Serra Da Capivara National Park: Ruinform Landscapes on The Parnaiba *Cuesta*

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Demétrio da Silva Mutzenberg, Antonio Carlos de Barros Correa, Bruno de Azevêdo Cavalcanti Tavares, and Daniela Cisneiros

Abstract

Serra da Capivara National Park (SCNP), situated in the south-east corner of the State of Piaui, north-east of Brazil, harbours one of the most expressive sets of ruinform landscapes carved on sandstone. Its geomorphological uniqueness arises from the combination of geological and climatic factors. The area is located next to the edge of the Parnaiba sedimentary basin of Paleozoic age, where it meets a Neoproterozoic fold belt and an Archean craton. SCNP lies in an ecotone between the caatinga and Cerrado biomes. Adding to its geomorphological singularity, the dramatic landscapes of the Park are overlapped by one of the most important prehistorical heritages of South America. Human presence on this remote tract of the Brazilian savannas dates back to the Late Pleistocene and is singled out by the exuberant collection of prehistoric rock painting and engravings. The relief of the SCNP is characterized by steep sandstone cliffs cut through by narrow valleys that form gorges and water gaps. The relief of the Park comprises three geomorphological units: the escarpment, the dip-slope and the longitudinal depression. Whereas along the escarpment one finds the most remarkable landmarks of the Park such as prominent cliffs and rock arches, gorges and canyons along the dip-slope also reveal an impressively dramatic scenery.

Keywords

Parnaiba Basin • Homocline structure • Ruinform relief • North-east of Brazil

23.1 Introduction

Serra da Capivara National Park (SCNP) was created by Federal decree in 1979. It is located in the south-east of the state of Piaui, north-east region of Brazil (Fig. 23.1). The area lies on the westernmost fringes of the caatinga biome, in the transitional zone to the Cerrado biome, thus along the boundary of the semi-arid and subhumid wet/dry tropical climates, constituting a unique biogeographical ecotone. In 1991, the SCNP was inscribed on the UNESCO list of world's natural and cultural heritage.

The SCNP includes a unique group of landforms associated with the geomorphological context of the border of a sedimentary plateau in homocline structure (*cuesta*). This morphostructure was subjected to several uplifts, fracturing and exhumation episodes that helped to shape escarpments, canyons, gorges and water gaps of remarkable beauty (Fig. 23.2), whose oldest evidence of human occupation constitutes one of the largest and most important collections of archaeological sites of South America.

The uniqueness of the early human presence in the area of the SCNP derives from the fact that it dates back to the Late Pleistocene (Guidon and Arnaud 1991; Parenti 2001),

D. da Silva Mutzenberg (✉) · D. Cisneiros
Department of Archaeology, Federal University of Pernambuco, Recife, Brazil
e-mail: demutzen@gmail.com

D. Cisneiros
e-mail: danielacisneiros@yahoo.com.br

A.C. de Barros Correa
Department of Geographical Sciences, Federal University of Pernambuco, Recife, Brazil
e-mail: dbiase2001@terra.com.br

B. de Azevêdo Cavalcanti Tavares
Federal University of Pernambuco, Recife, Brazil
e-mail: brunoactavares@yahoo.com.br

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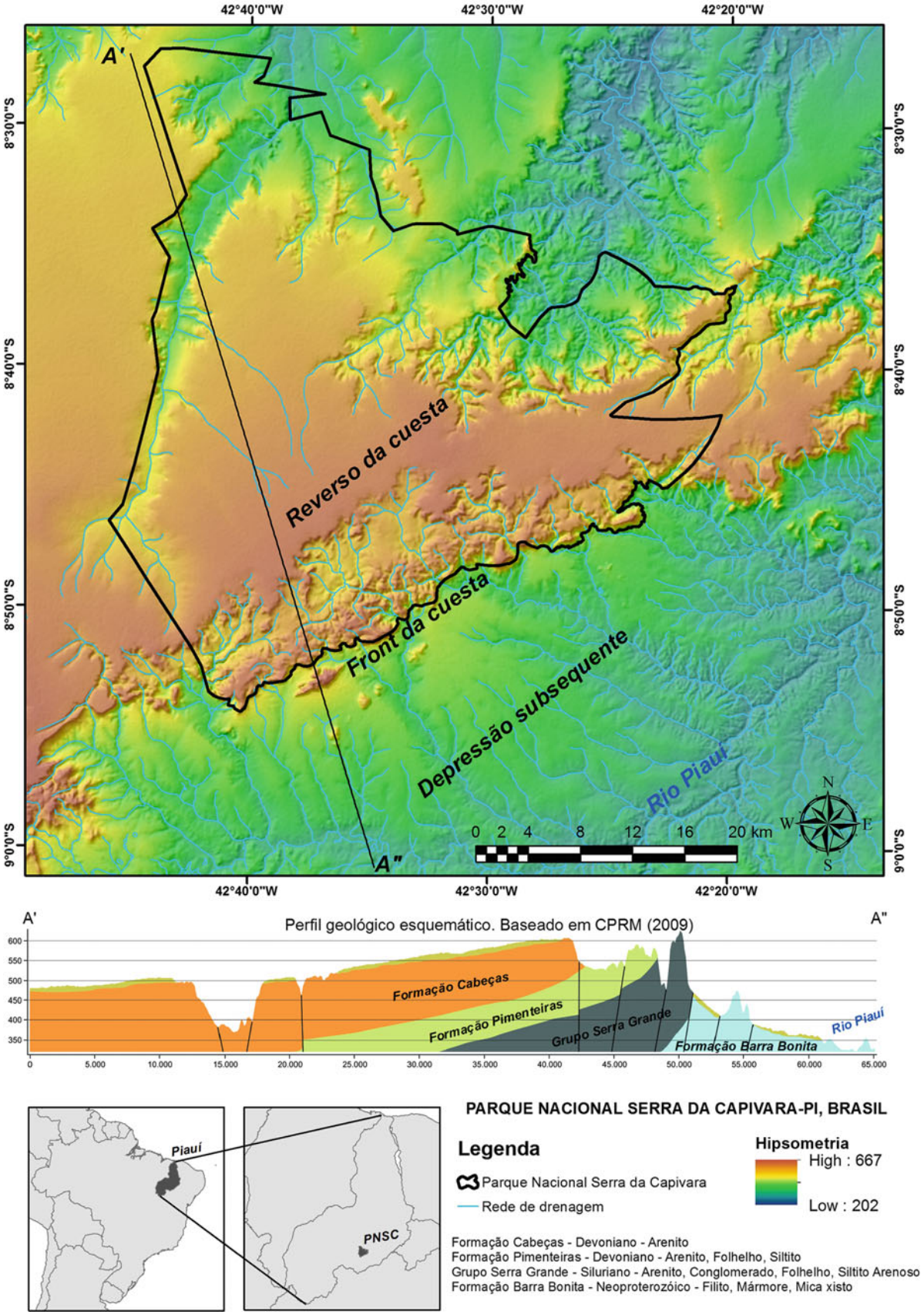

Fig. 23.1 Location of the Serra da Capivara National Park (SCNP), State of Piauí, north-east of Brazil. Shaded relief and schematic geologic transect

Fig. 23.2 Overview of the south-east border of Serra da Capivara National Park (SCNP), Baixão da Esperança site. The area synthetizes the singular landscape domains that integrate the Park. *Photograph* Luiz F.G.L. Katz

thus being one of the oldest in the continent and so confronting some of the current mainstream paradigms regarding the arrival of man in the Americas (Meltzer 2009). The area also stands out for the ubiquitous occurrence of rock paintings and engravings that make up one of the world's largest collections of their kind. The historical occupation of the area was characterized by displacement, extermination and acculturation of indigenous peoples, aiming at the establishment of cattle ranches at the onset of the seventeenth century. Such spatial transformation took place as an economically subsidiary activity to the European colonization process along the eastern coast of the north-east of Brazil, where sugar cane plantations thrived.

Due to the uniqueness of its geographical situation, in the transition between the semi-arid and wet/dry tropical climates where two of Brazil's large biomes merge, and at the junction of three geological provinces, the SCNP exhibits an extreme diversity of geomorphological landscapes. These comprise vast regional planar surfaces, sharp knickpoints along the cliffs, canyonlike entrenched drainages, residual buttes and mesas, as well as small-scale landforms shaped by differential erosion and weathering on different types of sedimentary and crystalline lithology.

23.2 Geology, Structures and Landscape Diversity

The SCNP is situated at the junction of three major continental geological provinces: São Francisco Province, Borborema Province and Parnaíba Province. The oldest of the three, the São Francisco Province, is formed by an Archean craton that integrates the basement of the South American platform (Trompette et al. 1992). This province outcrops to the south of the SCNP and contains mainly high-grade metamorphic rocks such as gneisses and migmatites, shaped into elongated hills in accordance with the axis of N–S-oriented folds.

The Borborema Province consists of a complex core of folded crystalline rocks whose origins date back to the Archean, when the basement suffered an initial tectonic deformation as a response to the Transamazonica Orogeny in the Paleoproterozoic (Mabessone 2002). Longitudinally, the Brasiliano Orogeny, from the Neoproterozoic onwards, affected thoroughly the structural framework of the province, leading to the establishment of shear zones and strike-slip faults of E–W and NE–SW directions. The Brasiliano

Orogeny triggered an intense granitic plutonic activity, regional metamorphism and reworking of older supracrustal belts.

Within the boundaries of the SCNP, the south-west sector of the Borborema Province crops out, marked by the presence of the Riacho do Pontal fold belt. This structure overlaps the São Francisco craton to the south and underlies the sedimentary deposits of the Parnaíba Basin to the west. In the area, it is still possible to identify evidence of the compressive ductile deformation that forced the Riacho do Pontal fold belt over the much older structures of the São Francisco craton. Locally, these structures were cut through by granitic plutons resulting from the Brasiliano Orogeny.

The Parnaiba Province comprises four sedimentary basins, one of them being the Parnaíba Basin, atop of which most of the SCNP lies, right next to the eastern and south-eastern borders of the basin. This intracratonic basin has a circular to elliptic outline, symmetrical profile and low subsidence rate. Lying above a large continental syneclise which later was subject to uplift, the basin was originally placed along Eo-Paleozoic rifts of NE–SW trend, in structural accordance with the Transbrasiliano lineament that cuts across a large portion of the eastern South American platform (Chamani 2011). Locally, this mega-structure separates the Borborema from the Parnaiba Province, displacing and uplifting the SE border of the basin, in the area of the SCNP. de Góes et al. (1993) believe these rifts were formed during the early breakup of the Gondwana supercontinent in the Eo-Paleozoic, when a vast network of fractures developed, thus creating an original intracratonic depression where the Parnaíba Basin is located. Later, continental rifting process from the Early Jurassic to the Late Cretaceous led to reactivation of Neoproterozoic shear zones. Reactivation of these shear zones, coupled with the opening of the Atlantic Ocean, resulted in the general uplift of the Borborema Province, the São Francisco craton and the Parnaiba Province alike.

In spite of the South America–Africa separation and the uplifting of old faulted structures initiated during the Mesozoic, the current intraplate tectonics is still in operation in several sectors of the Borborema, São Francisco and Parnaíba provinces (Hasui 1990; Saadi 1993). The Cenozoic reactivation of the shear zones played an important role in the dynamics and individualization of geomorphic compartments in the region, defining crystalline highlands, rejuvenated structural massifs and sedimentary plateaus structured on uplifted basins and syneclises (Brown et al. 2000; Bezerra et al. 2008, 2011; Chamani 2011). Within this context, the infilling of the syneclise occurred, with the deposition of five sedimentary sequences, correlated with global tectonic cycles (Soares et al. 1978; de Góes et al. 1992). Structural elements that are present in the basin are also strongly related to fault-line reactivations throughout the Phanerozoic.

In the SCNP, the outcropping rocks are related to Siluro-Devonian deposition and form the basal sequences of the Parnaíba Basin, corresponding to the Serra Grande and Canindé Groups, respectively. The Serra Grande Group comprises the Ipu, Tianguá and Jaicós Formation (da Cunha 1986), whereas the Canindé Group comprises the Itaim, Pimenteiras, Cabeças, Longá and Poti Formations (de Góes and Feijó 1994).

In the Park, Ipu Formation rocks (Serra Grande Group) are, in general, sandstones and conglomerates. The exposure of sedimentary structures along the scarps attests to various high-energy cycles within an alluvial fan system. These deposits have also been interpreted as fluvioglacial fans by Caputo and Lima (1984).

Pimenteiras Formation (Canindé Group) is lithologically represented by a predominance of finely laminated shale (CPRM 2009). Schobbenhaus (1984) suggests that these lithological and sedimentary characteristics point out to an infraneritic to coastal environment.

Cabeças Formation (Canindé Group) overlies the pelitic rocks of Pimenteiras Formation. The rocks of this Formation are predominantly layered and well-stratified sandstones. They are indicators of proximal tidal lobes transiting into tempestites and mudstones in distal sections (Santos and Carvalho 2009). The occurrence of striated rock pavements and faceted cobbles points to glacial influence (Caputo 1984).

Longá Formation (Canindé Group) is largely characterized by a pelitic section of shales interspersed with a package of sandstones and siltstones (de Lima and Leite 1978). The observed sedimentary structures are parallel laminations, cross-stratification, low-angle ondulations and ripple marks. According to de Lima and Leite (1978), the lithological, sedimentary and fossiliferous traits of Longá Formation suggest a regressive depositional environment.

23.3 Remarkable Ruinform Landscapes in a Homocline Structure

The distribution of landforms in the SCNP is directly linked to structural controls upon the hierarchy of geomorphological units. In fact, in the Park, combined lithological, structural and morphoclimatic controls operate at several scales to produce peculiar sets of morphologies. Regionally, the area can be described as the edge of an intracratonic basin with a homocline gently dipping towards NW. Starting with the structural context, it is possible to subdivide the SCNP into three large morphological domains of remarkable scenic appeal: the longitudinal depression, the cuesta escarpment and the dip-slope. Nested on those larger landform units, lithological controls and weathering play an important role in the evolution of smaller-scale landforms such as buttes,

Fig. 23.3 **a** Landform domains of the Parnaiba at the SCNP. *I* Escarpment, *II* dip-slope and *III* longitudinal depression. **b** Pedra Furada. Ruinform morphology developed along the crossing of fracture lines and the sedimentary bedding along an obsequent drainage gorge. *Photographs* Luiz F.G.L. Katz

rock arches, canyons, inselbergs and even karstic microforms (Fig. 23.3).

23.3.1 The Role of Structure

The reactivation of the South American platform since the Late Mesozoic, reinforced by the cyclic events of landform rejuvenation throughout the Cenozoic, emphasized the dipping of the homocline structures along the eastern border of the Parnaíba Basin, close to the deformational stress focal areas. These are located along the main fault and deep shear zones whose kinematic responses resumed during the reactivation of the platform. Thus, a sequence of structural landforms, typical of a reactivated basin edge, was created, with uplifted, tilted and subsided blocks. Within this context, the cuesta main escarpment can be described as a retreating fault scarp. However, at a more detailed scale of observation, the morphology of the escarpment is disrupted by a sequence of half-grabens and horsts that demonstrates the role played by shallow brittle tectonics on the spatial distribution of landforms and their geometry. The action of tectonics promoted uneven uplift of the border of the basin in the area of the SCNP, with a notable inflection of the faulted blocks from NE to SW. Tectonic deformation elevated the contact between the underlying metasediments of Riacho do Pontal fold belt and the basal siliciclasts of Serra Grande Group. In certain areas, such as to the SE of the Park, the uplift of the surrounding metamorphic fold belt has brought the area to elevations similar to those of the summit of the cuesta itself. The activity of normal faults, in shallow brittle regime, favoured the appearance of fault breccias along fault planes, formed between the metasediments and the overlying coarse sandstones of the Basin (Fig. 23.4).

The shear zones and subordinate brittle structures of NE–SW trend provide the limit for the cuesta escarpment, as well as control the entrenchment of the main water course of the region, the Piaui River, thus establishing a longitudinal drainage pattern as well as a local base level that lies up to 60 m below the surrounding pedimented surfaces. Shear zones and fault lines with an N–S and NW–SE trend act as secondary structural elements that command the distribution of the tributary drainage, which is equally adjusted to the prevailing structural controls. The role of the structural trends is particularly relevant in controlling spatial distribution of the obsequent drainage that carves its way through the cuesta main escarpment. The same is valid for the main consequent drainage that runs on the dip-slope of the

Fig. 23.4 **a** Faulted blocks along the escarpment of the cuesta. *I* Tilted block and *II* subsided block. **b** Uplifted geologic contact between the Riacho do Pontal fold belt (*base*) and Paleozoic siliciclastic sediments of the Parnaíba Basin (*top*). Normal fault with fault breccia accumulation along the displacement plane (*right corner*). *Photographs* Luiz F.G.L. Katz

homocline plateau within the area of the SCNP, the Serra Branca Valley (Fig. 23.5).

The geometry of the half-grabens, also tilted to NW, directly influences entrenching and direction of the drainage network. The major drainage lines are adapted to the limits between faulted and fractured blocks, so creating a repetitive pattern of fault-line and flexural slopes. In between the slopes, drainage courses and their corresponding Quaternary floodplain deposits are nested. The organization of the fluvial hierarchy within the drainage basins rigidly obeys the patterns of fracture distribution. As a consequence, headwater catchments are structurally adjusted to fracture planes that intersect the land surface. The low inclination of the summit and dip-slope lead to the evolution of solution microforms (honeycomb weathering), widely spread throughout the area, and scenic values of the rocky interfluves in the vicinities of major slope breaks (Fig. 23.6).

The backwearing of the cuesta escarpment is primarily subordinate to fault and fracture lines of NE–SW trend and, secondarily, to headward erosion promoted by the obsequent drainages, which are also controlled by brittle structures and the sedimentary bedding. Those drainages actively strip the planar stratification of the homocline structure, halting at the more resistant silicified or less pervious layers, thus initiating an exhumation process that creates structural and lithological levels that are very characteristic of low-dipping sedimentary plateaus. Gravitational faults along the major breaks of slopes and cliffs also collaborate to haste the pace of the retreat of the cuesta's escarpment. In certain areas, such as the Pedra Furada water gap, fluvial dissection along structural weakness lines resulted in the development of canyons, narrow gorges and other erosive landforms of great scenic beauty. In fact, the physiognomy of the subvertical rock cliffs that integrate the plateau escarpment, marked by texture, dip and colours of alternating sandstone and coarse conglomerate strata, superimposed on the differential erosion forms, constitutes the principal landmark of SCNP, synthetizing the rugged scenic appeal of this landscape.

The occurrence of residual buttes in front of the main escarpment, and aligned in the same NE–SW direction, reinforces the idea of the action of headward erosion in shaping this major landform, as obsequent rivers worked their way through the less resistant rock strata and more fractured areas (Fig. 23.7).

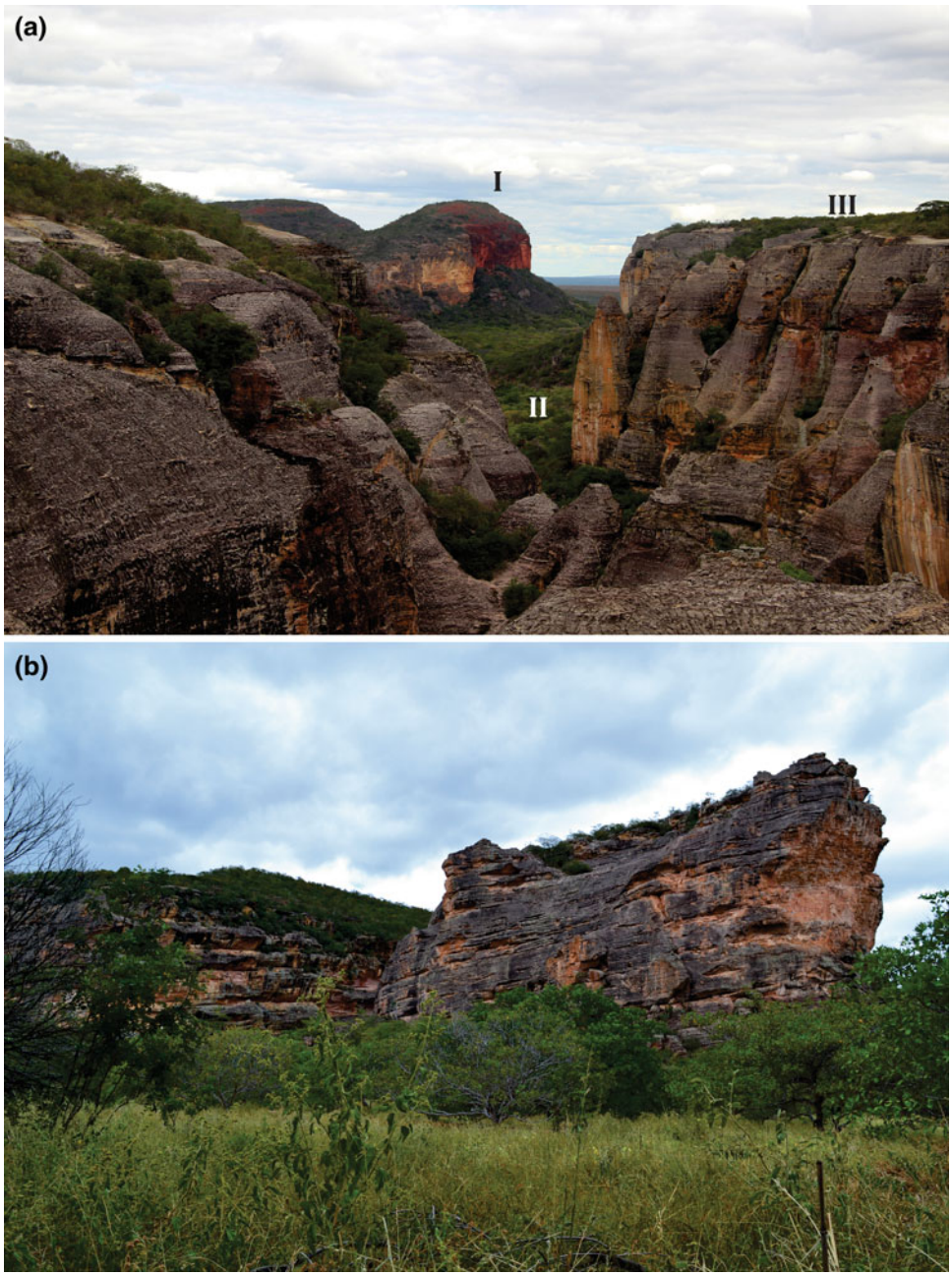

Fig. 23.5 **a** Obsequent drainage controlled by the structure at Baixão das Andorinhas. *I* Cuesta escarpment, *II* drainage axis and *III* subvertical fracture network. **b** Serra Vermelha butte at the cuesta escarpment. North-west dipping layers, to the south-west of SCNP. *Photographs* Luiz F.G.L. Katz

23.3.2 Weathering and Drainage

On the cuesta dip-slope, the predominance of sandstone lithology and the low inclination of the layers towards the Parnaíba Basin depocenter favoured the formation of deep weathering mantles that have evolved into quartz-rich soils. However, above the clay-rich substrate, such as mudstone or siltstone, oxisols and iron duricrusts have evolved. The loose and highly pervious soils explain low drainage density and the conservation of large tablelike interfluves along the dip-slope. Nonetheless, in the areas of intersecting structural lineaments, mostly the NNE–SSW trending with those of NE–SW direction, large topographical hollows have evolved in which soils and sediments have been eroded and the underlying Paleozoic strata exhumed. These processes have collaborated with the opening of entrenched elongated depressions below the top of the dip-slope. Those valleylike landforms display flat shallow bottoms preserved by the underlying impermeable layers. Along the neighbouring slopes, the contact of geological materials of contrasting perviousness facilitates the origin of the exudation line and the appearance of several springs that could have evolved into first-order tributaries by headward erosion. Drainage hierarchy and density depend on the exposure of the

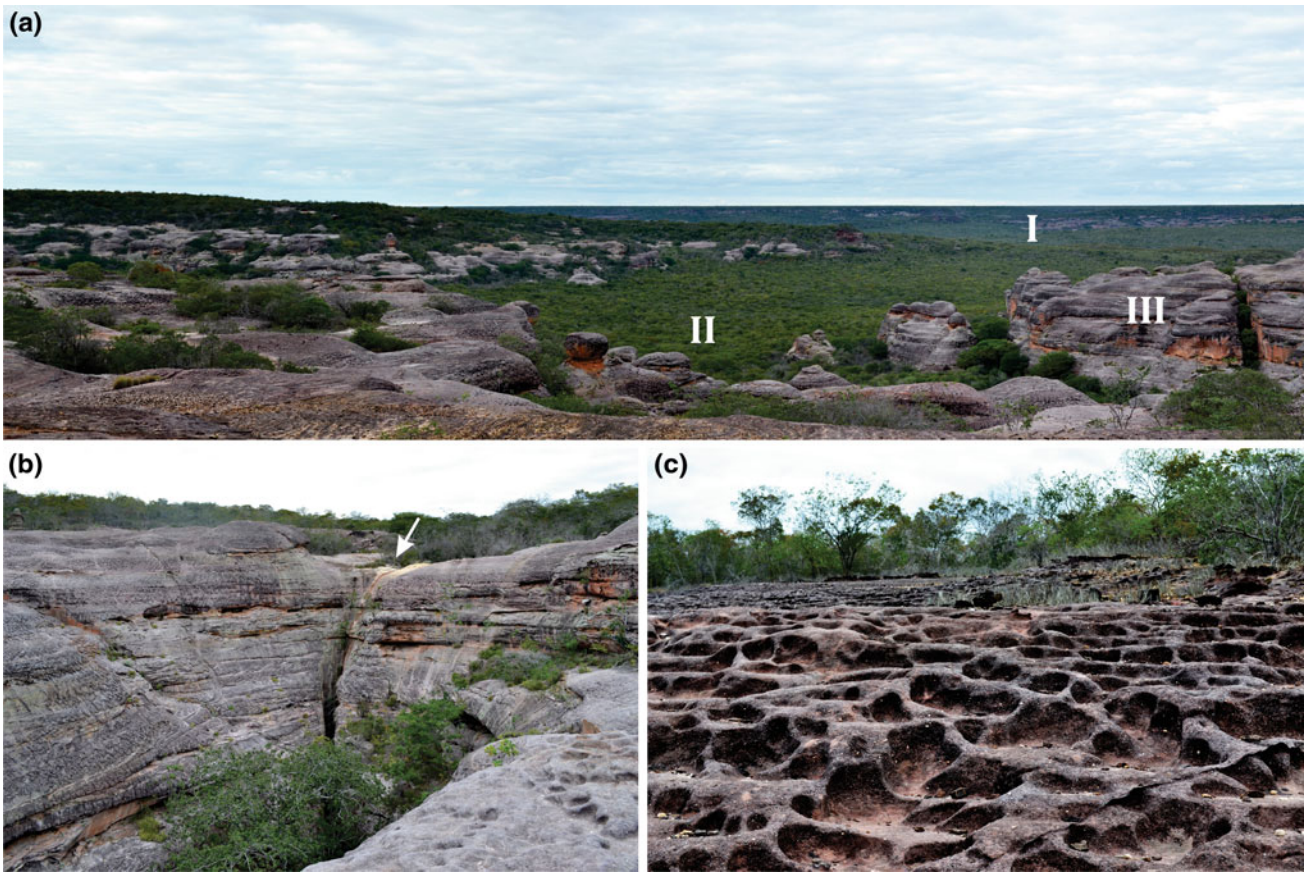

Fig. 23.6 **a** Consequent drainage of Serra Branca, western sector of SCNP. *I* Serra Branca canyon, *II* elevated catchment and *III* fractured blocks. **b** Consequent catchment controlled by fractures. **c** Honeycomb weathering on the rocky summits of Serra Branca Valley. *Photographs* Luiz F.G.L. Katz

underlying exhumed layers, as well as on the uplift of faulted blocks in the vicinity of the cuesta escarpment, accentuating the inclination of the homocline structure that dips towards the basin interior. The striking tectonic control on the summit of the plateau, at the transition area from the face of the escarpment to the dip-slope ramp, generates a landscape of *horsts* and *grabens*, mainly on the south-east border of the SCNP.

The consequent drainage basins on the dip-slope can be split into two distinct groups. Both are strongly controlled by fault-line systems that propagate all the way from the underlying metamorphic basement to the top of the thick sedimentary cover that overlies it. However, lithological differences and base-level control act differently upon the two units, thus leading to the elaboration of distinctive drainage patterns and corresponding dissected landscapes. Along the Serra Branca Valley, drainage is entrenched on subvertical cliffs, forming a straight and elongated canyon that cuts through the sandstones and conglomerates of Cabeças Formation of Devonian age. Unable to actively dissect the side slopes of the canyon, lower-order channels merely concentrate the overland flow into the network of fractures that cuts the valley transversally. In the north-east sector of the Park, the presence of pelitic rocks of Pimenteiras Formation (Devonian) and the occurrence of a large subsided fault block placed between the plateau summit and the regional base level to the east—the floodplain of the Piaui River—have resulted in the origin of a much more dissected landscape and therefore exhibiting a lower degree of fluvial entrenching due to the general lowering of the interfluves. From this difference in structural behaviour and lithological controls, two sets of landscapes arise, displaying varying degrees of scenic interest. In this context, the Serra Branca Valley distinguishes itself as more striking landscape feature as a consequence of deeper entrenchment and steepness of the slopes. The occurrence of gorges and water gaps along the valley contributes to the damming of sandy sediments that are washed away from the slopes, thus generating a flat-bottomed valley, veneered by a continuous sheet of whitish quartz sands.

The regional contact between the uplifted sedimentary basin to the west and the denuded Proterozoic fold belt to the

Fig. 23.7 **a** Obsequent drainage forming a gorge. Pedra Furada water gap, south sector of the SCNP. *I* fractured blocks, *II* valley bottom infilled by alluvium–colluvium fans and *III* strata tilted towards the depocenter of the Parnaíba Basin. **b** Obsequent drainage adapted to a fracture network. Capivara cliff, south sector of SCNP. **c** Residual butte parallel to the cuesta escarpment. Serra Grande Group. Jurubeba Hill, south sector of the SCNP. *Photographs* Luiz F.G.L. Katz

east, under the influence of harsh semi-arid climate, has resulted in two distinct scenarios of Neocenozoic unconsolidated sediment yield. Along the cuesta escarpment, the collapse of rocks of the Serra Grande Group led to accumulation of significant coarse-grained hill slope deposits, talus aprons and colluvial fans. The geographical distribution of steeper slopes and their basal knickpoints provides adequate accumulation space for Quaternary sedimentation derived from the overall erosion of the escarpment. To the east of the basin, lower rates of chemical weathering create a landscape mosaic dominated by pediments, displaying varying degrees of dissection, either mantled by thin residual soils or gravelly desert pavements.

The pedimented surfaces situated to the south-east of the escarpment are dotted with structural landforms, shaped in different rock types and subjected to the deformational regime that induced the rise of the basin edge. These landforms constitute ridgelike inselbergs, related to the outcrops of steeply dipping metamorphic limestone layers of the Riacho do Pontal fold belt. Over these ridges, some karstic features have developed, such as karren and caves. These testify to the occurrence of moister paleoclimates in the region, thus permitting the development of noteworthy limestone solution features.

Dome-shaped isolated inselbergs occur in Neoproterozoic granitic intrusions related to the Brasiliano Orogeny that cut discordantly the fold belts to the south-east of the SCNP. In the outcropping area of the Sobradinho–Remanso Complex (São Francisco craton), lithology is dominated by intrusive rocks that were affected by regional metamorphism during the Transamazonica Orogeny (Paleoproterozoic). These bedrock types do not result in particularly remarkable landforms, albeit elongated hills display a concordant alignment with the axial planes of the Archean folds.

The hierarchic distribution of erosive landforms related to the cuesta retreat has exerted an important control upon the choices and deliberations of early human groups that occupied the landscape of the SCNP. Thus, geomorphology studies complement those aimed at the reconstruction of the archaeological landscape of the area since the beginning of its prehistoric settlement. The antiquity of the peopling of the SCNP escarpment provides evidence that it occurred in synchronicity with the most dramatic paleoclimatic changes of the Late Pleistocene and Holocene that commanded the evolution of hill slope and fluvial accumulation landforms. Climate shifts during the Late Pleistocene and Holocene triggered the origin of landscapes ecologically quite distinct from the contemporary ones. The climatic cycles, with alternating moister and drier spells, some quite unlike the contemporary phase, have certainly influenced not only the operation rate of erosional and depositional processes, but certainly the availability of natural resources and the possibilities of landscape use for the first human dwellers of the area (Fig. 23.8).

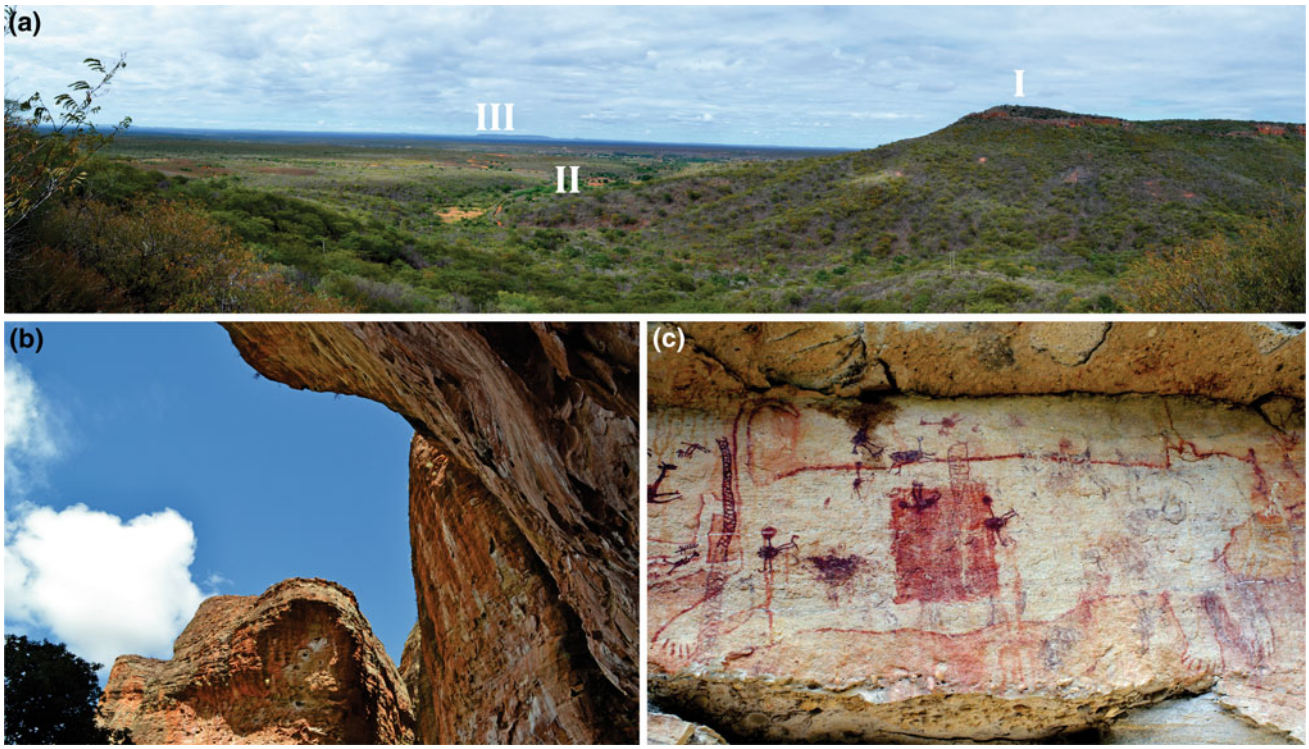

Fig. 23.8 **a** Panoramic view of the longitudinal depression to the south-east of the SCNP. *I* Escarpment, *II* longitudinal depression and *III* ridgelike inselberg. **b** Rock shelter Pedra Furada water gap rock shelter, southern sector of the SCNP. **c** Rock painting at Estevão III rock shelter, north-east sector of the SCNP. *Photographs* Luiz F.G.L. Katz

23.4 Epilogue

Landforms of the SCNP constitute three remarkable landscape units: the cuesta escarpment, the dip-slope and the longitudinal depression. Each of these units has a particular scenic beauty created by the overlapping of the exuberant ruinform morphologies and ecological singularities of the transition zone between two of Brazil's largest biomes, the caatinga to the east and the cerrado to the west.

The exuberance of geomorphic features of the SCNP can be appreciated at several scales of observation that range from the larger regional units, shaped at the convergence of three continental geological provinces, to the subtleties of erosional features and microforms that emerge over different rock types. The magnificence of this assembly of landforms of continental Brazil, coupled with one of the world's largest occurrence of archaeological sites, justifies the preservation of the SCNP as one of the globally most spectacular natural and cultural heritages.

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