRSEN, Quito, Ecuador

CLIRSEN, SENACYT, SENPLADES, MAGAP, SIGAGRO (2009b) Memoria técnica de la geopedología del cantón Naranjito. Proyecto: Generación de geoinformación para la gestión del territorio y valoración de tierras rurales en la cuenca del río Guayas escala 1: 25 000. CLIRSEN, Quito, Ecuador

CLIRSEN, SENACYT, SENPLADES, MAGAP, SIGAGRO (2009c) Memoria técnica de suelos del cantón Samborondón. Proyecto: Generación de geoinformación para la gestión del territorio y valoración de tierras rurales en la cuenca del río Guayas escala 1: 25 000. CLIRSEN, Quito, Ecuador

CLIRSEN, SENACYT, SENPLADES, MAGAP, SIGAGRO (2009d) Memoria técnica de suelos del cantón Vinces. Proyecto: Generación de geoinformación para la gestión del territorio y valoración de tierras rurales en la cuenca del río Guayas escala 1: 25 000. CLIRSEN, Quito, Ecuador

CLIRSEN, SENPLADES, MAGAP, INIGEMM (2011a) Memoria técnica de geopedología del cantón Montecristi. Proyecto: Generación de geoinformación para la gestión del territorio a nivel nacional escala 1: 25 000. CLIRSEN, Quito, Ecuador

CLIRSEN, SENPLADES, MAGAP, INIGEMM (2012a) Memoria técnica de la geopedología del cantón Santa Ana. Proyecto: Generación de geoinformación para la gestión del territorio a nivel nacional escala 1: 25 000. CLIRSEN, Quito, Ecuador

Collot J-Y, Michaud F, Alvarado A, Marcaillou B, Sosson M, Ratzov G, Migeon S, Calahorrano A, Pazmino A (2009) Visión general de la morfología submarina del margen convergente de Ecuador-Sur de Colombia: implicaciones sobre la transferencia de masa y la edad de la subducción de la Cordillera de Carnegie. In: Comisión Nacional del Derecho del Mar (CNDM) (ed) Geología y geofísica marina y terrestre del Ecuador desde la costa continental hasta las islas Galápagos. CNDM-IRD-INOCAR, Guayaquil, Ecuador

Huttel C (1997) Las grandes regiones climáticas y sus formaciones vegetales naturales. In: Winckell A, Marocco R, Winter T et al (eds) Paisajes naturales del Ecuador: las condiciones generales del medio natural. CEDIG - IPGH - IRD - IGM, Quito

Huttel C, Zebronski C, Gondard P, Bourliaud J (1999) Paisajes agrarios de Ecuador., vol V. Geografía Básica del Ecuador. Instituto Panamericano de Geografía e Historia, Quito, Ecuador

IEE (2012a) Geovisualizador Instituto Espacial Ecuatoriano. Mosaico de Geopedología 1:25 000. IEE. http://www.institutoespacial.gob.ec/geoportal/601-2/. Accessed 18 de diciembre 2014

IEE (2012b) Geovisualizador Instituto Espacial Ecuatoriano. Mosaico de Uso de la tierra 1:25 000. IEE. http://www.institutoespacial.gob.ec/geoportal/601-2/. Accessed 18 de diciembre 2014

IEE (2015) Perfiles de suelos de Ecuador. IEE. http://www.institutoespacial.gob.ec/geoportal/perfiles-de-suelos/. Accessed 10 de Octubre 2015

INEC (2013) Encuesta de superficie y producción agropecuaria continua Ecuador 2013. Dirección de Estadísticas Agropecuarias y Ambientales, INEC, Quito, Ecuador

Lasso L, Cruz G, Haro R (2010) Zonificación agroecológica de tres cultivos estratégicos: maíz (*Zea mays* L.), arroz (*Oryza sativa* L.) y caña de azúcar (*Saccharum oficinarum* L.) en tres cantones de la cuenca baja del río Guayas. Paper presented at the XII Congreso Ecuatoriano de la Ciencia del Suelo: El suelo como factor de mitigación del cambio climático, Santo Domingo, Ecuador

León J (2010) Manual de geografia del Ecuador. Universidad Andina Simón Bolívar, sede Ecuador - Corporación Editora Nacional, Quito, Ecuador

MAG, ORSTOM (1978) Inventario catográfico de la Costa ecuatoriana. MAG-PRONAREG, Quito, Ecuador

MAGAP (2014) Proyecto PIDAASSE. MAGAP. http://www.agricultura.gob.ec/pidaasse/. Accessed 5 de febrero 2015

Mejía L (1997) Suelos del Ecuador: Reconocimento general en base a su capacidad-fertilidad y mapa general de clasificación por Capacidad-Fertilidad de los suelos del Ecuador: Una interpretación básica sobre las características de los suelos del Ecuador Fundación Forestal Juan Manuel Durini; Instituto de la Potasa y el Fósforo (INPOFOS) - Instituto Geográfico Militar (IGM) - Instituto panamericano de Geografía e Historia (IPGH) - Sociedad Ecuatoriana de la Ciencia del Suelo (SECS), Quito, Ecuador

MIDENA, IEE, SEMPLADES, MAGAP, INIGEMM (2012a) Memoria técnica geopedológica del cantón Santa Elena. Proyecto: Generación de geoinformación para la gestión del territorio a nivel nacional escala 1: 25 000. IEE, Quito, Ecuador

MIDENA, IEE, SENPLADES, MAGAP (2013b) Memoria técnica geopedológica del cantón Valencia. Proyecto: Generación de geoinformación para la gestión del territorio a nivel nacional escala 1: 25 000. IEE, Quito, Ecuador

Ministerio de Transporte y Obras Públicas - INECA (2012) Estudio de ingeniería de la carretera Santo Domingo-Esmeraldas y la estructuración jurídica, técnica y económico-financiera. Geología y Geotecnia, vol 3. Ministerio de Transporte y Obras Públicas, Quito, Ecuador

Montúfar C, Yerovi F, Sánchez D, Lagos E (2010) Caracterización de la dinámica ambiental, a escala de tiempo humano, en el cantón milagro mediante el uso de herramientas geoespaciales. Paper presented at the Paper presented at the XII Congreso Ecuatoriano de la Ciencia del Suelo: El suelo como factor de mitigación del cambio climático, Santo Domingo, Ecuador

Moreno J (2001) Zonificación agroecológica de la cuenca baja del río Guayas-Ecuador con utilización de la Teledetección. Universidad Central del Ecuador, Quito, Ecuador

Pacheco R (2009) El Ecuador: Recursos naturales agrícolas y del medio ambiente. Imprenta Colón, Quito

PRONAREG-ORSTOM (1982) Inventario cartográfico de la Costa ecuatoriana: mapas de aptitudes agrícolas, escala 1: 200 000. Ministerio de Agricultura y Ganadería (MAG), Programa Nacional de Regionalización Agraria (PRONAREG), Office de la Recherche Scientifique et Technique Outre Mer (ORSTOM), Quito, Ecuador

Ramírez MF (2013) Registros de la deformación y del volcanismo en el dominio del antearco ecuatoriano: sedimentología y bioestratigrafía de la formación Borbón. Escuela Superior Politécnica del Litoral, Guayaquil Ecuador

Sevillano G (2010) Levantamiento geopedológico de la cuenca baja del río Guayas-Ecuador con aplicación del enfoque sistémico. Paper presented at the XII Congreso Ecuatoriano de la Ciencia del Suelo: El suelo como factor de mitigación del cambio climático, Santo Domingo, Ecuador

Soil Survey Staff (2006) Keys to soil taxonomy, 10th edn. USDA - NRCS, Washington

Tapia J (2012) Modelización hidrológica de un área experimental en la Cuenca del Río Guayas. Universidad Nacional de la Plata, Cuidad de la Plata, Argentina

Winckell A, Zebrowski C (1997) Los paisajes costeros. In: Winckell A, Zebrowski C, Sourdat M (eds) Los paisajes naturales del Ecuador: Las regiones y paisajes del Ecuador. CEDIG - IPGH - IRD, Quito

Winckell A, Zebrowski C, Sourdat M (1997) Los paisajes naturales del Ecuador, vol IV Las regiones y paisajes del Ecuador. Centro Ecuatoriano de Investigación Geográfica (CEDIG) - IPGH (Sección Ecuador) - IRD (Francia) - IGM, Quito, Ecuador

Zebrowski C, Sourdat M (1997) Los factores de la pedogénesis y los suelos en Ecuador. In: Winckell A, Marocco R, Winter T et al. (eds) Los paisajes naturales del Ecuador, vol Condiciones generales del medio natural. Centro Ecuatoriano de Investigación Geográfica (CEDIG) - IPGH (Sección Ecuador) - ORSTOM (Francia) - IGM, Quito, Ecuador

http://www.springer.com/978-3-319-25317-6

The Soils of Ecuador
Espinosa, J.; Moreno, J.; Bernal, G. (Eds.)
2018, VII, 164 p. 136 illus., 130 illus. in color.,
Hardcover
ISBN: 978-3-319-25317-6