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Research Article

Subterranean river captures in siliciclastic rocks in a semi-arid climate: the case of the Poti River Canyon, Brazilian Northeast

Capturas fluviais subterrâneas em rochas siliciclásticas sobre clima semiárido: o caso do cânion do rio Poti, Nordeste brasileiro

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Abstract: This research investigates a possible subterranean river capture responsible for the morphogenesis of the Poti River Canyon, which crosses the uplifted edge of the Parnaíba Basin, in the northern Northeast of Brazil. Morphological and lithostructural evidence of river captures was analysed using remote sensing products (e.g., drainage network, topography, paleotopography, structural framework) and field expeditions. The results indicated a sudden inflexion of the upper course of the Poti River, low and anomalous divides in the local geomorphological context, canyon with valley segments exhibiting asynchronous morphologies, and block collapse controlled by dissolution along fracture networks. Given this set of data, we propose an evolutionary model of subterranean river capture for the formation of the Poti River canyon, which, through paleotopographic modelling, was linked to the Pleistocene epoch. This drainage rearrangement would have been influenced by a Neogene-Quaternary morphogenetic framework of structural reactivations, regional uplift, and climatic oscillations. On this basis, it was concluded that epigenetic processes were significant for a drainage rearrangement of approximately 10,540 km² of areas in a semiarid region with sandstone substrate.

Keywords: Drainage rearrangement; Epigenesis; Parnaíba River.

Resumo: Esta pesquisa investiga uma possível captura fluvial subterrânea responsável pela morfogênese do cânion do rio Poti, que transpassa a borda soerguida da Bacia Sedimentar do Rio Parnaíba, no Nordeste Setentrional brasileiro. Foram analisadas evidências morfológicas e litoestruturais de capturas fluviais a partir de produtos de sensoriamento remoto (e.g. rede de drenagem, topografia, paleotopografia, trama estrutural) e expedições de campo. Os resultados indicaram brusca inflexão do alto curso do rio Poti; divisores rebaixados e anômalos ao contexto geomorfológico local; cânion com segmentos de vale com morfologias assíncronas; colapso de blocos controlado por dissolução em padrões de fraturamento. Diante desse conjunto de dados, propomos um modelo evolutivo de capturas subterrâneas para a formação do cânion do rio Poti, que a partir de modelagem paleotopográfica, teve seu encerramento vinculado ao Pleistoceno. Tal rearranjo de drenagem teria sido influenciado por um quadro morfogenético neogeno-quaternário de reativações estruturais, soerguimento regional e oscilações climáticas. Nesse contexto, concluiu-se que processos epigênicos foram importantes para um rearranjo de drenagem de aproximadamente 10.540 km² de áreas em uma região semiárida, com substrato arenítico.

Palavras-chave: Rearranjo de drenagem; Epigênese; Rio Parnaíba.

1. Introduction

Transverse drainages are rivers that cut across topographic barriers (e.g. mountain ranges, massifs, plateaus, tablelands, cuestas, and ridges) through gorges, transverse valleys, water gaps, and canyons, usually perpendicular to geological structures such as faults and folds (DOUGLASS; SCHMEECKLE, 2007; DOUGLASS et al., 2009). The genesis of transverse drainage is ascribed to four main mechanisms: antecedence, superimposition, river capture, and overflow (STOKER; MATHER, 2003). The antecedence and superimposition are adaptations of preexisting channels to the formation of a topographic divide (LARSON et al., 2017). River capture and overflow encompass drainage rearrangements posterior to the development of the topographic barrier (HILGENDORF et al., 2020).

In the past twenty years, absolute dating methods, measurement of denudation rates and computer modelling have demonstrated that drainage rearrangements are frequent mechanisms in the development of transverse drainages. Most of these drainage rearrangements correspond to fluvial captures that took place in active and passive margins, generally in extensive hydrographic divides (STOKES; MATHER, 2003; CLARK et al., 2004; MAHER; HARVEY; FRANCE, 2007; STOKES et al., 2008). Transverse valleys formed by river capture originate from the interception between rivers with distinct erosive potentials (HILGENDORF et al., 2020). Typically, these differences in erosive power respond to contrasts in the levels of dissection (elevation and slope) and the capacity of river incision. The aggressor river, which has greater erosive power, breaches a structural barrier, and catches drainage lines and areas of the river of lower erosive power – the victim river (HILGENDORF et al., 2020). Factors including lithostructural resistance, tectonics, climatic variation, phytopedological covers, eustasy and base level modifications control these variations in erosivity between riverbeds of adjacent rivers (WILLET et al., 2014).

In most of the reports found in the geomorphological literature, the river capture originates from river interceptions developed at the surface (e.g. headward erosion, absorption, and lateral planation) (CROSBY, 1937; CHRISTOFOLETTI, 1975). However, river captures also occur due to subsurface interception (epigenic) subordinated to processes such as seepage, groundwater sapping, and dissolution (PEDERSON, 2001) and are referred to as subterranean river captures, typical processes in terrains prone to karstification – chemical weathering of the geological substrate at the phreatic level (HILL; POLYAK, 2014). The presence of well-developed secondary porosity (e.g. fractures) and free flow of acidic solutions – water in reaction with CO_2 or organic compounds – enhance karstification (FORD; WILLIAMS, 2007). The formation of karst conduits (e.g. galleries and cavities) promotes the connection of subterranean channels and the fluvial reorganisation across a divide, in which the flow is captured by the river with a steeper gradient (HILL; POLYAK, 2014). The advance of the karstification may cause the collapse of the rocks supporting the divide and the opening of transverse valleys, like gorges and canyons (ORTEGA-BECERRIL et al., 2010).

Subterranean river captures are mainly reported in carbonate rocks (MARIANNELLI; PICCINI, 2011; HILL; POLYAK, 2014; RODET; WILLEMS; POUCLET, 2015); nonetheless, there are rare records of this process in siliciclastic rocks, usually restricted to works in humid/superhumid tropical or temperate regions (UAGODA; AVELAR; COELHO NETTO, 2011; VOJTKO et al., 2012; WRAY; SAURO, 2017). The paucity of the reports can be considered contradictory to diverse morphogenetic studies that demonstrate the significance and frequency of epigenic processes (e.g. seepage, groundwater sapping and dissolution) in the development of canyons in sandstones under arid and semiarid climates (LAITY; MALIN, 1985; YOUNG; YOUNG, 1992; DUSZYŃSKI; JANCEWICZ; MIGOŃ, 2018; BARRETO et al., 2022).

Within this context, the present research contributes to the discussion on the genesis of transverse drainages resulting from subterranean river captures and investigates the evolution of the Poti River Canyon, a tributary of the Parnaíba River – the principal drainage system in the semiarid equatorial margin of South America. The Poti River canyon, which flows across an uplifted sedimentary plateau in the eastern edge of Parnaíba Basin (~900 m a.s.l.), was chosen because it exhibits strong evidence of a recent drainage rearrangement (LIMA, 1982) and karstification in siliciclastic rocks of the region (MAIA, 2023). The first aim of this work is to test the hypothesis of canyon morphogenesis through river capture. Further, this research analyses the possibility of the capture development via a subsurface connection. For this purpose, morphological evidence extracted from remote sensing products, lithostructural evidence obtained in fieldwork and paleotopographic modelling were used.

2. Study area

The Poti River drains an area of ~52.270 km² and is located between the coordinates -4º 06′ e -6º 56′ latitude and -40º 00′ e -42º 50′ longitude. Regarding the geological context, the Poti River runs across distinct lithological units (Figure 1). The upper course drains Precambrian basement rocks of the northern Borborema Province, a geotectonic domain amalgamated during the Brasiliano/Pan-African Orogeny in the Neoproterozoic (BRITO NEVES et al., 2000). This orogenesis promoted the deformation of metamorphic protoliths and supracrustal covers and controlled the emplacement of plutons and magmatic suites in the crust (ARTHAUD et al., 2008).

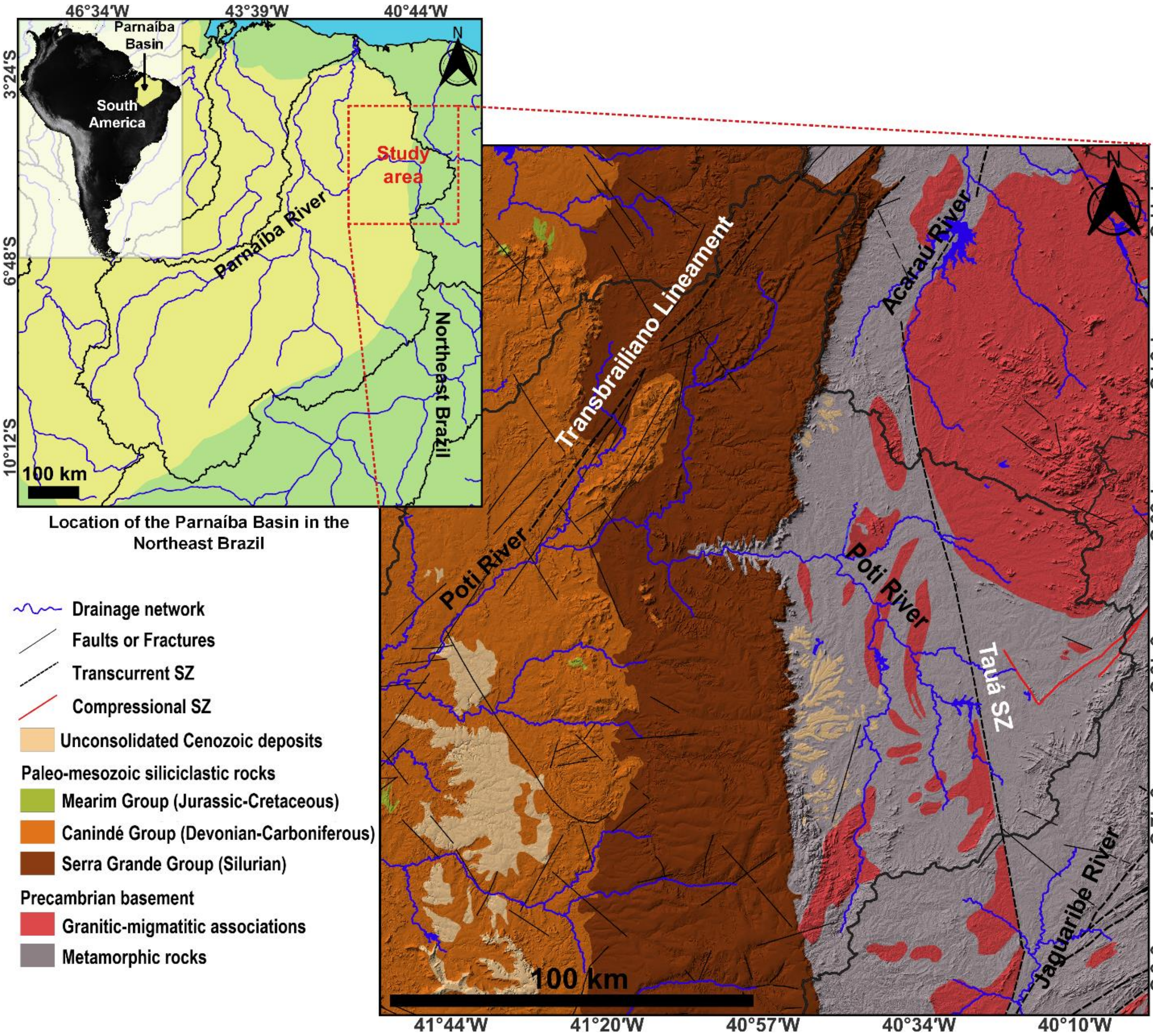

Figure 1. Location, simplified geology, and hydrographic divides of the Poti River in the Parnaíba Basin.

The stresses of these compressions formed ductile and ductile-brittle shear zones (SZ) (trending mainly NE-SW and E-W), especially the Transbrasiliano Lineament, the main suture zone of the Brasiliano/Pan-African Orogeny in South America (CORDANI et al., 2013). In the upper course of the Poti River, the lithological inheritance of the orogenesis is represented by ortho- and para-derived metamorphic rocks interlayered with pelitic metasedimentary sequences, and granitic-migmatitic complexes (CAVALCANTE et al., 2003).

From its middle course, the Poti River incises the siliciclastic packages of Parnaíba Basin, an intracratonic basin developed by syn- and post-Brasiliano/Pan-African Orogeny half-graben systems (DE CASTRO et al., 2014; DALY et al., 2018). The sedimentation cycles began in phases of thermal subsidence during the Ordovician period (VAZ et al., 2007; ASSIS et al., 2019). The deposits of the Poti River hydrographic basin encompass the Serra Grande

(Silurian), Canindé (Devonian to Carboniferous), Balsas (Carboniferous to Triassic and Mearim (Jurassic to Cretaceous) Groups, essentially composed of sandstones, shales, siltstones and claystones (VAZ et al., 2007).

The transverse channel of the Poti River drains the following formations: Jaicós (Serra Grande Group), Pimenteiras and Cabeças (both from the Canindé Group) (LIMA, 2020). The Jaicós Formation consists of texturally immature, quartz-rich, medium- to coarse-grained grey to white sandstone and conglomerates (CAPUTO; LIMA, 1984; GÓES; FEIJÓ, 1994). The Pimenteiras Formation is composed of fine- to medium-grained sandstone beds (which predominate in the study area) underlying grey to black shales (GÓES; FEIJÓ, 1994; VAZ et al., 2007). The Cabeças Formation, in turn, comprises well-sorted, fine- to medium-grained sandstones (VAZ et al., 2007).

During the Lower Cretaceous (~125 M.y), the Borborema Province underwent extensional and transtensional regimes related to the Cretaceous Rift Systems in the Northeast of Brazil (MATOS, 1992). Deriving from the Precambrian structural framework, the rifting promoted the opening of the Equatorial Atlantic Ocean and the formation of half-grabens, which host the Mesozoic basins in the region (MATOS, 1999). In the late Cretaceous, the drifting of the South America Plate imposed a new compressive regime to the region, accompanied by structural reactivations and alkaline magmatism into the crust during Oligocene and Miocene (CAVALCANTE, 2006; MORAIS NETO et al., 2009).

The setting of post-orogenic tectonic regimes and the progress of the dissection of Cretaceous structural compartments contributed to basin inversion and exhumation of the crystalline basement in the Cenozoic period (PEULVAST et al., 2008; MAIA; BEZERRA, 2019). Paleoclimatic data indicate that regional denudation took place under an arid climate with humidity peaks during the Pleistocene to the Middle Holocene (JENNERJAHN et al., 2004; FADINA et al., 2019). The primary inheritance of this morphogenetic framework to the study area is attested by the topographic inversion of the eastern edge of Parnaíba Basin and the consequent formation of a cuesta topography, named Ibiabapa Glint (Figure 2) (MOURA FÉ, 2018).

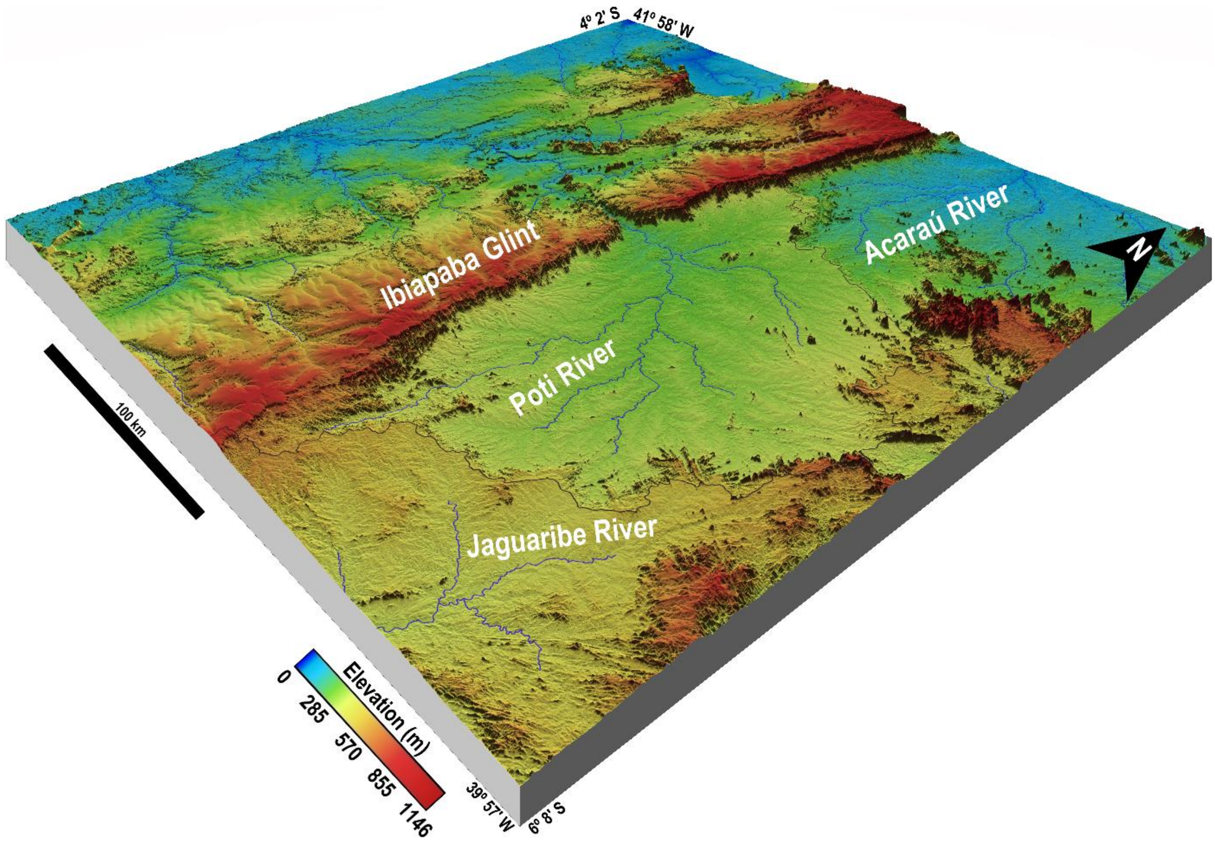

Figure 2. 3D Model of the upper course of the Poti River.

In the areas drained by Poti River, the uplifted edge of Parnaíba Basin presents a surface with a mean elevation of 900 m, approximately 700 m above the peripheral depression (upper course of Poti River. The frontscarp is characterised by steep hillslopes built of crystalline rocks in contact with the sandstones of the Jaicós Formation, which supports a vertical cornice approximately 100 m thick (Figure 3). The backslope has a generally gentle slope towards the west, following the dip direction of the strata.

Figure 3. Frontscarp of the Ibiapaba Glint, with a sandstone vertical cornice, without evidence of fluvial erosion.

The Poti River shares divides with the sub-basins of the Jaguaribe and Acaraú Rivers (Figure 2). Regarding the climate, the study area is located within a transition zone between a semiarid tropical climate and a sub-humid warm tropical climate (LIMA, 2020). The annual average temperature is 27°C, with a long dry season between May and November, and an irregular rainy season between December and April (SOU; LIMA, 2022). The annual average rainfall does not surpass 522 mm in the upper course and can reach 1.447 mm in the lower course (Figure 2) (MARCUZZO; NASCIMENTO; PINTO, 2019). These climatic characteristics influence the flow of the drainage network of the Poti River, which exhibits a predominance of ephemeral and intermittent channels in its upper course. The recharges are intensified in the main channel near the lower course due to topographical influence and the presence of springs of porous aquifers in the region (Cabeças and Serra Grande Formations) (LIMA, 2020). Soils and plant cover also point to climatic-geological conditioning in the environmental context of the study area. In the upper course of the Poti River, there is a predominance of Argisols covered by arboreal caatinga near the frontscarp, in addition to spots of Luvisols and Planosols covered by open shrub caatinga in the surrounding depression (RIBEIRO; ALBUQUERQUE, 2020). On the Glint backscarp, the soils are thicker and acidic, with a predominance of Ferrasols covered by humid forest, "Carrasco" vegetation and dry forest (RIBEIRO; ALBUQUERQUE, 2020).

3. Materials and Methods

The hypothesis of an underground river capture in the evolution of the Poti River Canyon was discussed based on the identification and analysis of morphological and geological evidence. In the first place, the analyses were carried out using data obtained from remote sensing products. Secondly, field surveys were conducted in the hydrographic divides and along the Poti River, to investigate potential epigene evidence and former paleoconnections between the rivers in the study area.

Fluvial terraces on watershed divides or rolled pebbles in dry/inactive valleys (wind gaps) are the most undoubted evidence reported for the identification of river captures (BISHOP, 1995; ZAPROWSKI; EVENSON; EPSTEIN, 2002); however, they are rarely preserved in the zone of river interception (BISHOP, 1995; HILGENDORF et al., 2020). Among the morphological evidence, we highlight (i) drainage elbows (termed elbows of capture when there was a transference of flow between rivers); (ii) orthogonal or barbed drainage patterns; (i) knickpoints; (iv) topographically anomalous sectors of the divide (low divides); and dry valleys (wind gaps) present in the divides (PRINCE SPOTILA; HENIKA, 2010; SORDI et al., 2018).

Initially, morphological traces of river capture were investigated based on remote sensing products. Data related to the drainage network (planimetric and longitudinal) and topography (mean slope and local relief) were derived from the Advanced Land Observation Satellite (ALOS) Digital Elevation Model (DEM), model AWD30, with a spatial resolution of 30 m.

Drainage network, longitudinal river profiles (distance x elevation), knickpoints and watershed divides were extracted using TopoToolBox, an assemblage of native scripts in the MATLAB software (SCHWANGHART; SCHERLER, 2014). These data were extracted using the D8 flow direction algorithm (TARBOTON, 1997), based on pixel threshold >1km².

Owing to the low spatial resolution and the presence of errors in the DEM (noises, waterbodies, null values, among others), we opt for the extraction of longitudinal profiles and knickpoints using the Quantile Carving algorithm of TopoToolBox (SCHWANGHART; SCHERLER, 2017), a script that allows the quantification of the minimum elevation (tolerance) to smooth the longitudinal profiles. Consequently, it was possible to make an efficient distinction between knickpoints and slope breaks throughout the longitudinal profiles that are generated by errors in the DEM. The tolerance value used was 47 m, also used for the delimitation of knickpoints with the algorithm knickpointfinder (SCHWANGHART; SCHERLER, 2017).

Subsequently, the local relief and mean slope of the Poti River were extracted for the morphological characterisation of the surfaces. The local relief is calculated by the difference between maximum and minimum elevations within moving windows of fixed dimensions along the study area. The quantification of the local relief was carried out using the Local Topography algorithm in TopoToolBox (SCHWANGHART; SCHERLER, 2014), with 0,5 x 0,5 km moving windows, considering a predominantly flattened regional topography. The slope data were quantified in degrees in the ArcGIS software and then resampled in windows of 0,5 x 0,5 km for the computation of the mean slope.

In addition to this, swath profiles were produced for comparison between elevation data and local relief. Swath profiles reveal the longitudinal distribution of elevation in pre-determined areas, allowing the plotting of mean, maximum and minimum elevations of the terrain (TELBISZ et al., 2013). The Swaths were generated using the Extract Swath Profiles add-in in ArcGIS (PÉREZ-PEÑA et al., 2017) within rectangular windows of 10 km in length.

To complement the topographic analyses, paleotopographic models were produced to model paleo drainage arrangements (incision and position of hydrographic divides) and correlative determination of ages for the development of the canyon drainage network (estimate of the beginning of the likely capture process). In this context, we opt for the utilisation of the Seppômen Method of topographic reconstruction (MOTOKI et al., 2018), which corresponds to an interpolation of elevation data derived from DEMs, based on the valley filling according to the maximum altitudes within the pre-determined moving windows (COUTO et al., 2012;). The dimensions of the windows influence the level of valley filling, as the larger the dimensions, the fewer maximum elevation points will be extracted, leading to an increased generalisation of the interpolations (COUTO et al., 2012). Therefore, the analyses of these models are used for the evolutionary assessment of fluvial systems, as they permit an estimation of the incision advance of a drainage network on a certain surface (FREITAS et al., 2022). In this research, the Seppômen models were generated from tests (alterations in the window size) conducted in the ArcGIS software. The windows of 2 x 2 km, 1 x1 km, 0,5 x 0,5 km, and 0,3 x 0,3 km dimensions exhibited the highest precision and pertinence for this study.

The age estimation of the canyon was made by the computation of erosion volume per depth (m^3/m), proposed by Freitas et al. (2022). This calculation was derived from the difference (pixel by pixel) between the AW3D30 DEM and the Seppômen model which indicated the moment of canyon formation (Volume = DEM AW3D30 – Seppômen Model), divided by the value of the drainage area confluent with the canyon. Next, the value of eroded material was divided by the mean denudation rate for the regional depression (Sertaneja depression) - ~7,7 m/Ma, measured by cosmogenic isotopes (^{10}Be) (LIMA, 2008; MORAIS NETO, 2012) – to quantify the time required for the removal of the eroded volume and possible age of the onset of river capture. It is worthwhile to note that the region still lacks denudation rates data in a sufficient sample amount to determine the assessed events. Therefore, the calculations conducted with Seppômen models are interpreted as complementary, correlative, and speculative.

Lastly, morphostructural lineaments of negative topography (brittle structures) were mapped, according to the distinction proposed by Alves and Rossetti (2015) to investigate lithostructural lineaments, which may attest to an epigenic morphogenesis in the evolution of the canyon. Accordingly, the mapped lineaments correspond to fractures (faults or joints) in bare rocks or segments of rectilinear channels and lithological discontinuities such as bedding, lineations and banding. This mapping was conducted by the vectorisation over (i) shadings generated with directional filters derived from AW3D30 DEM in ArcGIS (azimuths 0°, 45°, 90°, 135°, 180°, 225° and 315°, and vertical lighting of 45°); (ii) high-resolution coloured compositions and false-colour compositions available on Google Earth (Quickbird and Geoeye-1 -Digital Globe images – accessed with the Basemap plugin in ArcGIS). We opt for a fixed scale of identification of 1:40.000 for the vectorisation. Thereafter, an analysis of lineament density per km² (frequency/km²) was performed in ArcGIS and an analysis of the preferential directional lineament trends was conducted by the elaboration of rose diagrams for each lithological domain crosscut by the Poti River (crystalline basement, Serra Grande Group and Canindé Group).

4. Results

4.1. Evidence of drainage rearrangement

The Poti River originates in the peripheral depression of the Ibiapaba Glint – around 22 to 25 km from the frontscarp – with a main N-S flow direction and ~100 km of extension, discordantly with the Tauá SZ, the primary regional structure in this sector (Figure 4, A). The upper course drainage presents a radial pattern converging towards the canyon, with barbed tributaries guided by joints and faults trending S-N, SE-NW, and SW-NE. In sectors near the divides of the Jaguaribe and Acaraú rivers, it is possible to identify channels exhibiting signs of reversion in acute angles (SE sector of the upper course). Near the canyon, the main channel undergoes an abrupt inflexion at the drainage elbow, marking a redirection from S-N to E-W. The E-W direction is verified in some tributaries in the southern part of the middle course, generally assuming parallel and subparallel drainage patterns. In the zone of influence of the Transbrasiliano Lineament (TBL), the main channel flow adopts a NE-SW direction through the drainage anomaly marked by orthogonal drainage elbows (Figure 4. B). The tributaries in the northern margin acquire the same orientation in this sector (NE-SW), with a few subsequent streams, with relation to the sedimentary layers. The course of the main channel extends for over 120 km until it undergoes a new inflexion to the SE-NW direction, beginning to flow in the lower course of the hydrographic basin towards its confluence with the Parnaíba River.

Analysing the longitudinal profiles of channels in the backslope of the Glint, it is noticeable the difference in the incision between southern and northern channels flowing to the canyon (Figure 4, C). The channels in the southern margin present fewer incised channels and are also less adjusted to the main channel than the rivers in the northern margin, which exhibit more incised longitudinal profiles and are more adjusted to the topography of the transverse valley of the Poti River (local base level). The channels of both margins are steeper when flowing across the sandstone of Serra Grande Group in comparison with the channels draining other units in the backslope.

In the Canindé Group, the rivers in the northern margin become more concave, while those in the southern margin flow across a less steep and higher level, occasionally surpassing 200 m of altitude, towards the level of the Poti River. Generally, the knickpoints are well scattered in the sandstones of Serra Grande Group (70% of the total), whereas in the downstream direction, the higher concentration occurs in small tributaries (2nd order channels) that converge to the main channel over the rocks of Canindé Group. This context suggests a strong influence of the TBL in the erosive pulse of the middle course, a condition reinforced by the fact that the substrates drained by the margins of the Poti River present no significant differences in resistance to erosion.

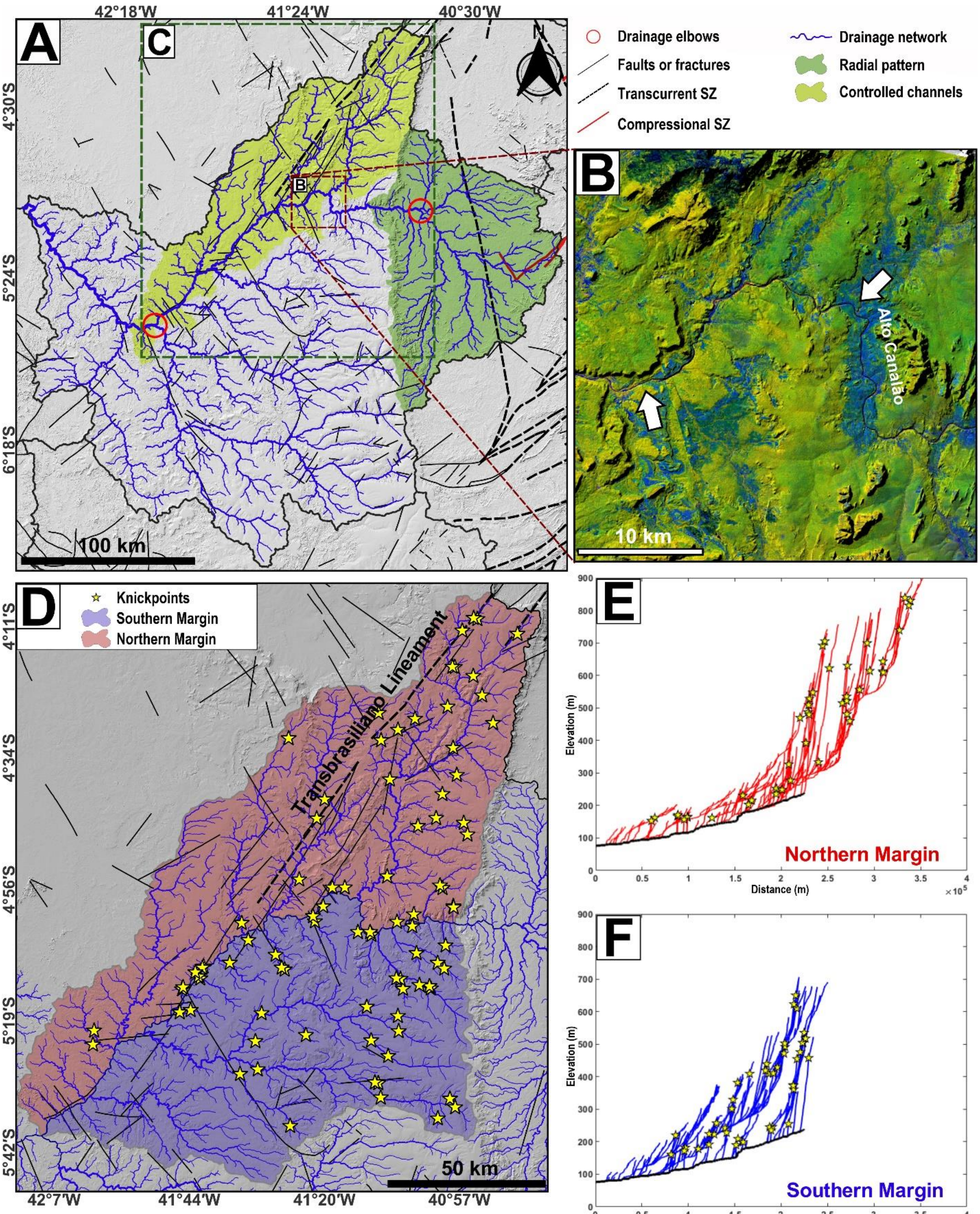

Figure 4. Drainage network and longitudinal profiles of Poti River. A- Drainage patterns and drainage inflexions. B – Orthogonal drainage anomalies (white arrows mark the inflexions). C – Longitudinal profiles of channels draining the middle course of the Poti River. D and F – Longitudinal profiles of the rivers in the northern (D) and southern € margins. Chart C indicates the location of the topographic data in Figure 5.

The local relief and the mean slope of Poti River demonstrate a predominance of low values (50 m and < 10°), with higher values noted in the areas of the backslope drained by the middle course (Figure 5, A and B and Table 1).

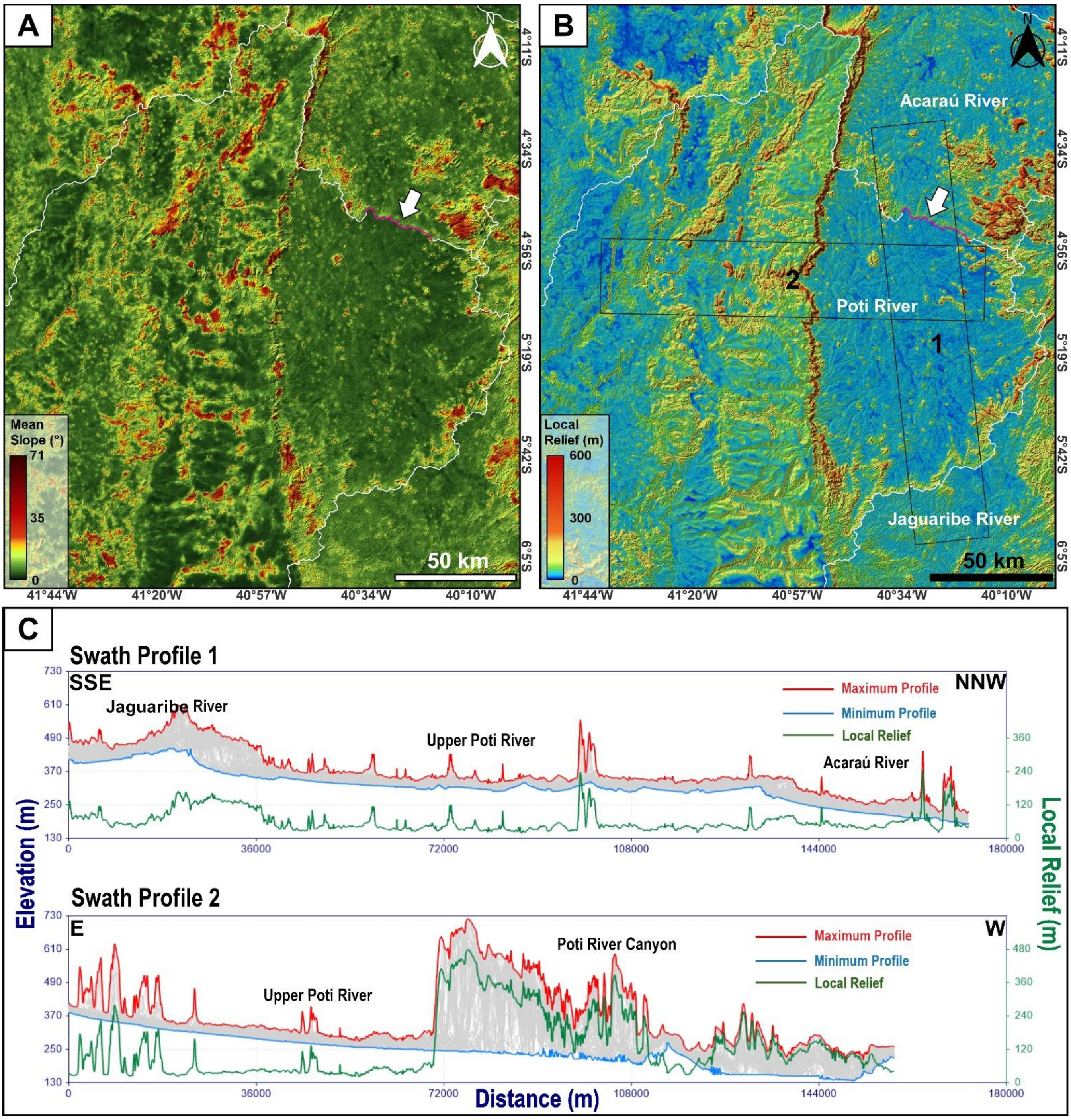

Figure 5. Mean Slope (a), Local Relief (B) and Swath Profiles (C) of terrains drained by Poti River. In A and B is presented a lowered segment in the divide between the Poti and Acaraú rivers (purple line indicated by white arrows).

Table 1. Distribution of the local relief and mean slope in the upper course of the Poti River and its divides.

		Local relief (m)	Mean slope (°)
Sub-basins	Upper course	49,288005	7,954895
	Middle course	53,024139	9,916019
Divides	Poti/Acaraú	50,1599/69,988049	12,029362/9,064856
	Poti/Jaguaribe	84,982379/55,775771	7,676608/11,658721

In the upper course, values tend to increase towards the divides with the Jaguaribe River (south and east), Acaraú River, and the Glint frontscarp on account of the depressed morphology of the basement. To the north and south of the Poti River basin, the divides are characterised by a gently undulating to flattened topography, which compartmentalises depressions into subtle steps, with slightly steeper slopes facing toward the Poti River (in the divide with Jaguaribe River) and the Acaraú river (in the divide of Poti River and Acaraú river). Moreover, it was possible to identify a low and anomalous divide segment in the divide with Acaraú River (Figure 5, purple line), which denotes 31,36 m of local relief and 6,53° of slope.

Generally, the backslope topography is typified by a stepped sedimentary formation towards the depocenter of the Parnaíba basin – to the west (Figure 5, A and B). The local relief and mean slope values increase in the transition between formations, exhibiting discontinuous plateaus tilted towards the west. The tributaries of the Poti River deepening their valleys are either consequent or subsequent drainages in relation to the bedding supporting these plateaus. The drainage incision increases toward the northern margin, forming a wide depressed sector in the backslope between the Jaicós and Pimenteiras Formation, where is located the canyon, and where the channels are structurally controlled by the TBL (Figure 5, C). This setting indicates steeper and more entrenched surfaces and gradients in the middle course, compared to the surfaces and gradients in the upper course.

The morphology of the transverse valley of the Poti River demonstrates variation in the local relief and men slope values, presenting valley segments with distinct characteristics along the middle course (Figures 5 and 6). Near the frontscarp, crossing the Serra Grande Group, the local relief and mean slope reach 400 m and 55°, respectively.

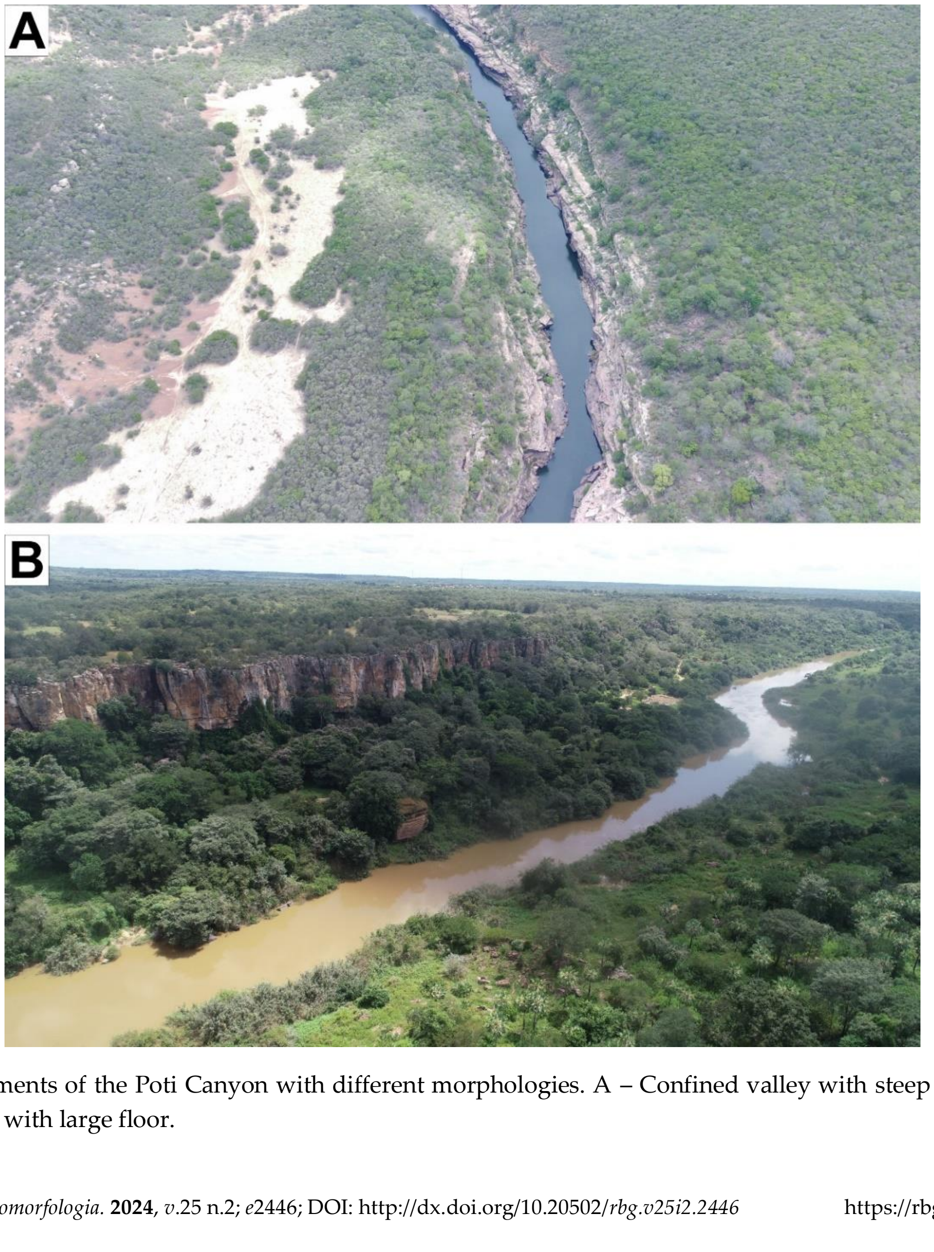

Figure 6. Segments of the Poti Canyon with different morphologies. A – Confined valley with steep walls. B – U-shaped valley with large floor.

In the southwestern sectors of the canyon, where the Canindé Group (Cabeças Formation) occurs, the local relief and mean slope values reach up to 300 m and 40/, respectively. In the depressed area between Serra Grande and Canindé Groups, the canyon displays the lowest values of mean slope and local relief (>150 m and 15°); this is the same sector where the orthogonal inflexion of the main channel towards the TBL takes place (Figure 4, B). This context encompasses an alternation between canyons with incised confined valleys (V-shaped) and with large floors (U-shaped) (Figure 6).

The paleotopographic models are suggestive of a few alterations in the compartmentalisation of the actual surfaces – levels of dissection in the study area including the depression, the frontscarp, the uplifted plateau, and the backslope (Figure 7).

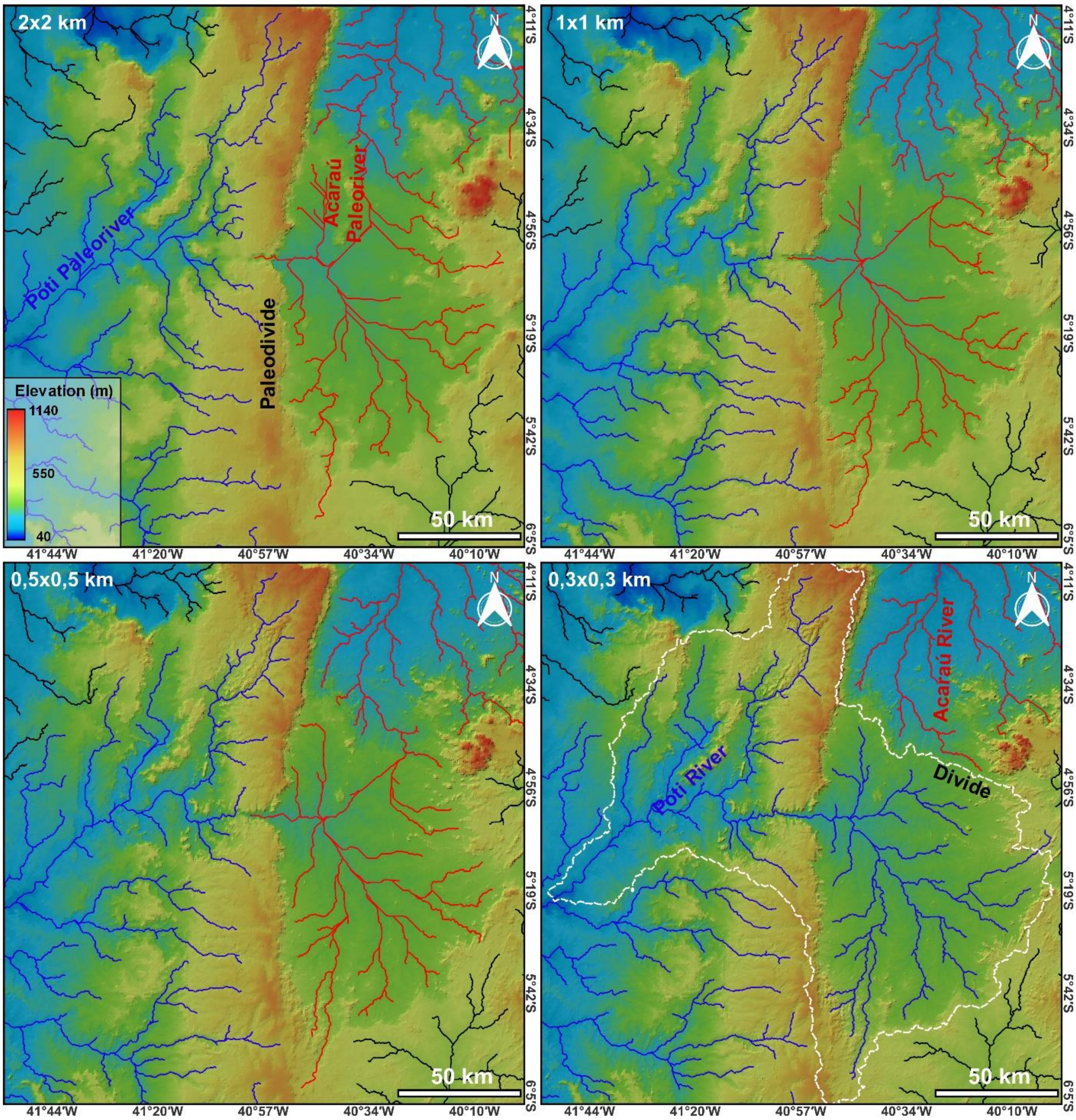

Figure 7. Paleotopographic models of the terrains drained by Poti River. Note that, according to the diminishing of the sample windows, the scenarios suggest a river capture involving Acaraú and Poti River.

Minimal topographic variations are observed at the incision level of channels as in the backslope. The pattern of most channels, especially those segments controlled by the TBL and the depressed sector between Jaicós and Pimenteiras Formation, is already verifiable in the model with the widest temporal cut (2 x 2 km).

Conversely, the organisation of hydrographic divides and the arrangement of drainage networks present substantial modifications in the produced models. In the 2 x 2km model, the transverse channel was still not developed and the sector comprising the upper course flows toward the Acaraú River (Figure 7, 2x2 km). In this model, the frontscarp forms a wide divide between the waters flowing to the Acaraú paleoriver, which would be two times larger than the present river. In the other models, the sequential break-up of the paleodivide between the rivers (Ibiapaba Glint) is noticeable, and the drainage network undergoes several rearrangements in lower-order channels. Among the rearrangements, we highlight one verified in the orthogonal anomaly in the middle course (Figure 4, B and Figure 7, models 1 x 1 km e 0,5 x 0,5 km). The connection between the Poti paleoriver and the headwaters of Acaraú paleoriver is concluded in the model 0,3 x 0,3 km, promoting transference of drainage areas of approximately 10,540 km² to the Parnaíba River (Figure 7, 0,3 x 0,3 km).

Considering the 0,3 x 0,3 km model as the moment of connection between the paleoheadwater of Acaraú and Poti Rivers, from a pre-determined local base level at 40 m (Figure 7, D), it is estimated that ~137,53 km³ were eroded until the level of dissection exposed in the AW3D30 DEM. This eroded material comprises around 6,97 m depth by km² (m/km²). According to the mean denudation rates of the regional depression (Sertaneja depression) obtained by cosmogenic isotopes (10Be) - ~7,7m/Ma (LIMA, 2008; MORAIS NETO et al., 2012), the present transverse drainage would have required ~0,90 Ma to remove the volume in the 1 x 1 km model. Accordingly, the connection would have been initiated in the Pleistocene.

4.2. Lithostructural analyses

14.770 lineaments corresponding to fractures and segments of rectilinear channels were identified (Figure 8). From the total, ~46,9% are contained within the limits of the Canindé Group (6937 lineaments), ~38,9% of the Serra Grande Group (5749 lineaments) and ~14,2% in the basement area (2084 lineaments). Generally, the rose diagrams show lineaments aligned preferentially along the pair NE-SW/NW-SE (Figure 8).

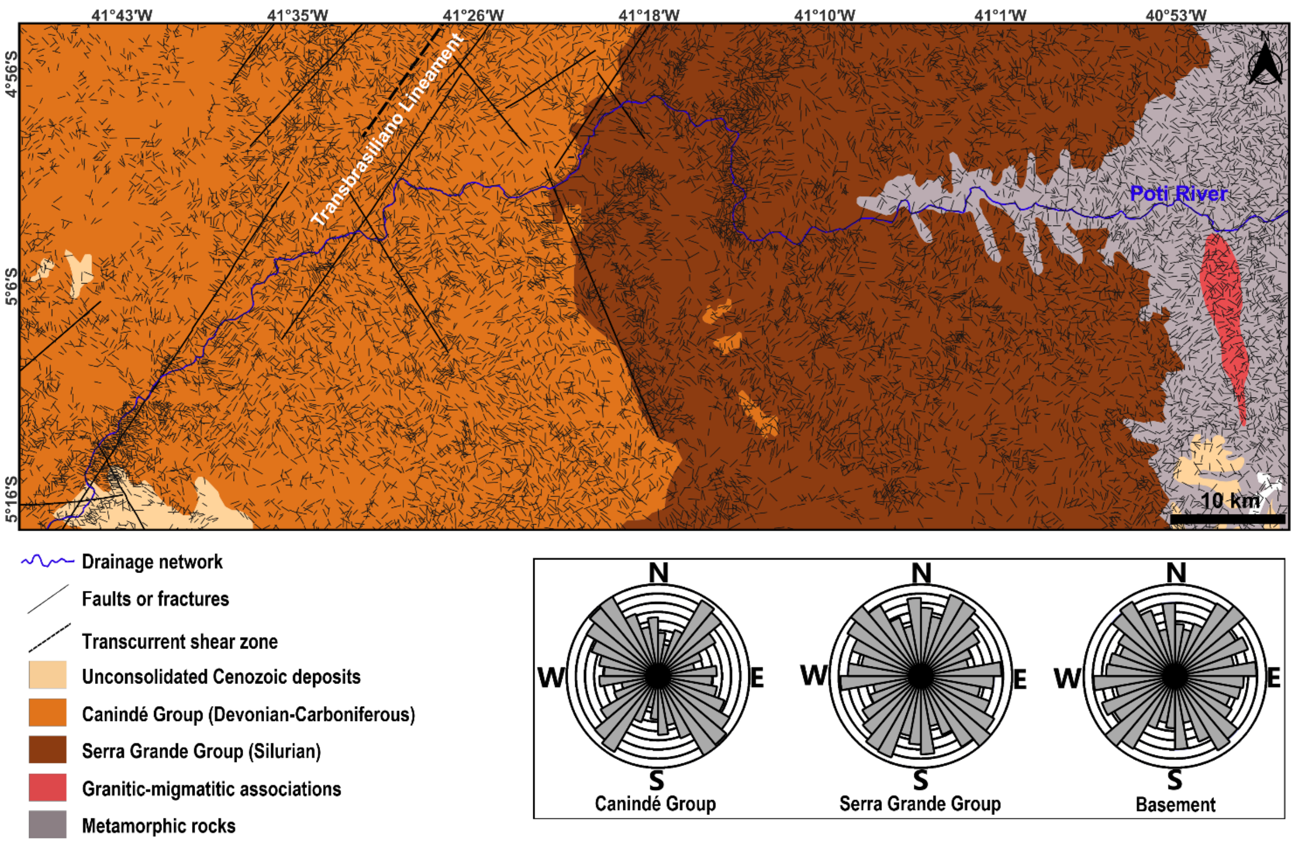

Figure 8. Mapping, distribution, and preferential direction (rose diagrams) of the lineaments present in the Canindé and Serra Grande Groups, and the lineaments identified in the crystalline basement.

The diagrams also reveal secondary direction trends to E-W and N-S, more frequent in the basement and the Serra Grande Group. In the Canindé Group, it is observed a predominance of the preferential pair, especially in the area under the influence of the TBL. The preferential pair points to a correlation of regional faults related to the TBL, which denote primary directions similar to those verified in the Canindé Group's rose diagram.

Concerning the lineament density (Figure 9, A), the mapped area exhibits a preponderance of low to moderate values (<4 freq./km²). The average density is higher in the basement (2,13 freq./km²), compared to averages in the sedimentary terrains, with a minimum advantage to the Canindé Group in relation to the Serra Grande Group (1,80 freq.km² and 1,75 freq./km²). The distribution of the higher averages in the basement conforms to its age and degree of deformation. However, the larger patches of density in the area are subject to the influence of the TBL, reaching the maximum value in the southeast sector of the density map (8,60 freq./km²).

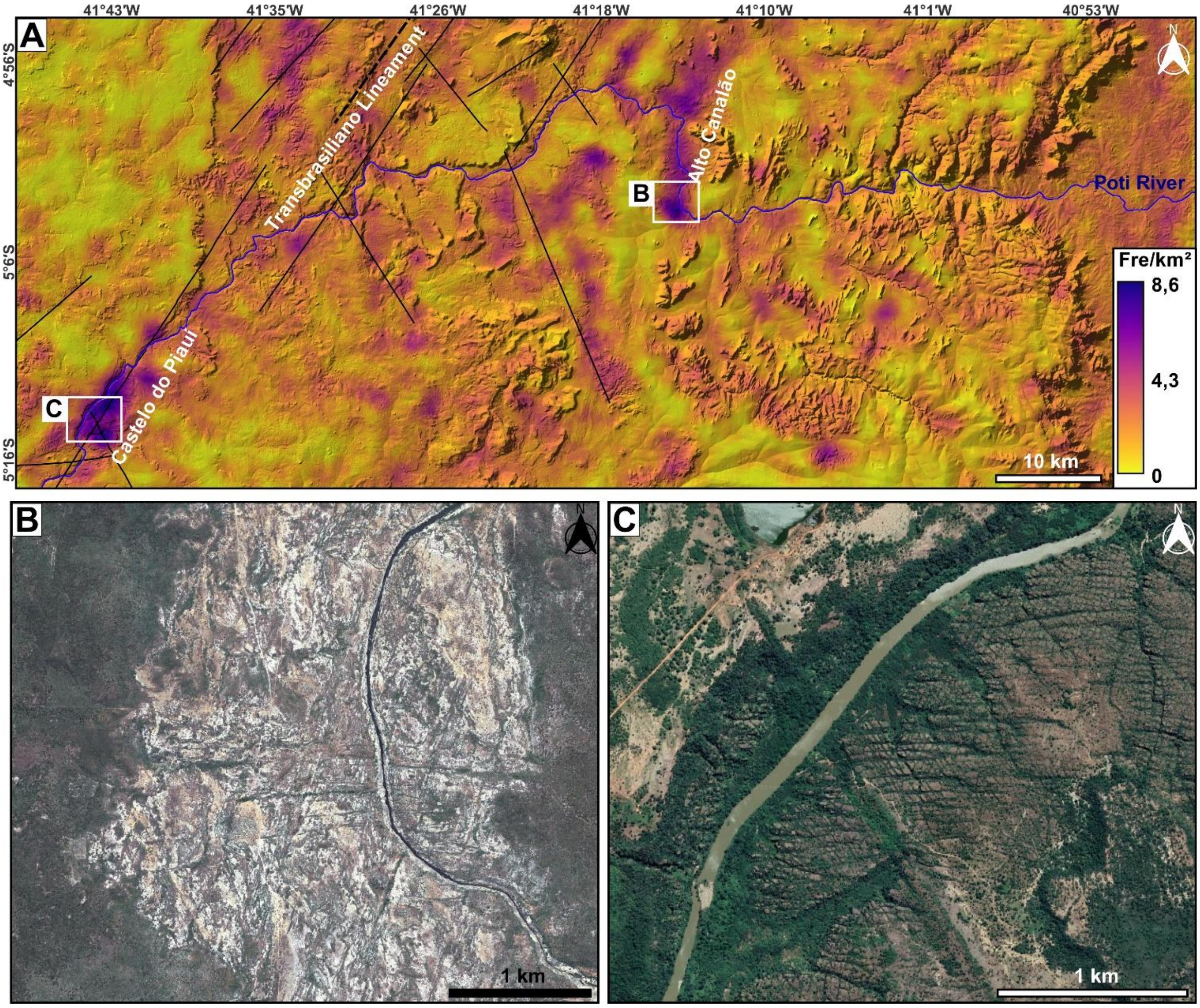

Figure 9. Lineament density (Frequency/km²) mapped along the Poti River Canyon (A). B and C – Rocky pavements in Alto Canalão (B) and Castelo do Piauí (C). Note the complex orthogonal fracture systems and their influences on the density values. Source: Satellite images from Geoeye-1 (Digital Globe) available in Google Earth (2023).

In the Serra Grande and Canindé Groups, it is noticeable that the densities do not exceed 4 freq./km²; despite this, from the transition between the Serra Grande Group and the Canindé Group, density patches of > 4,3 freq./km² become more continuous and extensive in the valleys alternating with discontinuous plateaus in the backslope. Regarding the main channel of Poti River, as its course gradually adopts a NE-SW direction, the substrates of the canyon begin to exhibit an increase in density values (> 4.3 freq./km²), particularly as they enter the segment influenced by the LTB. The two sectors with higher density (colder colours) are observed in Castelo do Piauí and the segment locally named Alto Canalão (Figure 9, B and C). These sectors characterise rocky pavements crosscut by fractures arranged mainly along the preferential trends NE-SW and NW-SE. (Figures 9, B and C).

Most of the transverse segments of the Poti River flow across fracture systems, whereas their meanders adapt to zones where structures with different orientations intersect (Figure 10). As in the rocky pavements with high lineament density (Figure 9, B and C), orthogonal fracture sets control many segments of the transverse valley, usually related to short segments with sharp elbow inflexion (Figure 10, A).

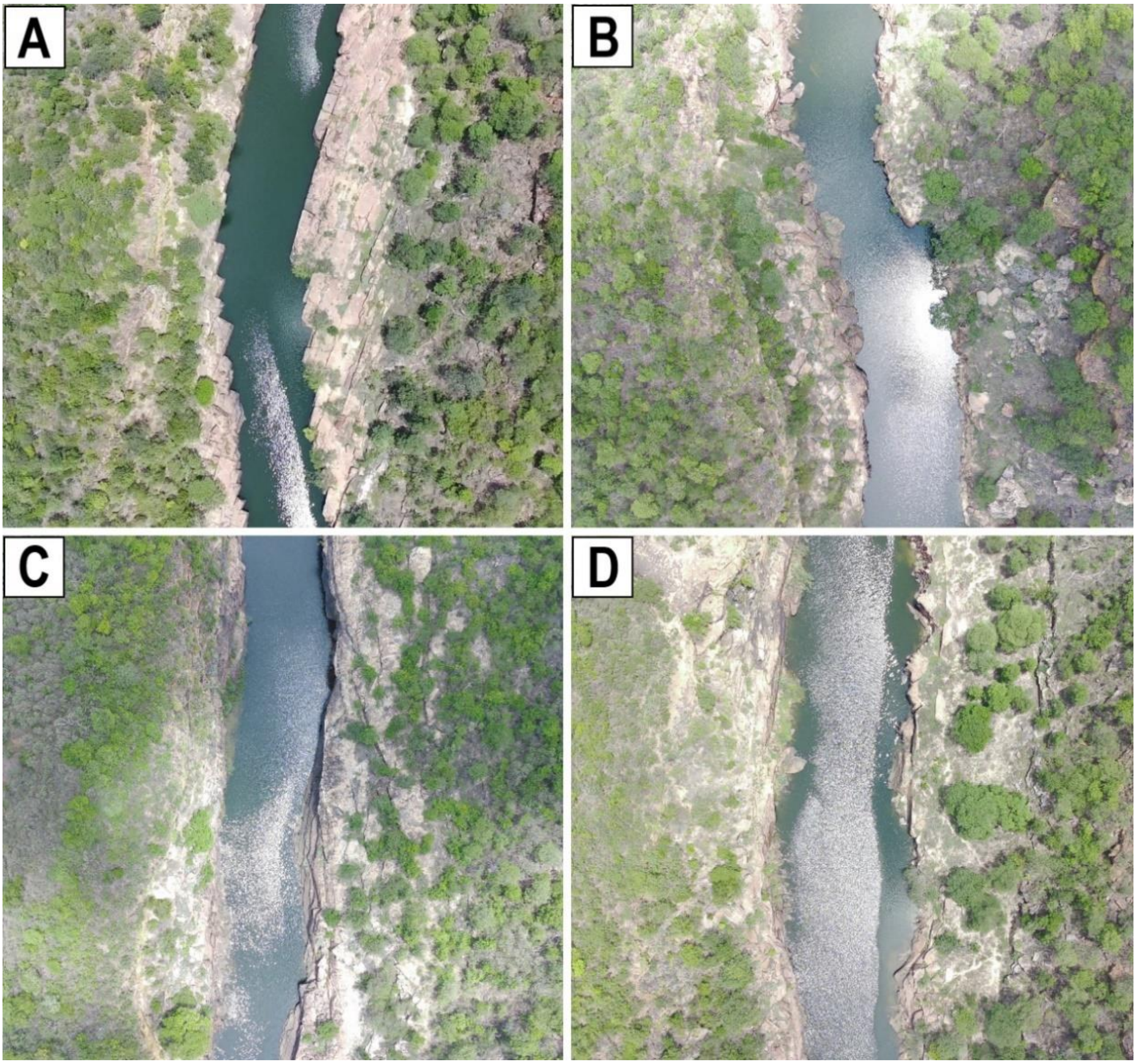

Figure 10. Structural control on the Poti River. A – Drainage elbow entrenched into orthogonal structures. B – Asymmetrical valley with collapsed boulders. C and D – Fractures controlling walls and notches due to rockfall.

In the segments of asymmetrical valleys, especially in subsequent channels in relation to the dip of strata, blocky chaos at the foot of less steep walls is observed (Figure 10, B). In symmetrical valleys, generally consequent to the dip of strata in the siliciclastic rocks, the walls are controlled by straight and curved fractures (Figure 10, C and D).

At the top of canyon walls, is also possible to verify sandstone blocks detached in situ following structural intersection planes and large collapsed boulders in the floor of Poti River resulting from gravitational movement (Figure 11). The detachment and collapse of these blocks are controlled by vertical fractures crosscutting horizontal discontinuities in the sandstone. Overall, the top of walls in the canyon segments does not present evidence of fluvial erosive processes related to riverbed incision (e.g. abrasion, corrosion, and cavitation) and exhibit steep smooth walls cut by fractures, mostly joints.

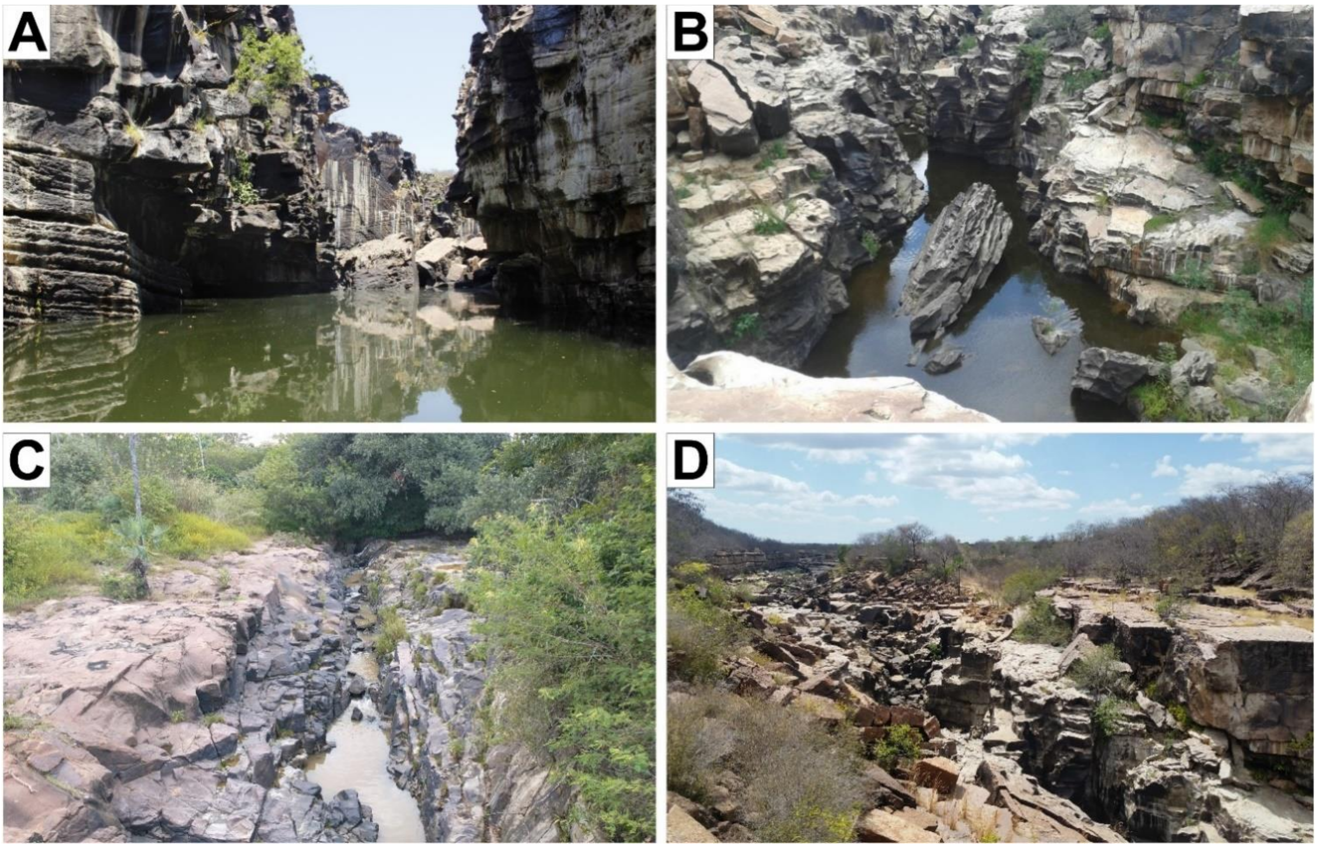

Figure 11. Examples of block collapse resulting from structural control in Poti River. A and B – Examples of collapsed boulders in the floor of Poti River along the valley cutting the rocky pavement named Alto Canalão. C and D – Detachment of blocks following orthogonal fracture systems occurring in low-order tributaries of the Poti River throughout the study area.

Deeper in the valley of the Poti River, we observe erosive features such as ripple marks and potholes, linked with the present dynamics of incision of the fluvial system. Therefore, the superficial portions of the canyon suggest preservation against the fluvial action, with morphologies controlled by the vertical and horizontal structural planes of weakness. This context is also identified in some cross-sections along the main channel, exhibiting valleys with widened floors and narrow upper sections.

Along the canyon walls, we perceive some fracture systems and bedding planes presenting signs of preserved epigenic weathering, subordinated to seepage, groundwater sapping, and granular disintegration of the sandstones (Figure 12). At the outcrop scale, enlarged horizontal and vertical fractures were seen in the walls, usually filled with sand soils and shrub vegetation, in addition to several blocks prone to collapse at the top of the steep walls (Figure 12). Along the canyons and steep walls, fine-grained thin facies display more favourable conditions of permeability to the epigenic action (Figure 12).

In these rocks, the flow of acidic fluids is facilitated by the percolation of meteoric waters through vertical fracture, concentrating flow in the direction of deeper portions. The horizontal fractures exhibit a role of lateral percolation in the beds more prone to disintegration, subordinating the chemical weathering in these facies (Figures 12 and 13). The fracture network promotes the increase in the secondary porosity, while in zones with high fracture density, vugs are developed concomitantly with the continuous enlargement of the planes of weakness (Figure 13, A).

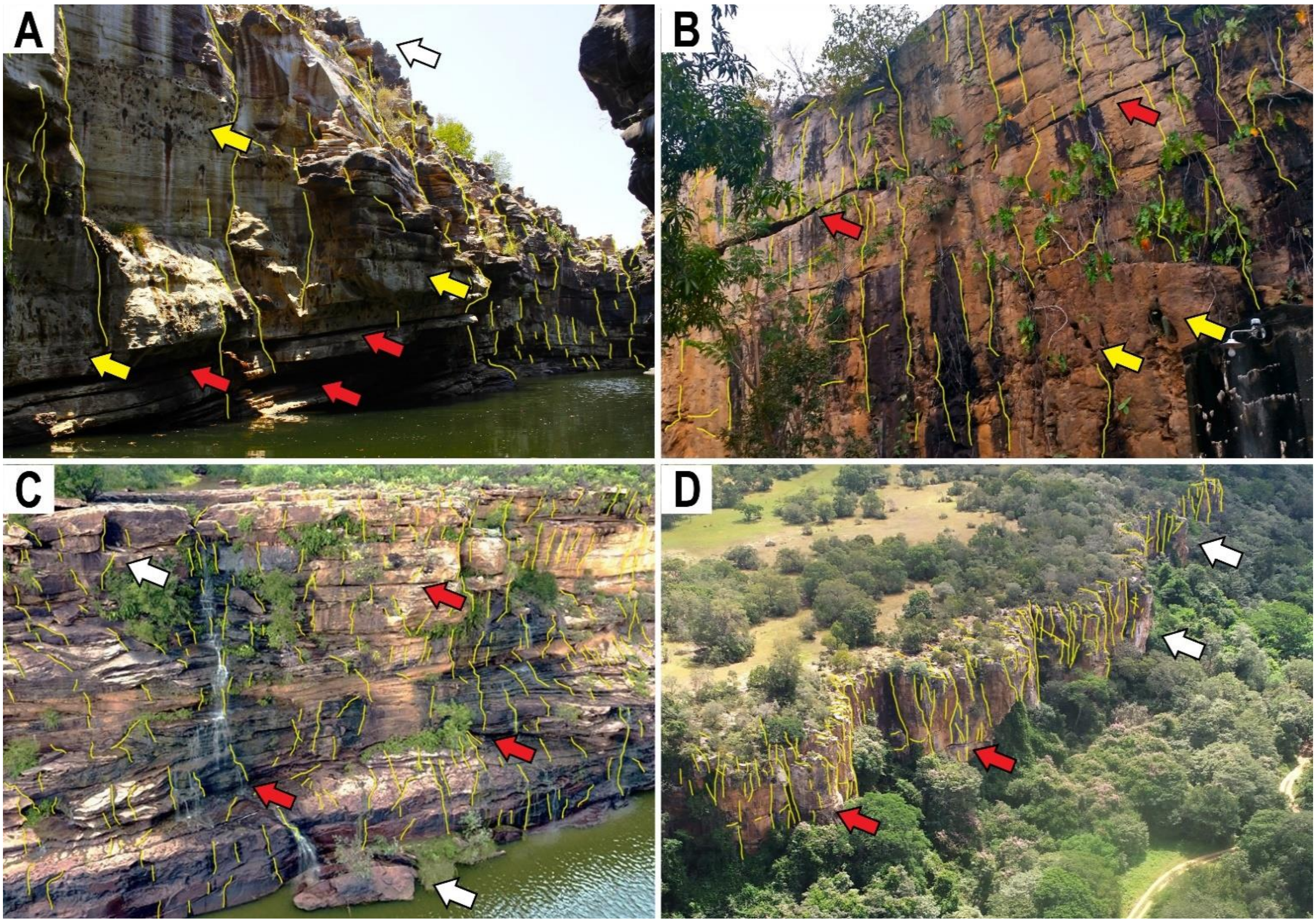

Figure 12. Fracture systems identified in the wall segments of the Poti River Canyon. A – Segment of the canyon over the sandstones of Jaicós Formation (Serra Grande Group) and rocky pavement in the Alto Canalão. B – Rocky wall drained by tributaries of the Poti River in the substrate of Cabeças Formation. C - Segment of the canyon over sandstone of Pimenteiras Formation (Canindé Group) with pre-collapse blocks. D – Rocky wall in a large segment of the canyon over Cabeças Formation (Canindé Group) indicating the presence of towers in a pre-collapse phase. The white arrows point to the location of blocks undergoing collapse or already collapsed. The red arrows indicate enlarged horizontal fractures. The yellow lines correspond to systems of less apparent vertical joints that facilitate the percolation in the substrates of the study area.

The progression of weathering favours the interconnection among the vugs, controlling the formation of vugs and tubes that diminish the sandstone cohesion (Figure 13, B). The constant granular alteration sets favourable circumstances for the formation of disintegration alveoles in the permeable packages as a result of the connection between tubes and conduits (Figure 13, C and D). In some areas, the expansion of alveoles provided good conditions for gallery and doline formation along the axis of fracture intersection, through a gradual collapse of the weathered strata.

5. Discussion

5.1. Mechanisms of fluvial evolution

Some studies suggest that the morphogenesis of the Poti River Canyon is connected to processes of cataclinal drainage superposition to the Ibiabapa Glint (BARRETO; COSTA, 2014; MOURA FÉ, 2018; CLAUDINO-SALES, 2016).

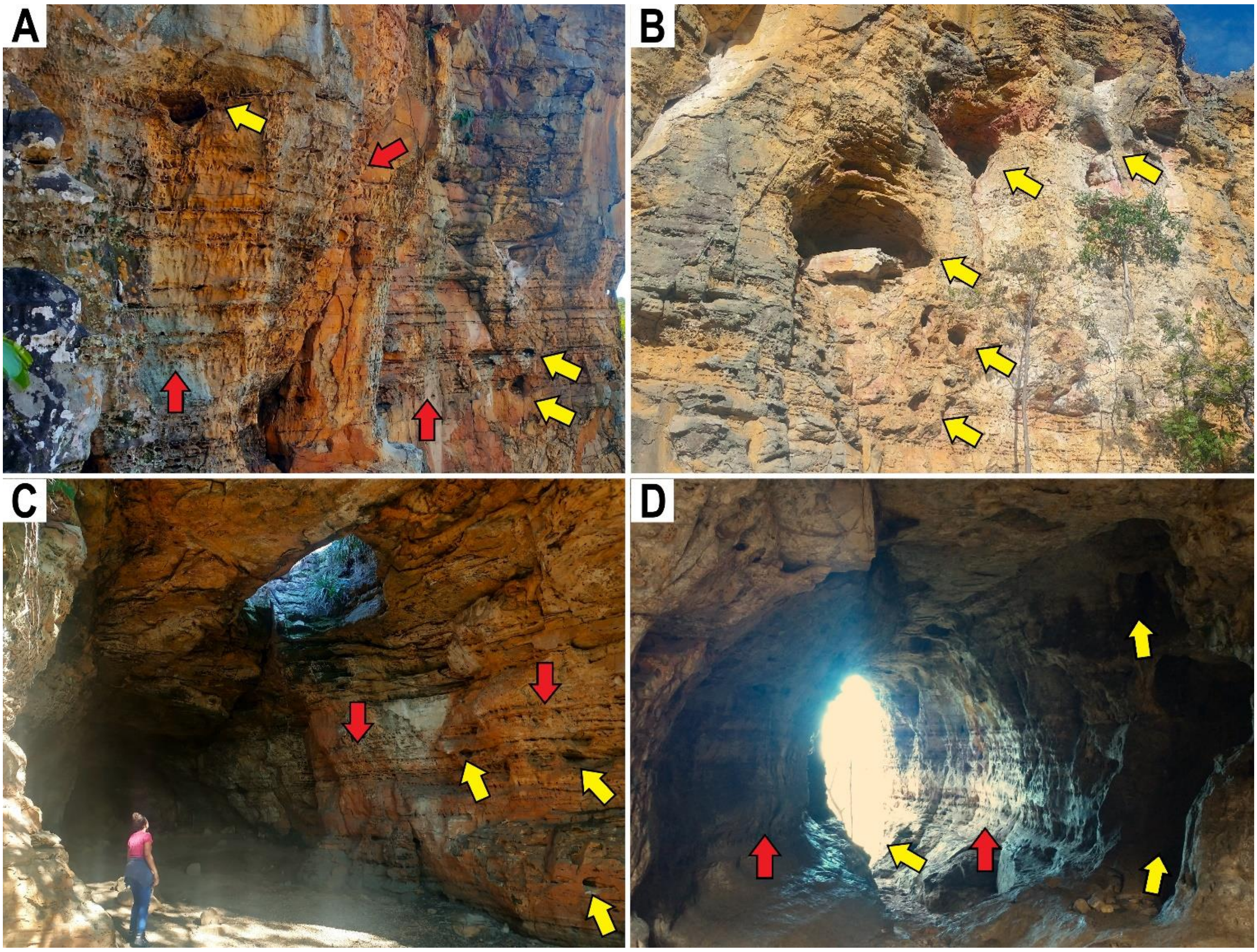

Figure 13. Dissolution and collapse features identified in the substrates of the Cabeças Formation (Canindé Group), at altitudes 200 m above the Poti River floor. A – Intercalation of thick and thin beds in the sandstones of the Cabeças Fm., with evidence of vulgular porosity in horizontal discontinuity surfaces. B – Tubes and conduits being connected along planes of weakness in rocky walls. C and D – Alveoles, cavities and doline formed by the collapse of weathered strata. The red arrows indicate the location of thin beds with vulgular porosity, developed in discontinuity planes. The yellow arrows localize the tubes, conduits and solutional alveoles developed by the widening of vugs.

In the superimposition process, the channel deepens its incision on a substrate of low lithological resistance in response to the uplift of the structural barrier (STOKES; MATHER, 2003). The progressive vertical erosion gives origin to a transverse valley, usually perpendicular to the trend of the underlying lithological structures (DOUGLASS et al., 2009). In the evolutionary model by superimposition, it was assumed that the siliciclastic packages of Parnaíba Basin extended along the present peripheral basement, whilst the incision of Poti River would be inherited from Cretaceous extensional episodes. The depression drained by the upper course channels would result from the burial of the basement. The contact between the siliciclastic rocks with the basement, especially in the frontscarp, would evince the process, with the TBL structures being explored by the drainage to facilitate the incision.

On the contrary, the evidence presented in this research is not satisfactorily explained by a model of superimposition of such an old age, particularly regarding the drainage patterns. Firstly, there is no apparent regional structure to justify the sudden inflexion of the Poti River from S-N to E-W (Figure 4) and its probable former existence (prior to the uplift of the edge of Parnaíba Basin). Only the NW-SE segment, which is related to the control exerted by the TBL, indicated probable longevity concerning the uplift of the Glint. Data obtained by Cacama (2015) point to reactivation phases of the TBL connected with rift (dextral and sinistral transcurrence) and drift phases in the opening of the equatorial Atlantic Ocean (shortening) preserved in fractures that transverse the east edge of Parnaíba Basin. Regarding more recent reactivations, Riente (2022) identified faults with low cohesion breccias, striated according to a transcurrent movement, in Cenozoic deposits associated with the northern sector of the Ibiapaba Glint, that may have reactivated former TBL planes of weakness. Accordingly, we consider that only transverse segments controlled by the TBL are likely to precede the cuesta-like plateau. Still, besides the absence of signs of fluvial erosion at the top of the canyon and the vertical cornice in the frontscarp, the lack of preserved deposits in the top of the transverse segments sustaining the longevity of the Poti River and its erosive action, hinder the applicability of a superposition model for this canyon.

In addition to this, a series of thermochronological (AFT) and field data have demonstrated that the Borborema Province underwent Cenozoic events significant to its geomorphological evolution such as intraplate magmatism (MUZISAKI et al., 2012), reactivation of Precambrian structures (CAVALCANTE, 2006), and uplift of Paleogene-Neogene formations (MORAIS NETO et al., 2009), correlated to the transition between Oligocene and Miocene. Therefore, it seems rather unlikely that the Poti River canyon portrays a direct inheritance of such past tectonic episodes (Cretaceous).

Another hypothesis for the evolution of the transverse segment of the Poti River concerns the river capture process through subaerial interception (LIMA, 1982). In this model, the primary evidence concerns the anomalous barbed arrangement of the upper course channels, intense headward erosion in the channels of the backslope of the Poti River, and occurrence of gravelly levels (rolled pebbles) capping the alluvial deposits of streams in depressed areas of the upper course (LIMA, 1982; 2020). In parallel, the sharp elbow of the Poti River and the organisation of the drainage network towards the north, upstream of the elbow, is also highlighted. The heterogeneity in composition, roundness and dimensions of the pebbles reported by Lima (1982) are discordant with the low-gradient rivers with which they are associated, suggesting that these streams composed more extensive and steeper drainages than those in the present fluvial context in the upper course. Consequently, this assembly of evidence allowed the interpretation of a drainage rearrangement through a river capture, which, in this theory, would be related to the integration of an endorheic basin peripheral to the Ibiapaba Glint (LIMA, 1982). A tributary of the middle course of the Poti River would have entrenched its incision by taking advantage of the structural zones of weakness of the TBL, intercepting a tributary of the adjacent system, victimising the paleoriver and rearranging its drainage towards the Parnaíba River.

Part of the evidence discussed by Lima (1982) is conformable to the geomorphometric data present in this research, as they suggest a context of river capture. The reverted drainage patterns and the higher incision of the channels observed in the northern margin support the field evidence presented by the author (LIMA, 1982). The topographic evidence of our work also concurs with the observations made by Lima (1982) on the disposal of gravelly levels, supporting the assertion about the existence of a paleoriver captured by the Poti River, possibly linked with the Acaraú River. The lack of data related to the age of the deposits mentioned by Lima (1982) and the absence of preserved terraces on top of the divides hinder the unravelling of the pirated stream's extension; despite that, it is assumed that at least the upper course of Acaraú paleoriver was victimised in the capture process (Figure 7). Ergo, the preservation of gravelly levels and the paleotopographic estimation of capture age (Seppômen method) direct attention to the correlation between this arrangement with an important period of global paleoclimate transition during the Pliocene to Pleistocene (BRIDGLAND; WESTAWAY, 2008). Several drainage rearrangements, controlled by an increase in the fluvial incision during Plio-Pleistocene glacial-interglacial transitions, were responsible for fluvial captures and integration of endorheic basins in different parts of the planet (STOKES et al., 2017; CUNHA et al., 2019; FREITAS et al., 2022).

Accordingly, a capture model is considered suitable for the morphogenesis of Poti Canyon according to the correlation between the following evidence: (i) sharp drainage inversion in a barbed pattern, indicating a substantial reversion of flow; (ii) preferential organisation from southern to northern Poti River hydrographic basin, in clear opposition to the orientation of the middle/low course; (iii) the slightly stepped topographic pattern of the depressions peripheral to the Glint, pointing to a connection among the drainages flowing across these surfaces; (iv) the presence of a low divide with the Acaraú river, which suggests the location of the valley of Acaraú paleoriver; and (v) steeper hillslopes in the backslope of the Glint, being a sign of more energetic gradients for the drainages linked with the Parnaíba River.

5.2. Role of epigenic weathering

Despite the referred correlation, the lithostructural analyses undertaken in our research point to fundamental differences regarding the type of river capture that occurred in the Poti paleoriver. The context of field evidence suggests that the process was established by the influence of epigenetic processes, and not only by the headward erosion over the Ibiapaba Glint.

Seepage, groundwater sapping, and dissolution at the phreatic level are regular epigenic processes observed throughout the evolution of canyons in siliciclastic rocks (LAITY; MALIN, 1985; DUSZYŃSKI; JANCEWICZ; MIGOŃ, 2018; MIGOŃ; DUSZYŃSKI, 2022). Such processes are subordinate to the correlation between porosity (both primary and secondary) and arenisation (LAITY; MALIN, 1985; WRAY; SAURO, 2017). Secondary porosity is essential to the chemical weathering in siliciclastic rocks, given that fracture planes control fluid flow and increase substrate permeability (WRAY; SAURO, 2017). Areas with high fracture density provide lithostructural zones of weakness conducive to epigene weathering (MIGOŃ, 2021). The arenisation – a term used to describe the solutional disintegration of siliciclastic rocks (WRAY; SAURO, 2017) – is controlled by the porosity and is effective in the chemical alteration of the cementing material, starting at grain boundaries (WRAY, 2013). The arenisation process is more intense in fine-grained quartz-rich rocks owing to the greater contact surface between grains (WRAY, 2013). With the progressive cement dissolution, the grains are disintegrated and etched by fluids through the fracture network (WRAY, 1997).

The opening of canyons in siliciclastic rocks is established by gravitational collapse according to structural planes of weakness (MIGOŃ; DUSZYŃSKI, 2022). The decrease in lithological cohesiveness due to the weathering of cement materials through fracture systems controls the formation of disintegration alveoles and a constant in situ detachment of rock blocks (DUSZYŃSKI; JANCEWICZ; MIGOŃ, 2018). The progressive enlargement of lithological discontinuities governs a gradual increase in subsurface fluid flow, favouring the groundwater sapping according to the topographic gradient (WRAY; SAURO, 2017; MIGOŃ; DUSZYŃSKI, 2022). The detached blocks coalesce, promoting valley opening and fracture-guided formation of canyons (WRAY; SAURO, 2017).

Within this framework, the Poti River Canyon presents evidence conforming to morphogenetic mechanics influenced by epigene weathering. In petrographic terms, the sandstone packages in the study area are coarsening-upward – coarse-grained towards the top – and essentially quartz-rich (AZEVEDO, 2015; FREITAS FILHO, 2018; LOUREIRO, 2019). The cementing materials usually compose 1% of these sandstones and consist of quartz, phyllosilicates and, iron oxide (AZEVEDO, 2015; FREITAS FILHO, 2018). This framework reinforces the tendency to epigene alteration of these terrains, given the influence of the coarser counterparts in the percolation and the thinner strata on the development of solutional features identified during the fieldwork.

The predominant occurrence of Ferrasols – soils formed by intense chemical weathering and leaching (RIBEIRO; ALBUQUERQUE, 2020) – capping the middle course areas strengthens the predisposition to seepage due to the primary porosity of sandstones in the study area. The secondary porosity appears to be another significant factor for the setting of local epigene alteration, considering the high distribution of lineaments mapped along the canyon. The context of reactivation in the TBL conforms to the location of areas with high lineament density, suggesting its influence over the position of transverse valleys. These areas with a high density of structural features, mainly associated with the Canindé Group, coincide with areas where the greatest amount of evidence of preserved epigene processes in the region was found (Figure 11). Furthermore, the location of the TBL also points to an important influence of rock strength, accounting for the difference in channel incision between streams in the northern margin of the middle course, which present deeper entrenchments, and the southern margin (Figure 4, C and D).

Additional environmental factors promote suitable conditions for epigene weathering in the study area such as high recharge at the phreatic level related to the presence of sparse aquifers of Serra Grande Group (LIMA, 2020), which is suggestive of favourable conditions for the recurrence of subsurface humidity, and the framework of Neogene-Quaternary regional paleoclimatic oscillations, resulting from maximums of atmospheric humidity (JENNERJAHN et al., 2004; FADINA et al., 2019; MORAIS NETO et al., 2009), which also explain the water availability for the long-term underground disintegration.

The evidence of solutional processes in the canyon walls correlated to the presence of collapsed blocks over the riverbed of the Poti River is indicative of a valley formation through the collapse of weathered substrates, as demonstrated in other canyons in sandstone rocks elsewhere (MIGOŃ; DUSZYŃSKI, 2022). Duszyński, Jancewicz and Migoń (2018) point out that the canyons formed via block collapse in the Broumov Highland (Czechia) exhibit cross-section with discontinuous morphologies along their valleys, which is similar to the context of transversal segments of the Poti River. These authors state that valleys opened by recent collapses are filled with large blocks and show narrow openings, as verified in sectors of Alto Canalão (Figure 5 and Figure 10). Recently exposed karst conduits denote a strong morphostructural control, composing valleys in narrow, fracture-guided corridors (ORTEGA-BECERRIL et al., 2010; HILL; POLYAK, 2014), a setting that is consistent with various segments of the Poti River (Figure 5). Valleys with a similar origin were reported in the brazilian semiarid region, both in carbonate (BAGNI et al., 2020; FURTADO et al., 2022) and siliciclastic rocks (MARTINS; SALGADO; BARRETO, 2017; BARRETO et al., 2022).

On that ground, beyond the lithostructural control exerted on the resistance to weathering, we consider that the substrates with high fracture density, connected to an important regional tectonic reactivation zone (TBL), favoured the development of subterranean fluvial interceptions. Indeed, the preservation of galleries and cavities is locally restricted with relation to the dimension of the study area, considering that no subterranean drainages were verified during the fieldwork. Despite this, we understand that the conjunction of lithostructural factors favourable to epigene weathering, the pronounced structural control on the canyon's segments, the frequent evidence of collapse present in the riverbed of the Poti River, and the asynchronous morphology of the cross-sections are indicators that the referred capture involved subterranean stream interception. According to the data presented, we hypothesise that the main sector of subterranean interception of this capture corresponds to the rocky pavement of Alto Canalão. This assumption is based on the fact that, in this segment, the canyon displays a narrower morphology compared to the main channel, its course exhibits the largest drainage inflexion over the E-W extension, and its depressed topography is bounded by steep and energic slopes associated with the immediate backslope of the Glint.

Accordingly, we understand that, since the last stages of regional structural reactivation (Oligocene-Miocene), the area has its lithological planes of weakness accentuated. The paleo-drainage network of the Poti River, controlled by the slope and array of TBL, gradually increased the topographic gradients in the northern margin, by taking advantage of the erodibility that results from epigene weathering and collapse of the sandstones (Figure 14, A). Similarly, the headward erosion of the Acaraú paleoriver advances towards the Ibiapaba frontscarp, as a function of energetic differences associated with the levels of dissection existing among the sedimentary plateau and the peripheral depression. The development of a differential gradient in the immediate backslope edge, related to the depressed zones that comprise the present Poti canyon, provided an energetic gain for the headwater of the Poti paleoriver (channels in the northern margin) in comparison with the tributary of the Acaraú paleoriver. Insofar as the Acaraú paleoriver headwater moves forward to the zone of influence of the TBL, their flows might have been captured by underground conduits developed in the Alto Canalão area, given the difference between the gradients established in the sedimentary plateau of the Serra Grande Group and the depressed surface in the immediate backslope edge. With the advance of the groundwater-sapping processes in the epigene conduits, the surfaces of Alto Canalão gradually collapsed, opening the N-S segment of the valley in the middle course (Figure 14, C).

From the established connection inherited from the analysed rearrangement, the upper course of the Acaraú paleoriver was reorganised towards the Parnaíba River through a large inflexion of drainage, which flows in the direction of the middle course of the Poti River. Such a river rearrangement encompassed a transference of drainage areas of approximately 10,540 km^2 between the paleodrainages of Acaraú and Poti rivers, possibly, the largest drainage rearrangement verified in the northern semiarid of Brazil. According to the paleotopographic data presented in this work, this capture would have been concluded (total transference from the upper course of the Acaraú paleoriver to the Poti paleoriver) after the Pleistocene, as a result of the gradual opening of the segments of the Poti River Canyon.

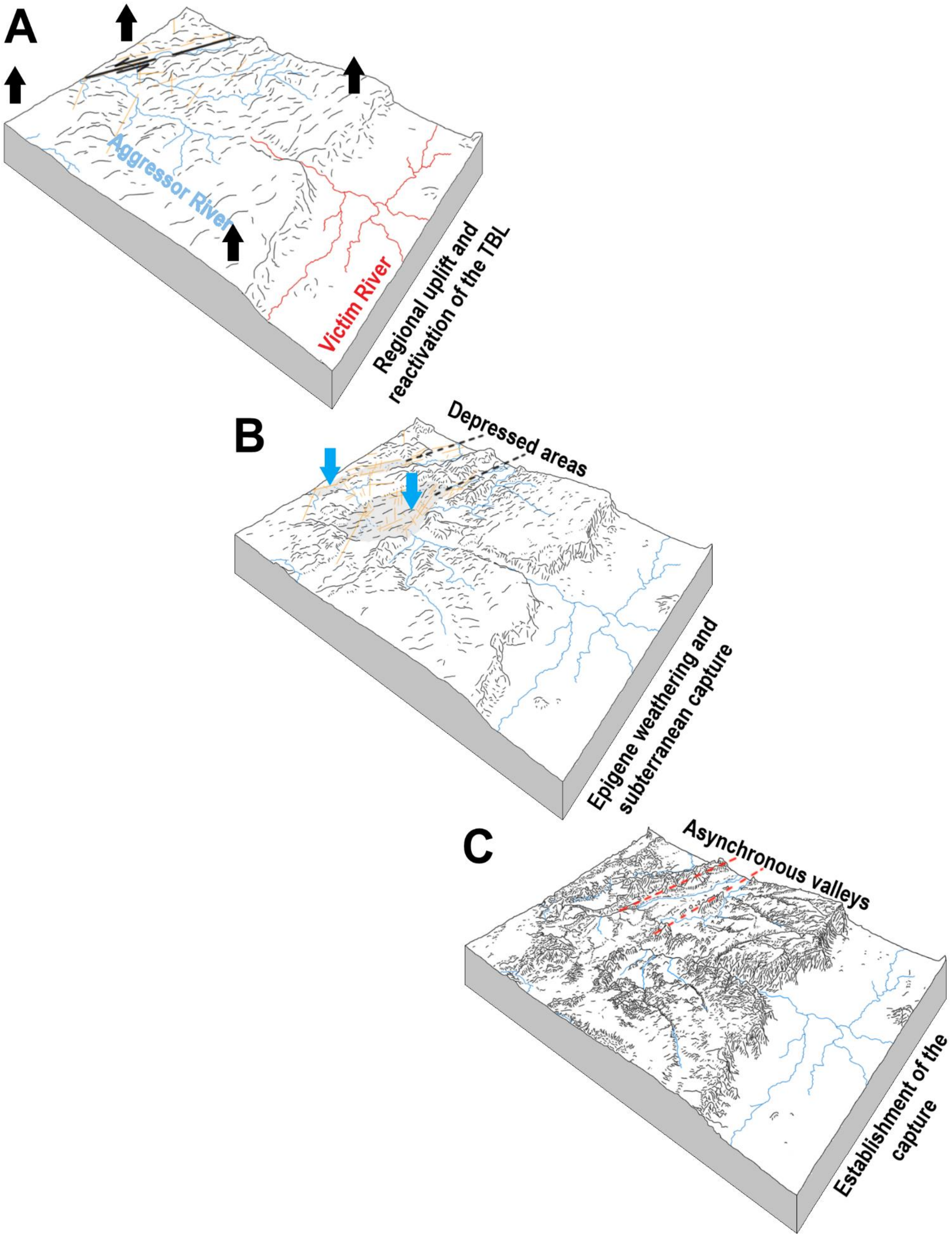

Figure 14. Evolutionary model of the Poti River Canyon. A – Cenozoic structural reactivations in the TBL, increasing the brittleness of the substrate due to the high fracture density. B – Development of subterranean conduits and differential gradient in the edge of the sedimentary plateau. C – Progressive collapse of sandstone rocks, controlling the opening of the canyons and the establishment of the capture. The black arrows indicate the regional uplift. The blue arrows point to the seepage through structural planes of weakness.

6. Conclusions

Within the given context, we first conclude that the transverse drainage of the Poti River originated after the uplift of the eastern edge of Parnaíba Basin, during the opening of the equatorial Atlantic Ocean in the Cretaceous. The episode appears to have been decisive for the onset of scarp retreat, the burial of peripheral depressions, the structural control of drainage systems in the backslope, and the beginning of the headward erosion of channels associated with the Acaraú River.

Cretaceous regimes may likely have promoted the diversion of possible past fluvial systems that would connect drainage areas in the upper-middle course; however, the study area does not present clear evidence that testifies to such an old age for superimposed channels with sudden inflexions. The evidence pointed out in this work indicates that the morphogenesis of this canyon is related to a drainage rearrangement between adjacent rivers by river capture.

Such a process was responsible for the piracy of the upper Acaraú paleoriver, which drained the peripheral depression of the Ibiapaba frontscarp. Its genesis would possibly be related to new energetic gains of fluvial gradients and the increased weakening of the substrate crosscut by the TBL, during the period of regional uplift in the Oligocene-Pleistocene and brittle reactivation of structures. Contrary to what was proposed in the pioneer model for the area (LIMA, 1982), the results of the present work indicate a strong possibility that this rearrangement was not established by a superficial fluvial interception. The headward erosion seems to possess a fundamental role in the progressive erosional lowering of the crystalline slopes supporting the frontscarp; nevertheless, the evidence of dissolution and block collapse reinforces the hypothesis that this capture occurred underground or, at least, with a significant contribution of subterranean solutional processes.

Therefore, the river capture was likely established through subterranean conduits in areas of high structural density associated with the TBL. The seepage of meteoric waters through the fracture network encountered subsurface beds prone to arenisation, providing favourable conditions for conduit inception. As the connections between the conduits increased, the underlying strata began to collapse asynchronously, guided by the structural planes of weakness, thus leading to the opening of transverse valleys that compose the Poti River Canyon. The existence of steeper gradients in the backslope was decisive for the capture, while the Neogene-Quaternary climatic oscillations promoted underground disintegration. In terms of age, we stipulate that this capture might have been completed since the Pleistocene; however, no absolute measurements were acquired to confirm this age. This context suggests new possibilities for research concerning the dating of fluvial deposits in the upper course of the Poti River and erosion rates involved in the opening of the canyon.

Finally, it is concluded that fluvial rearrangements, even under counterintuitive climatic conditions, are key in promoting relief evolution through the reordering of hydrographic divides and should be assessed with more attention. Arid and semiarid areas in South America, still little explored in this regard, are a fertile field of research due to the existence of other extensive transverse rivers lacking exploration in morphogenetic terms. Additionally, we highlight that the presented data is conformable with recent morphogenetic studies related to the opening of canyons in siliciclastic rocks elsewhere, supporting the role of solutional processes in the evolution of these valleys in different climatic regions on the planet.

Author Contribution: Conception, W. F. Rodrigues, R. P. Maia and A. A. R. Salgado; methodology: W. F. Rodrigues and A. A. R. Salgado; validation, W. F. Rodrigues, R. P. Maia and H. V. M. da Silva; formal analysis W. F. Rodrigues and R. P. Maia; research, W. F. Rodrigues; resources, H. V. M. da Silva and R. P. Maia; data preparation, W. F. Rodrigues; article writing, W. F. Rodrigues and R. P. Maia; review: A. A. R. Salgado and R. P. Maia; supervision, A. A. R. Salgado and R. P. Maia.

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