BARREIRAS SEDIMENTS AND LANDFORMS: OBSERVATIONS ON THE GEOMORPHOLOGICAL MEANING OF THE LATE CENOZOIC ONSHORE SEDIMENTATION ALONG THE EQUATORIAL MARGIN OF NORTHEASTERN BRAZIL

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RESUMO
O estudo sobre os Sedimentos Barreiras no Nordeste brasileiro fornece importantes dados acerca do último estágio da evolução da paisagem regional. Nas abordagens clássicas, a deposição desses sedimentos corresponderia às últimas fases de aplainamento do interior do continente. A partir de estudo morfo-estrutural detalhado, propomos uma revisão dessa correlação e uma nova interpretação sobre o significado geomorfológico desse depósito, na qual tectônica, eustasia e fatores climáticos são considerados. A espessura limitada dos sedimentos Barreiras e sua distribuição em uma estreita faixa costeira refletem apenas a denudação de uma camada fina de rocha, compatível com a remoção de antigos saprólitos e fraco downwearing e backwearing, impedindo qualquer desenvolvimento de um novo ciclo de erosão. Sua formação e parcial preservação talvez possam ser explicadas não apenas por mudanças climáticas e/ou tectônicas no Terciário Superior, mas também por subsidência da previamente aplainada faixa costeira.

ABSTRACT
The study of the Barreiras sediments in northern Brazilian Nordeste gives interesting clues on the last stages of landform evolution. In classical views, their deposition would correspond to the last planation phases of inland regions. On the basis a detailed morphostructural study, we propose a reassessment of this correlation and a new interpretation of the geomorphological meaning of these sediments, where tectonic, eustatic and climatic factors are taken into account. The limited thicknesses of the Barreiras sediments and their distribution on a narrow coastal strip only reflect the denudation of a thin rock slice, compatible with stripping of former saprolites, and weak downwearing and backwearing processes, precluding any development of a new cycle of erosion. Their formation and partial preservation might be explained not only by climatic and/or tectonic changes in the Upper Tertiary, but also by subsidence of a previously planated coastal strip.

Key words : barreiras, correlative sediment, etchplanation, palaeo-piedmont, planation surface, subsidence.

1. INTRODUCTION

From the Amazon delta to the Rio de Janeiro coast, a thin Late Cenozoic sedimentary sequence called the Barreiras Group crops out along more than 4,000 km of the Brazilian littoral zone. Formed late in the history of Atlantic opening, these clastic sediments are correlative of the last stages of inland morphological evolution. In classical views, their deposition would correspond to the last planation phases (Bigarella, 1975). On the basis of a detailed morphostructural study of the equatorial margin of northeastern Brazil (Peulvast & Claudino Sales, in prep.), we propose a reassessment of this correlation and of the geomorphological meaning of these sediments.

2. LOCATION AND SETTING

The studied area is part of the Brazilian Equatorial continental margin, formed after oceanic opening in Aptian times. Onshore, the structural pattern is organized around NE-SW Mesozoic rift structures intersected by the transform margin in the Potiguar Basin area. A thin dissected layer of Cenozoic sediments (the Barreiras Group) is preserved on a coastal strip, forming low-lying plateaus or "tabuleiros" (10 to 60 m) between the two segments of a discontinuous "Great Escarpment" (from Fortaleza to the Northern Ibiapaba, and south of the Potiguar basin) and the shallow continental shelf. This 10 to 80 km wide strip is almost interrupted near Fortaleza, where coastal mountains rise up to 800 m a few kilometres only from the shoreline.

These slightly dissected lowlands form the transition between the coast and the vast pediplains (the « Sertaneja Depression ») which extend far inland on the basement, between these mountains, forming the floor of a huge and complex amphitheatre pattern surrounded by the Ibiapaba, Araripe and Borborema plateaus. The Barreiras sediments directly overlie the weathered basement, but also lie unconformably on Late Cretaceous sediments in the Potiguar Basin. Covering the distal parts of the Sertaneja surface, they are reduced to erosive remnants disconnected from source areas and dissected by rivers flowing to the ocean. They mostly overlook the sea by low active or abandoned sea-cliffs resulting from the marine erosion which obscures the lateral relationships with shelf sediments. Narrow basement outcrops locally separate the "tabuleiros" from the continental shelf, forming weakly prominent points.

3. GEOLOGY

The Cenozoic onshore deposits differ from their offshore counterparts - the upper part of the Tibau Formation - by their limited thickness (less than 80 m, often less than 15 m) and their relatively uniform

distribution along the coast. These clastic sediments are known as part of the "Barreiras Group" (Mabesoone et al., 1972 ; Bigarella, 1975). They slightly dip seaward from a few tens of meters inland to sea level or lower at the coast. They present multiple vertical and lateral facies variations, and are probably diachronous. On the calcareous Chapada do Apodi, on both sides of the Rio Apodi valley, a few hills usually considered as built with sediments of the Barreiras Group present greater thicknesses (up to 180 m) and altitudes (210 m and 270 m), suggesting a locally more complex depositional, erosive and tectonic history.

Inland sections show layers of reddish to yellow or white argilaceous sands with minor amounts of quartz gravel, and more clay beds at depth. Many sea cliff outcrops also expose coarser deposits, below dune and palaeodune deposits. Silt and clay beds (kaolinite) are intercalated among layers of massive ferruginous sandstones or conglomerates with rounded to sub-angular quartz and crystalline pebbles, often poorly sorted ; bedding may be obliterated by synsedimentary plastic deformations. Ferruginous gravels and clay balls, and also carbonate concretions and bioturbations are also found in these conglomerates. A more or less developed lateritic horizon locally tops this layer, below argillaceous sands which grade upwards to white, yellow to reddish sands with sparse sub-angular quartz gravels. Commonly referred to as palaeodune material, these sand deposits are probably more complex, representing weathered material formed in dune, interdune (creeks and ponds), lagoon and shore environments (Menezes *et al*., 1998; Claudino Sales, 2002). Conglomeratic materials are best represented in the vicinity of present river mouths and of mountains approaching the coast.

In the Natal area, relative dating by palaomagnetism and micropollen indicates a Miocene to Pliocene age (Bezerra *et al*., 2001). According to Shimabukuro & Arai (2001), the identification of the effects of the Tortonian regression on sediments of the the margin would lead to distinguish a pre-Tortonian series of Aquitanian-Serravallian age from a post-Tortonian series of Neomiocene to Pliocene age. It has been suggested that the Barreiras sediments of eastern Ceará lie in the continuation of the Faceira Formation, a fluvial terrace deposit preserved along the lower courses of the Jaguaribe and Banabuiu Rivers, on their left side.

4. BARREIRAS SEDIMENTS AND LANDFORM EVOLUTION

Classical models

The Brazilian Nordeste is at the centre of classical debates in geomorphology. One of them concerns stair-stepped systems of planation surfaces considered as the result of cyclic evolution related to break-up of the Gondwana supercontinent and uplift of eastern Brazil since the Cretaceous (e.g., King, 1956). Another matter of interest is the meaning of the landscapes of pediplains strewn with residual massifs and inselbergs, and the relationships between the formation of some of them and the Barreiras sediments. In classical views, these deposits would be correlative of the last planation phases (Pd1 and P2 or Patos or Sertaneja ; Bigarella, 1975).

All authors recognize the existence of several stair stepped planation surfaces, more or less covered by or related to Mesozoic and Cenozoic sediments (Mabesoone & Castro, 1975), and mostly correlated with those defined in other regions of Brazil. Among them, an intermediate surface or pediplain (Pd1) would be correlated with Upper Tertiary sediments (Guararapes Formation). The upper deposits of the Barreiras Group would be correlative of the planation of the lowest main surface (Patos, P2, Sertaneja), which bears the most conspicuous inselbergs and inselgebirge. Lower pediments (P1, Paraguaçu) would have been carved into this surface during glacial-interglacial cycles of mid- or upper Pleistocene age.

The pre-Barreiras surface : a palaeo-piedmont

Although we do not find the same pattern of multiple erosion surfaces in the studied area, stair-stepped landforms of different natures are present throughout the region. We identify high surfaces, forming plateaus or narrow butte tops between 700 and 1000 m, and low surfaces – the Sertaneja surface -, mostly below 300 m, connected seaward to the wide coastal surface bearing and including the tabuleiros. Whereas high surfaces bevel practically all structures exposed to erosion, low surfaces only reflect partial planation, forming erosion piedmonts below residual volumes. They are not systematically younger than the upper surfaces. The most conspicuous of them is the low exhumed pre-Albian surface of the Potiguar region, which forms the piedmont of high rift shoulder remnants and whose continuations are recognized around the lower Jaguaribe valley (“Jaguaribe Surface”). Its development indicates strong syn-rift erosion, before burying in the Albian-Cenomanian. Today, parts of the surrounding Sertaneja surface correspond to this exhumed surface.

The lateral topographic continuity between this surface and the low pediplains that surround the mountains of northern Ceará might suggest similar ages for these pediplains. The low planation surface partly buried below the Cenozoic Barreiras sediments belongs to this palaeo-piedmont, whose inner parts are exposed in the plane of the clastic deposits. It is well identified around the gently dipping contacts between the sediments and their substrate, along the coast and along shallow valleys incised down to the basement. Though it generally forms a flat surface, it is locally more irregular, with low rounded hills and inselbergs protruding through the sedimentary cover. Around Fortaleza, the Barreiras sediments surround volcanic necks towering on the buried surface, and locally fill depressions of the underlying weathered basement (Cunha & Castelo Branco, 2002).

In western Ceará, this surface is the distal continuation of the slightly dissected Sertaneja depression. It clearly post-dates Cretaceous faulting along the Sobral-Pedro II shear zone. In eastern Ceará, its profile coincides with the continuation of the Jaguaribe surface, but at regional scale, it bevels both the basement and the sediments of the Chapada do Apodi, therefore appearing as a post-

Campanian surface. The deposition of Barreiras argilaceous sands around volcanic necks in the Fortaleza area implies that the underlying surface was shaped or re-shaped after erosive destruction of the former volcanoes, formed 35 Ma ago.

Erosion and the origin of the Barreiras sediments

Burying of planated and dissected topographies carved into deformed post-Campanian sandstones, conglomerates and laterites on the coast of the Potiguar basin between Peroba and Ponta Grossa (Icapui) suggests that parts of this surface record a complex pre- and syn-Barreiras erosional history, whose last stages may have been controlled by Late-Cenozoic sea-level falls. Therefore, far from being simple, the piedmont surface is a composite one, whose buried distal parts as well as exposed proximal elements intersect each other at low angles (fig. 1) and locally comprise dissected surfaces. Both buried and exposed parts, whose last stages of erosional shaping probably provided the Barreiras deposits, are diachronous in age. Rather than resulting from of a cyclic erosion sequence, such a geometry implies some kind of acyclic evolution, such as described in distal parts of uplifting areas, in wide flexural zones where interplay between moderate uplift and variations of the base level remain unsufficient for triggering stages of deep dissection and renewed pediplanation.

In the classical views, the sediments of the Barreiras Group would have been produced by stripping of weathering profiles formed in humid conditions, and deposited near the base level in the form of coalescent alluvial fans (Claudino Sales, 2002), by rivers or debris flows, under semi-arid climates. The present inland distribution of saprolites and waste deposits gives only limited information on the origin of these sediments. Rather thin soils and saprolites prevail, in relationship with mainly semi-arid climatic conditions (lithic soils, brown or beige soils, "planossols"). Remains of waste deposits, argillaceous, often ferruginous, sands and gravels of fluvial to colluvial origins are found either on high basement surfaces (southwest Ceará), or on slightly dissected pediplains at low altitudes. The most of them probably represent old formations, even on low surfaces, since a slight entrenchment of valleys now cuts them from the escarpements that probably once formed their source areas, up to 20 or 30 km away (Baturité and Quixadá areas). North of the Banabuiú river, some of these deposits probably belong to transitional facies of the fluvial Faceira Formation.

Preliminary observations of sparse deposits of coarse quartz and quartzite pebbles and gravels, several meters thick, were made on dissected fans, pediment roots and high fluvial terraces, 40 to 140 km from the coast, south of the Potiguar basin, north of the Baturité massif, and along the upper Curu river. Their presence implies the occurrence of periods of active erosion of mountain slopes and of alluvial fan construction on proximal parts of the low pediplains, followed by partial destruction and river entrenchment. This dissection, similar to that of the Barreiras sediments, may suggest a stratigraphic relationship between both sets of deposits. Such a correlation would indicate that slight scarp retreat, downwearing and even beginning dissection of the Sertaneja pediplain, were involved in this process.

Nevertheless, the limited thicknesses of the Barreiras sediments and their distribution on a narrow coastal strip (5 to 40 km) only reflect the denudation of a thin rock slice – a few metres -, since contributing areas are generally as wide as the buried ones or wider. Therefore, an abrupt change of the regional geometry, involving the development of an entirely new cycle of erosion, can be precluded (fig. 1).

Sedimentation and sea level

Dissection of the Barreiras deposits in triangular remnants by shallow valleys, down to the basement suggests that they previously formed a more continuous apron before the earliest (Tortonian, Messinian) or last (Pleistocene) sea level falls which occurred in the Late Cenozoic. The presence of erosion unconformities suggests a complex history where only the last Pleistocene regressions allowed this dissection. The main deposition episodes must therefore be older, Middle Miocene or Pliocene. Erosion regimes had prevailed in older times, as suggested by planation or local dissection of the substrate, which therefore should have been accomplished in a context of high pre-Tortonian sea levels (40 to 150 m), or of variable sea levels until the Lower Pliocene (Tortonian and Messinian regressions). High sea levels (up to 80 m) still prevailed during long parts of the Pliocene. Nevertheless, Tertiary, pre-Barreiras marine sediments are not found on this surface.

Therefore, either the pre-Barreiras surface was formed at higher levels than its present altitudes (30-80 m to 0 or less) or marine sediments were deposited on it (it would therefore have to be older, but not older than 35 Ma), and then stripped by erosion before the Barreiras sedimentation. In both cases, the continental facies presently found down to the present sea level or lower would have been deposited in areas which underwent later subsidence (fig. 1). An alternative interpretation would be that the Barreiras sediments, like the so-called “Continental Terminal” deposits of Senegal (Lappartient, 1985), contain more deposits of marine origin than presently assumed (Menezes et al., 1998 ; Claudino Sales, 2002). The thin and discontinuous sedimentary cover of inner surfaces – no thick bajada deposit is preserved at the foot of major escarpments - suggests that erosional regimes prevailed at distance from the coast, in response to flexural uplift and in relation with a very long lasting re-shaping and downwearing process.

5. DISCUSSION: MORPHOTECTONIC AND PALAEOENVIRONMENTAL IMPLICATIONS

Barreiras sediments and the evolution of the passive margin

A suggested higher, the formation and partial preservation of the Barreiras sediments might be explained not only by climatic and/or tectonic changes in the Upper Tertiary, but also by subsidence of a previously

planated coastal strip belonging to a wide marginal flexural pattern. Sedimentation continued until the subsidence rate was overstepped by increasing rates of sea level fall, in the Late Miocene, and since the Late Pliocene, as shown by the end of the building process of wide coalescent alluvial fans and by their final dissection, after a complex interplay between continental and marine deposition, at least in distal areas. The more common occurrence of coarse continental deposits around Fortaleza and to the west than on the easternmost coastline may reflect both the proximity of higher mountains, the occurrence of denudation pulses in these mountains and a lesser subsidence around the Baturité-Fortaleza region, less favourable to such interplays.

As in the Late Cretaceous layers of the Potiguar basin, the horizontal or gentle dips of the Barreiras sediments do not suggest strong deformation of the coastal area, but are compatible with the effects of the last stages of a flexural movement of the margin. Their dissection in large triangular plateaus probably reflects this gentle flexuration. The preservation of old surfaces at low altitudes and the lacking evidence of Cretaceous and Tertiary marine transgressions on large parts of them suggest that downwarping of the coastal areas may have occurred until recent times. Inland, beyond the hinge line of this wide flexure, we rather have evidence of prevailing uplift, erosion and possible but limited scarp retreat. These patterns are inconsistent with deep denudation having occurred along and across the whole of the coastal strip below the escarpment.

Barreiras sediments and palaeoenvironments

The presence of iron-rich horizons at several levels of the Barreiras sediments, and of true laterites on older formations on the Apodi and other plateaus suggests that seasonally dry tropical environments prevailed during significant parts of the post-breakup history. According to Tardy & Roquin (1998), conditions favourable to laterite formation might have occurred in northeastern Brazil mainly during Early Tertiary, whereas later and drier periods (Neogene) would have only allowed sporadic formation of ferruginous gravels in "latossolos" at low altitude. Such a trend also appears in larger areas of tropical South America for the past 13 m.y. – especially from 12 to 10.5 Ma and since 8 Ma - from the study of the terrigenous sedimentation on the Ceará Rise (Harris & Mix, 2002). If, as suggested by Molnar (2001), increased aridity enhances large-scale erosion, it might also explain the increase in the clastic sedimentation observed in the offshore Potiguar basin since the Miocene (Pessoa Neto, 2002), related or not to significant uplift of adjacent inland areas.

In return, the moderate average erosion rates evaluated from the identification of palaeosurfaces at different levels may explain the globally moderate uplift triggered by denudational rebound. The transient accelerations observed in erosion rates, including the Neogene, which is the period of the Barreiras deposition, seem to have been mainly controlled by climatic, tectonic or eustatic factors. Climatic changes probably induced numerous short term fluctuations (particularly in the intervals 13-10.5 and 4-0 Ma), involved in the etchplanation that contributed to regrade the low planation surfaces and extend them in the interior. The identification of coarse alluvial fans on dissected pediments, below high mountain slopes bearing marks of deep denudation and demolition of rock cornices, and the presence of thick gravel terraces along major rivers probably reflect the occurrence of periods favourable to widespread stripping of deep soil horizons and even to erosion of bare rock slopes and surfaces. Such events may have taken place in relation with dry conditions and discontinuous vegetation cover, allowing the occurrence of debris flows and torrential floods, and they were followed by dissection stages in periods of more humid climate and/or of lower sea level.

6. CONCLUSION

The study of the Barreiras sediments in northern Nordeste gives interesting clues on the last stages of landform evolution. The formation and the partial preservation of the Barreiras sediments is explained not only by climatic and/or tectonic changes in the Upper Tertiary, such as suggested by most authors, but also by slight subsidence of a previously planated coastal strip belonging to a wide marginal flexural pattern. Sedimentation continued until the subsidence rate was overstepped by increasing rates of sea level fall, in the Late Miocene, and since the Late Pliocene, as shown by the end of the building process of wide coalescent alluvial fans and by their final dissection, after a complex interplay between continental and marine deposition, at least in distal areas. The diversity of combinations between morphoclimatic and bioclimatic sequences, and the eustatic fluctuations probably reflects a very complex palaeoenvironmental history in the Upper Cenozoic. The geographical diversity of situations along the studied margin suggests that its evolutionary history is a composite one, but all these patterns are inconsistent with deep denudation on the coastal strip. Variations in relief in the highlands and across the coastal strip below the escarpments, and the associated differential preservation of palaeosurfaces may reflect significant changes in the morphotectonic styles along the margin.

REFERENCES

BEZERRA F.H.R., AMARO V.E., VITA-FINZI C. & SAADI A., 2001. Pliocene-Quaternary fault control of sedimentation and coastal plain morphology in NE Brazil. J. South Am. Earth Sci., 14: 61-75.

BIGARELLA J.J., 1975. The Barreiras Group in Northeastern Brazil. An. Acad. Bras. Ciên., 47: 365-393.

CLAUDINO SALES V.2002. Evolution géomorphologique de la zone côtière de Ceará (Nord-est du Brésil) : du long terme au court terme. Thèse de doctorat, Univ. Paris IV, 524 p.

CUNHA L.S. & CASTELO BRANCO R.M.G., 2002. Configuração 3-D dos sedimentos quaternaries baseada em inverses de dados geofísicos elétricos e eletromagnéticos, região costeira de Cascavel – Ceará. XLI Congr. Bras. Geol., João Pessoa, Anais, p. 85.

HARRIS S.E. & MIX A.C., 2002. Climate and tectonic influences on continental erosion of tropical South America, 0-13 Ma. Geology, 30, 5:447-450.

KING L.C., 1956. A geomorfologia do Brasil oriental. Rev. Bras. Geografia, (18)2: 3-121

LAPPARTIENT J.R., 1985. Le Continental Terminal et le Pléistocène ancien du bassin sénégalo-mauritanien : stratigraphie, sédimentation, diagenèse, altération ; reconstitution des paléorivages au travers des cuirasses. Thèse, Aix-Marseille 3, 285 p.

MABESOONE J.M., CAMPOS E SILVA A. & BEURLEN K., 1972. Estratigrafia e origem do Grupo Barreiras em Pernambuco, Paraíba e Rio Grande do Norte. Rev. Bras. Geoc., 2: 173-188.

MABESOONE J.M. & CASTRO C., 1975. Desenvolvimento geomorfológico do nordeste brasileiro. Bol. Núcleo Nordeste da SGB, Recife, 3:5-35.

MENEZES M.R.F., DANTAS E. P. & CALDAS L.H., 1998. Estudos sedimentológicos na formação Tibau, porção emersa da Bacia Potiguar. An. Congr. Bras. Geol., Belo Horizonte, p. 77.

MOLNAR P., 2001. Climate change, flooding in arid environments and erosion rates. Geology(29)12:1071-1074.

PESSOA NETO O.C., 2002. Estratigrafia de seqüência do Neogeno da Bacia Potiguar, NE do Brasil. Anais XLI Congr. Brasileiro Geologia. João Pessoa, Anais, p. 276.

PEULVAST J.P. & CLAUDINO SALES V., in prep. Landforms, Great Escarpment and structural heritage on the northern Brazilian "Nordeste".

PEULVAST J.P. & CLAUDINO SALES V (2002). Superfícies de aplainamento: revisitando um problema clássico em Geomorfologia. Mercator – Revista de Geografia da UFC 1:113-150

PEULVAST J.P. & VANNEY J.R., 2002. Géomorphologie structurale, tome2. Relief et géodynamique. CPI-GB Science Publ., Paris, et BRGM Editions, Orléans, 523 p.

SHIMABUKURO S. & ARAI M., 2001. A discordância tortoniana e sua relação com o arcabouço estratigráfico do Grupo Barreiras e unidades correlatas (Neogeno do Brasil). XVII Congr. Bras. Paleontologia, Acre, Boletim de resumos, p. 54.

TARDY Y. & ROQUIN, 1998. Dérive des continents, paléoclimats et altérations tropicales. BRGM, Orléans, 473p.

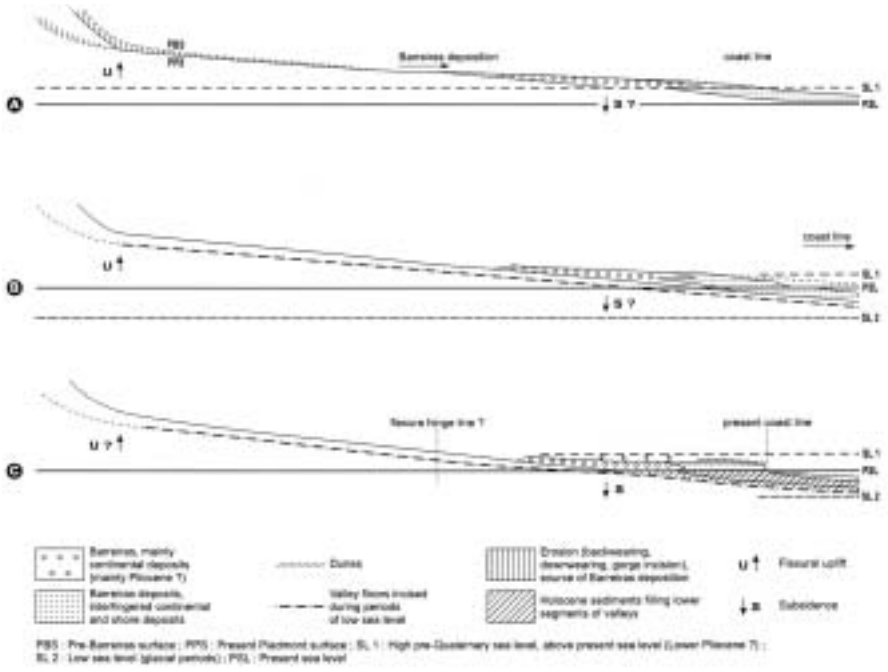

Figure 1. Sketch-diagramme showing possible relationships between the Upper Cenozoic tectonic evolution of the margin, the Pliocene and Quaternary sea levels and sequences of deposition and erosion of the Barreiras sediments.
A : Pliocene (?), high sea level, Barreiras deposition ;
B : period of low sea level stand (Pleistocene, glacial maximum), dissection ;
C: Interglacial or Present, infilling of low valleys.