Géographie physique et Quaternaire

Geomorphology of an Exhumed Carboniferous Paleosurface in the Southern Gaspé Peninsula, Québec: Paleoenvironmental and Tectonic Implications

Géomorphologie d'une paléosurface exhumée dans le sud de la Gaspésie, Québec : implications tectoniques et environnementales.

Geomorphologie einer aufgedeckten Karbon-Paläooberfläche in der südlichen Gaspé-Halbinsel: Folgen für Paläoumwelt und Tektonik.

Pierre Jutras et Jacques Schroeder

Volume 53, numéro 2, 1999

URI : https://id.erudit.org/iderudit/005690ar
DOI : https://doi.org/10.7202/005690ar

Aller au sommaire du numéro

Éditeur(s)

Les Presses de l'Université de Montréal

ISSN

0705-7199 (imprimé)
1492-143X (numérique)

Découvrir la revue

Citer cet article

Jutras, P. & Schroeder, J. (1999). Geomorphology of an Exhumed Carboniferous Paleosurface in the Southern Gaspé Peninsula, Québec: Paleoenvironmental and Tectonic Implications. *Géographie physique et Quaternaire*, *53*(2), 249–263. https://doi.org/10.7202/005690ar

Résumé de l'article

La sédimentation du Carbonifère dans le sud de la péninsule gaspésienne a fossilisé une paléosurface qui est maintenant graduellement exhumée par érosion. Une partie de cette surface a été coupée à l'horizontale au cours d'un épisode majeur de pénéplanation s'étant déroulé entre 290 Ma (Permien) et 200 Ma (Jurassique). L'exhumation de cette surface, sous la ligne de pénéplanation, doit aussi avoir débuté au cours du Jurassique en réponse au soulèvement « en bloc » des marges passives de l'océan Atlantique, alors en processus d'ouverture. Certains traits géomorphologiques de la paléosurface exhumée fournissent des indices concernant la tectonique et les paléoenvironnements du Carbonifère. Une surface d'aplanissement limitée par un escarpement, lequel mène à une autre paléosurface surélevée occupée par les mêmes formations rocheuses, est ici considérée comme une paléoterrasse d'abrasion (associée à la transgression du Windsor) car celle-ci ne peut s'expliquer dans un contexte d'érosion différentielle, de mouvement de faille ou d'« etchplanation ». Une série d'escarpements de faille découpant les surfaces d'aplanissement sont considérés comme étant le résultat d'une activité de faille post-acadienne. La préservation de crêts calcaires sur la paléosurface exhumée, montrant un faciès morphologique témoignant d'un climat aride, est ici considérée comme étant liée à une fossilisation clastique pré-windsorienne ou à un déplacement latéral post-windsorien. Le réseau fluvia- tile très étroitement encaissé, qui encore présentement dissecte la surface d'aplanissement principale de la péninsule, et les systèmes karstiques de cette surface et de la paléosurface exhumée, sont interprétés comme ayant évolué depuis les temps jurassiques. Cependant, quelques cas d'antécédences fluviatiles dans les hautes-terres du centre-nord gaspésien, représenteraient des entailles fluviatiles encore plus anciennes.

Géographie physique et Quaternaire, 1999, vol. 53, n° 2, p. 249-263, 10 fig.

GEOMORPHOLOGY OF AN EXHUMED CARBONIFEROUS PALEOSURFACE IN THE SOUTHERN GASPÉ PENINSULA, QUÉBEC : PALEOENVIRONMENTAL AND TECTONIC IMPLICATIONS

Pierre JUTRAS* and Jacques SCHROEDER**, Département des Sciences de la Terre, Département de Géographie, Université du Québec à Montréal, C.P. 8888, succursale Centre-ville, Montréal, Québec H3C 3P8.

ABSTRACT Carboniferous sedimentation in the southern Gaspé Peninsula has fossilized a paleosurface which is now gradually being exhumed by erosion. Part of the surface was horizontally cut by a major peneplanation event that took place between 290 Ma (Permian) and 200 Ma (Jurassic). Exhumation of the surface below the peneplanation line must also have started by Jurassic time in response to the *en bloc* uplift of the evolving Atlantic Ocean's passive margins. Some geomorphic features of the exhumed paleosurface bring clues regarding Carboniferous paleoenvironments and tectonics. A planation surface limited by a scarp, which is leading to a higher planation surface occupied by the same rock formations, is here interpreted as a paleowave-cut platform (associated to the Windsor transgression) for it cannot be explained by differential erosion, fault movement or "etchplanation". A series of fault scarps cutting through planation surfaces are interpreted as being the result of post-Acadian fault activity. The preservation of limestone hogbacks on the exhumed paleosurface, which are interpreted as having evolved under an arid climate, is believed to be either related to a pre-Windsor clastic fossilization or to post-Windsor lateral displacement. The tightly embanked river system, which is still currently dissecting the Peninsula's main planation surface, and the karstic systems of both that surface and the exhumed paleosurface, are interpreted as having evolved since Jurassic Time, except for a few cases of river antecedence in the north-central highlands which are interpreted as representing even older river routes.

RÉSUMÉ *Géomorphologie d'une paléosurface exhumée dans le sud de la Gaspésie, Québec : implications tectoniques et environnementales.* La sédimentation du Carbonifère dans le sud de la péninsule gaspésienne a fossilisé une paléosurface qui est maintenant graduellement exhumée par érosion. Une partie de cette surface a été coupée à l'horizontale au cours d'un épisode majeur de pénéplanation s'étant déroulé entre 290 Ma (Permien) et 200 Ma (Jurassique). L'exhumation de cette surface, sous la ligne de pénéplanation, doit aussi avoir débuté au cours du Jurassique en réponse au soulèvement « en bloc » des marges passives de l'océan Atlantique, alors en processus d'ouverture. Certains traits géomorphologiques de la paléosurface exhumée fournissent des indices concernant la tectonique et les paléoenvironnements du Carbonifère. Une surface d'aplanissement limitée par un escarpement, lequel mène à une autre paléosurface surélevée occupée par les mêmes formations rocheuses, est ici considérée comme une paléoterrasse d'abrasion (associée à la transgression du Windsor) car celle-ci ne peut s'expliquer dans un contexte d'érosion différentielle, de mouvement de faille ou d'« *etchplanation* ». Une série d'escarpements de faille découpant les surfaces d'aplanissement sont considérés comme étant le résultat d'une activité de faille post-acadienne. La préservation de crêts calcaires sur la paléosurface exhumée, montrant un faciès morphologique témoignant d'un climat aride, est ici considérée comme étant liée à une fossilisation clastique pré-windsorienne ou à un déplacement latéral post-windsorien. Le réseau fluviatile très étroitement encaissé, qui encore présentement dissecte la surface d'aplanissement principale de la péninsule, et les systèmes karstiques de cette surface et de la paléosurface exhumée, sont interprétés comme ayant évolué depuis les temps jurassiques. Cependant, quelques cas d'antécédences fluviatiles dans les hautes-terres du centre-nord gaspésien, représenteraient des entailles fluviatiles encore plus anciennes.

ZUSAMMENFASSUNG *Geomorphologie einer aufgedeckten Karbon-Paläooberfläche in der südlichen Gaspé-Halbinsel : Folgen für Paläoumwelt und Tektonik.* Die Sedimentierungen im Karbon in der südlichen Gaspé-Halbinsel führte zur Fossilisation einer Paläooberfläche, die jetzt durch Erosion langsam bloßgelegt wird. Ein Teil der Fläche wurde horizontal durch ein bedeutendes Einebnungs-Ereignis durchschnitten, das zwischen 290 Ma (Perm) und 200 Ma (Jura) stattfand. Die Bloßlegung der Fläche unter der Einebnungslinie muss auch in der Jura-Zeit begonnen haben als Reaktion auf die « en bloc »-Anhebung der sich entwickelnden passiven Küstenzone des Atlantischen Ozeans. Einige geomorphologische Merkmale der aufgedeckten Paläooberfläche liefern Hinweise in Bezug auf Paläoumwelt und Tektonik im Karbon. Eine Einebnungsoberfläche, die durch einen Abhang begrenzt ist, welcher zu einer höher gelegenen Einebnungsfläche mit denselben Felsformationen führt, wird hier als eine Paläo-Abrasionsplatte interpretiert (welche mit der Windsor-Transgression in Verbindung gebracht wird), denn sie kann nicht durch Differentialerosion, Verwerfungsbewegung oder « Etchplanation » erklärt werden. Eine Reihe von Verwerfungshängen, welche die Einebnungsoberflächen durchschneiden, interpretiert man als Ergebnis einer post-akadischen Verwerfungsaktivität. Die Erhaltung von Kalkstein-Graten auf der bloßgelegten Paläooberfläche, von denen man meint, dass sie sich in einem trockenen Klima entwickelt haben, führt man entweder auf eine Prä-Windsor-Fragmentalfossilisation oder eine Post-Windsor-Lateralverschiebung zurück. Das eng eingesenkte Flusssystem, das immer noch die Haupt-Einebungsoberfläche der Halbinsel durchschneidet und die Karst-Systeme sowohl dieser Oberfläche wie auch der bloßgelegten Paläooberfläche interpretiert man als Ergebnis einer Evolution seit dem Jura. Davon ausgenommen sind einige vorausgehende Fluss-Ereignisse im zentralen nördlichen Hochland, die man als noch ältere Flussrouten interpretiert.

Manuscrit reçu le 27 août 1998 ; manuscrit révisé accepté le 10 février 1999

* E-mail address: d322144@er.uqam.ca

** E-mail address: schroeder.jacques@uqam.ca

INTRODUCTION

An exhumed Carboniferous paleosurface has been identified in the southernmost section of the Gaspé Peninsula, in eastern Québec (Bail, 1983; Jutras, 1995; Peulvast *et al.,* 1996). A closer structural geomorphology examination has provided clues regarding Carboniferous paleoenvironments and post-Acadian deformations. Analysis of the exhumed paleosurface was done through superimposing geological and topographic field data with a study of geological maps, topographic maps, aerial photographs, numerical 3-D models and various remote sensing images. The study area, covering approximately 4 500 km^2 (Fig. 1), is currently being investigated in terms of its Carboniferous stratigraphy, sedimentology and structural geology. This paper can therefore be regarded as a preliminary geomorphological study.

GEOLOGICAL SETTING

The basement of the paleosurface, in the study area, is mainly occupied by Silurian rocks of the Chaleurs Group. It covers part of a structural zone which is now generally referred to as the "Chaleur Bay Synclinorium" (Bourque *et al.,* 1995) (Fig. 1c). It is also occupied, to the west, by Ordovician rocks (the Honorat Group) seemingly untouched by the Taconian phases that affected rocks of the same age in the northern part of the peninsula (De Broucker, 1987; Bourque *et al.,* 1993). These rocks are part of a structural zone which is now generally referred to as the "Aroostook-Percé Anticlinorium" (Bourque *et al.,* 1995) (Fig. 1c). To the east, the paleosurface is occupied by the "Maquereau-Mictaw Inlier" (Fig. 1c), comprising older rocks of Late Precambrian to Middle Ordovician age. The Maquereau Group (Late Precambrian to Cambrian) was deformed by early Appalachian phases (Late Cambrian to early Lower Ordovician) that were first attributed to the "Gaspesian orogeny" by Ayrton (1967), a term that is now obsolete, and later considered to represent early Taconian phases by Rodgers (1967) and De Broucker (1987).

All these structural zones were involved in the Middle Devonian Acadian orogeny, which evolved from purely compressive to transpressive tectonics (Béland, 1982; Malo *et al.,* 1995; Malo and Kirkwood, 1995; Kirkwood *et al.,* 1995) as the Iapetus ocean closed (Kent and Opdyke, 1985; Briden *et al.,* 1988; Kent and Keppie, 1988). The resulting structures are a set of open folds which are oriented nearly parallel, or at low angle, to major dextral strike-slip faults (Malo and Béland, 1989; Brisebois *et al.,* 1992; Bourque *et al.,* 1993; Malo *et al.,* 1995; Malo and Kirkwood, 1995; Kirkwood *et al.,* 1995). These major post-Taconian displacements, through dextral strike-slip, would explain why the Ordovician rocks of the southern Gaspé Peninsula had such a different tectonic history during the Taconian orogeny than those now located in the nearby northern part of the peninsula (Béland, 1981; Béland *et al.,* 1983; De Broucker, 1987; Malo *et al.,* 1992; Bourque *et al.,* 1993).

There is then a major gap of over 60 Ma in the stratigraphic record. The youngest rocks constituting the paleosurface are of Silurian age (Bourque *et al.,* 1995). They are unconformably overlain by the Bonaventure Formation, which has not been dated directly but which is regarded as contemporaneous to the Cannes-de-Roches Formation (Alcock, 1935; Rust, 1981), a Middle to Late Viséan (Rust, 1981, from personal communications by M. Barss, 1976, 1979) or Early Namurian (Hacquerbard,1972) clastic sequence according to spore analysis.

The Bonaventure Formation is traditionally interpreted as an exclusively terrigeneous clastic sequence, although a discontinuous limestone base a few metres thick has been identified by Kirkwood (1989) in the Percé area. This limestone is interpreted as a groundwater calcrete associated with the La Coulée Formation, a newly identified post-Acadian clastic sequence almost entirely eroded prior to deposition of the Bonaventure Formation (Jutras *et al.,* in press). Zaitlin and Rust (1983) have interpreted Chaleur Bay as a Carboniferous paleovalley, a subbasin of the great Maritimes Basin that evolved from Late Devonian to Early Permian time. The Maritimes were affected during Permo-Carboniferous time by the Alleghanian (Hercynian) deformation, which is related to the closing of Theïc Ocean, the southern extension of the then-already-closed Iapetus (Arthaud and Matté, 1977; Piqué, 1981; Lefort and Van der Voo, 1981; Russel and Smythe, 1983; Haszeldine, 1984; Kent and Opdyke, 1985; Lefort *et al.,* 1988) . The Chaleur Bay area appears to have remained quite untouched by post-Acadian deformations apart for some Viséan dip-slip, to account for the Carboniferous sedimentation (Rust *et al.,* 1989), and some minor post-Carboniferous normal fault readjustments (Rust, 1981; Kirkwood, 1989; Peulvast *et al.,* 1996).

GEOMORPHOLOGICAL SETTING

From our point of view, very little knowledge is solidly established concerning the pre-Quaternary geomorphic evolution of the Gaspé Peninsula as a whole. Mostly, what we have are interpretations from personal observations by various authors (Mattinson, 1964; Gray and Hétu, 1985; Grant, 1989; Peulvast *et al.,* 1996). The geomorphological setting will here also be presented in a hypothetical way, combining our observations and interpretations with those of the above-mentioned authors.

Most of Gaspé Peninsula is characterised by a southward dipping 400 to 600 m-high planation surface (Fig. 1a), which is referred to as the "Gaspesian Plateau" (Gray and Hétu, 1985). To the south, this surface falls down to a complex exhumed Carboniferous paleosurface (Bail, 1983; Jutras, 1995; Peulvast *et al*., 1996).

A recent apatite fission track study has suggested that up to 4 km of the original Carboniferous cover in the Maritimes has been removed by erosion (Ryan and Zentilli, 1993). The same study suggested that most of this erosion took place between 270 Ma (Permian) and 200 Ma (Jurassic), and was related to what they interpret as a pre-rift bulging. To fit this erosional rate model, the main planation surface of the Peninsula would have to be of Jurassic age, thus corresponding to the time when the erosion rate declined. This would have been quickly followed by the opening of the Atlantic Ocean, an event that also took place in Jurassic time and which the

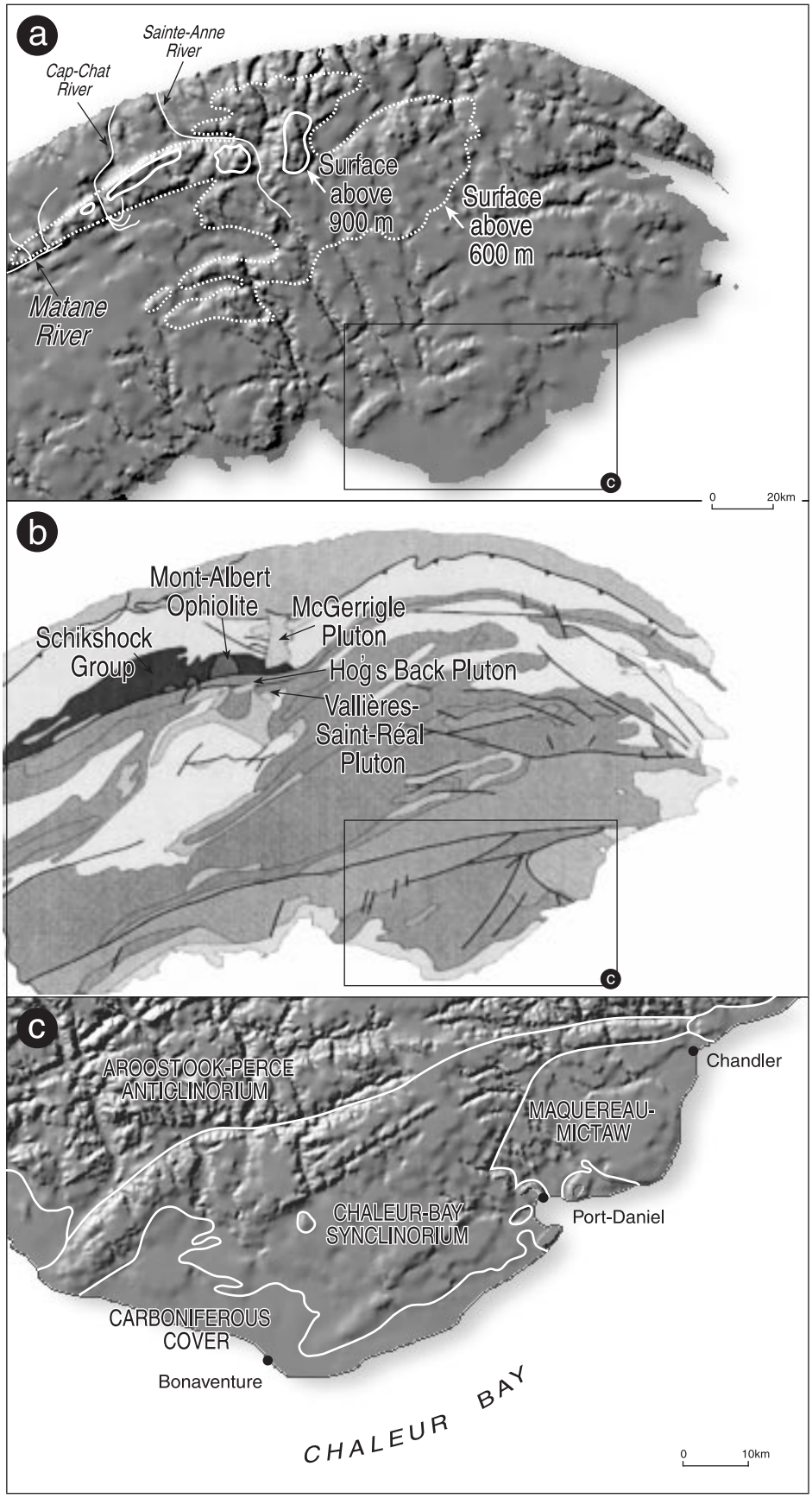

FIGURE 1. a) Topographic model of the Gaspé Peninsula; b) Disposition of the main geological zones in the Peninsula (modified from Veillette and Cloutier, 1993), c) Study area with limits of the local structural provinces.

a) Modèle numérique de terrain de la péninsule gaspésienne ; b) disposition des principaux ensembles géologiques de la péninsule (modifié de Veillette et Cloutier, 1993) ; c) zone d'étude avec limites des provinces structurales locales.

rejuvenation of the surface is interpreted as being related to (Peulvast *et al.,* 1996). This is in accord with Bird (1972) who, based on the disposition of Early Cretaceous sediments in relation to erosional surfaces, suggested that the upland surface of the Maritime Provinces is no younger than the Early Cretaceous. Ryan and Zentilli (1993) also proposed a slower rate of erosion between 200 and 100 Ma, which may be explained by the *en bloc* uplift and the synchronous dissection of the Northern Appalachian Plateau, and very little since.

Massive residual relief in the north-central part of the peninsula suggests that peneplanation of the Gaspesian Plateau was suddenly interrupted by post-rift rejuvenation. The north-central highlands are interpreted by Gray and Hétu (1985) and by Grant (1989) as consisting of two superimposed paleoplain remnants, an hypothesis that is only weakly supported by the geomorphology.

As can be observed on Figures 1a and b, the morphology of the Peninsula is closely related to geological structures and is therefore mainly related to differential erosion. The generalized contour of the 600 m isohypse has been traced on the topographic model of Figure 1a. It corresponds approximately to the limits of Gray and Hétu's "Chic-Chocs Plateau" (Gray and Hétu, 1985). This surface is not flat-topped however, as is generally the case for paleoplains, and gradually rises to heights exceeding 1 200 m in the McGerrigle Pluton, which is located in the centre of the bulge (Fig. 1a and b). All the irregularities of the bulge can be explained in terms of differential erosion, but not the bulge itself.

This plutonic complex at the centre of the north-central highlands comprises magmas ranging from Devonian to possibly Mississippian age (Whalen, 1987; Whalen *et al.,* 1991), and adjacent smaller plutons have an estimated age as young as 338 ± 6 Ma (Viséan; Mount Vallières-de-Saint-Réal; Larocque, 1986) and 338 ±10 Ma (Mount Hog's Back; De Römer, 1974) (Fig. 1b). Even though the hypothesis of episodic magmatism for these plutons has been questioned by Whalen *et al.* (1991), the north-central highlands of the Peninsula may possibly be correlated to other such highlands in different sectors of the Maritimes which also contain Devonian through Carboniferous plutonic complexes. According to St. Peter (1993), these plutonic highlands served as periodical sediment sources in a horst and graben system that characterised the Maritimes throughout the Upper Devonian and Mississippian, during intermittent periods of extension.

Because of the rejuvenation that would accompany each plutonic event in the north-central highlands, some of which might not be exhumed, peneplanation never was achieved in this area. By the time the Appalachian *en bloc* uplift occured, in Jurassic time, the Gaspé peneplain was still incomplete. This reasoning means that the spectacular cases of river antecedence in the north-central highlands (the Cap-Chat, Matane and Sainte-Anne rivers; Fig. 1a), first observed by Mattinson (1964), are pre-Jurassic in age. These rivers literally cut through the few hundred metre-high wall formed by the resistant rocks of the Shickshock Group (Fig. 1a and b). Gray and Hétu (1985) have proposed a glacial explanation to account for the surprising path of these rivers; but based on the extended Quaternary mapping by Veillette and Cloutier (1993), we believe that glacial erosion was far too insignificant in the Gaspé Peninsula to account for such valley openings. We propose that these river beds must have first developed in the rocks that were overlying the Shickshock Group nappe, and that very slow uplift has enabled the rivers to maintain their trajectory through the resistant rocks of that group during the Permian-through-Jurassic erosion event.

If the river system of the north-central highlands is pre-Jurassic in age, then the rest of the river system in the Peninsula, cutting through the Jurassic peneplain surface, must be younger; but the narrow and deeply embanked river-cuts, in the planation surface, imply that the river system must not have changed much in its design since it started installing itself along with the Appalachian *en bloc* uplift.

It is impossible to define the original extent of the Permo-Carboniferous sedimentation in Gaspé, for everything above the 400 to 600 m level (except for the residual north-central highlands) has been cut by the Permian-through-Jurassic peneplanation event. It is however possible to define the approximate extent of what remains of the Carboniferous paleovalley, under the peneplanation line, since the exhumed Carboniferous paleosurface contrasts in many ways, as defined below, with the Gaspesian Plateau surface. The remainder of this paper is focusing on the geomorphological analysis of the exhumed paleosurface and the paleoenvironmental indications which they provide.

GEOMORPHOLOGY OF THE EXHUMED PALEOSURFACE

TWO CONTRASTING MORPHOLOGICAL UNITS

The paleosurface that lies below the peneplanation line is complex and presents itself in two contrasting morphologic units with associated transition zones (Fig. 2).

The first unit shows what we have called an "inherited topography". In contrast with the Gaspesian Plateau, its interfluves are not flat topped and are of varying heights; and when the topography of the Gaspesian Plateau is entirely controlled by the currently active fluvial system, where the degree of incision is directly proportional to the size of the stream, this surface displays a different architecture in which small brooks can occupy large valleys. We therefore call it "inherited" for it was not exclusively shaped by the currently active erosional system.

The second unit shows a "perfectly truncated" surface where all structures are horizontally cut. In contrast with the Gaspesian Plateau that overlooks it, this nearly perfect planation surface is very poorly dissected. It is usually separated from the Gaspesian Plateau by the "inherited topography" unit, except in the Saint-Elzéar area where it comes in direct contact with the Gaspesian Plateau along the 200 to 300 m-high Garin Scarp, first identified by Bail (1983).

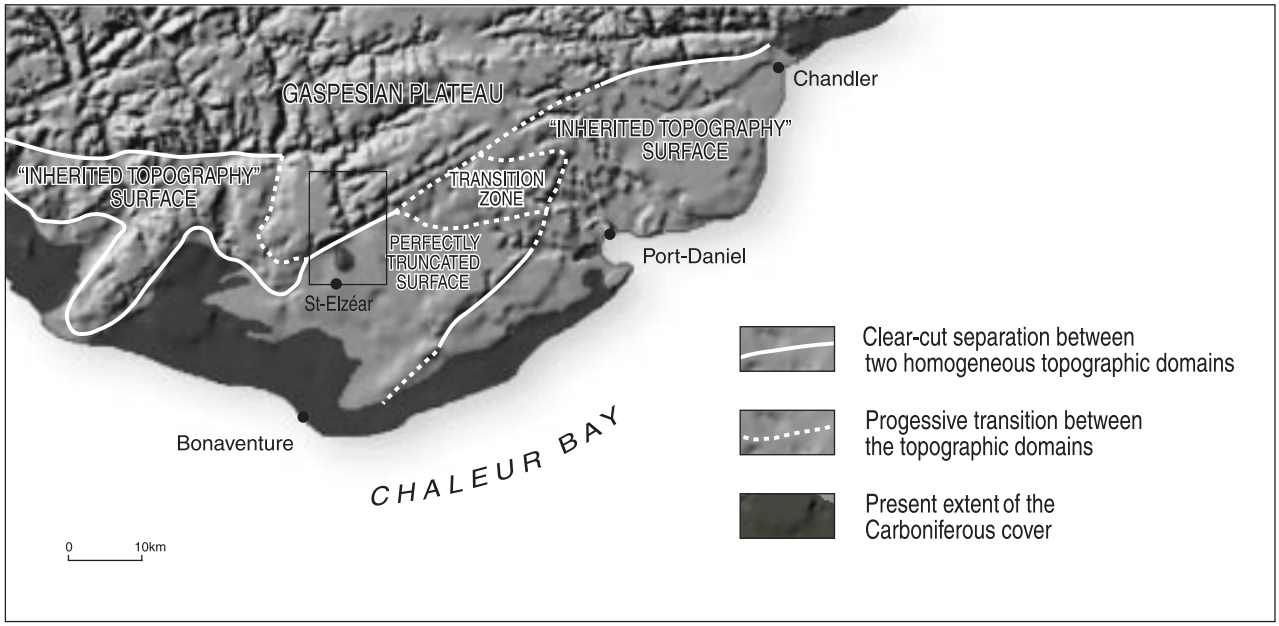

FIGURE 2. Morphologic units in the southern Gaspé Peninsula. *Unités morphologiques du sud de la Gaspésie.*

GEOMORPHOLOGICAL CLUES FOR A VISÉAN MARINE TRANSGRESSION IN THE SOUTHERN GASPÉ PENINSULA

Special attention will now be given to the Saint-Elzéar paleosurface. Figure 3 shows the Saint-Elzéar area in a plan view (a), a cross-section view (b) and a 3-D view (c), respectively.

North of the Garin Scarp, we observe a typical Appalachian morphology where valley incisions occupy softer formations while more resistant rocks form hogbacks. The result is a typical *en treillis* river system. South of the scarp, the same formations have been perfectly truncated. A residual hill of Carboniferous clastic rocks, attibuted to the Bonaventure Formation, overlies this truncated surface, less than one kilometre away from the scarp (Bail, 1983). This proves that the lower planation surface pre-dates sedimentation of the Bonaventure Formation, which is roughly attributed to the Viséan (Middle Mississippian).

In geomorphology, such flat surfaces abruptly separated from highlands are usually referred to as pediments. Although attempts have been made to give the term "pediment" a more restricted use (Whitaker, 1979), it has been attributed to the product of a very wide range of geomorphic processes. Hence, it is only used here as a descriptive, nongenetic term.

In order to understand the genesis of the Saint-Elzéar pediment, we have proceeded by elimination. In folded sedimentary rocks, there are only four known geological processes that can lead to such a geomorphic setting where two planation surfaces are separated by a scarp:

1 - Truncation of a planation surface by a fault scarp: since no fault is involved, this option can be disregarded.

2 - Etching and double planation: Thornbury (1954) has proposed that "etchplains" can form due to local differential lowering of a peneplain surface. Büdel (1977-82) further developed this concept of "double planation", which forms as a consequence of alternate weathering and stripping, a process that was first described by Mabbutt (1966). "Etching" concentrates in depressions and eventually leads to differential lowering of surfaces. Although more typical of hard-rock (usually granitic) landscapes, Büdel (1977-82) recognizes "etchplanation" in all types of geological settings.

Like the Saint-Elzéar surface, etchplains have a very low gradient of less than 1° (Thomas, 1994), being mainly the product of downwearing; but they are flat only when covered by thick saprolite. They are, otherwise, inselberg-studded plains with moats around the inselbergs and along the scarp which leads to the higher planation surface (Büdel, 1977-82; Petit, 1990; Thomas, 1994). Since the Saint-Elzéar surface is quite flat, inselberg-free and reportedly occupied by fresh rocks (Peulvast *et al.,* 1996), the etchplain hypothesis, in itself, does not fit well with its morphology.

3 - Rock pedimentation controlled by differential erosion: Thomas (1994) briefly describes the problem of a tenuous differentiation between etchplains and flat footslope surfaces developed on fresh rocks or covered by thin saprolite, and which are usually referred to as "rock pediments". They typically have a gradient of 2° to 4° (Thomas, 1994). Their flatness can be maintained by lateral erosion and they can be affected to a certain degree by scarp backwearing (Cooke *et al.,* 1993), but etching (alternate weathering and stripping) is the only process proposed so far that can elegantly explain their genesis (Thomas, 1994). They probably are exhumed etchplains where stripping becomes the dominant agent of erosion as a result of climate change or tectonic uplift.

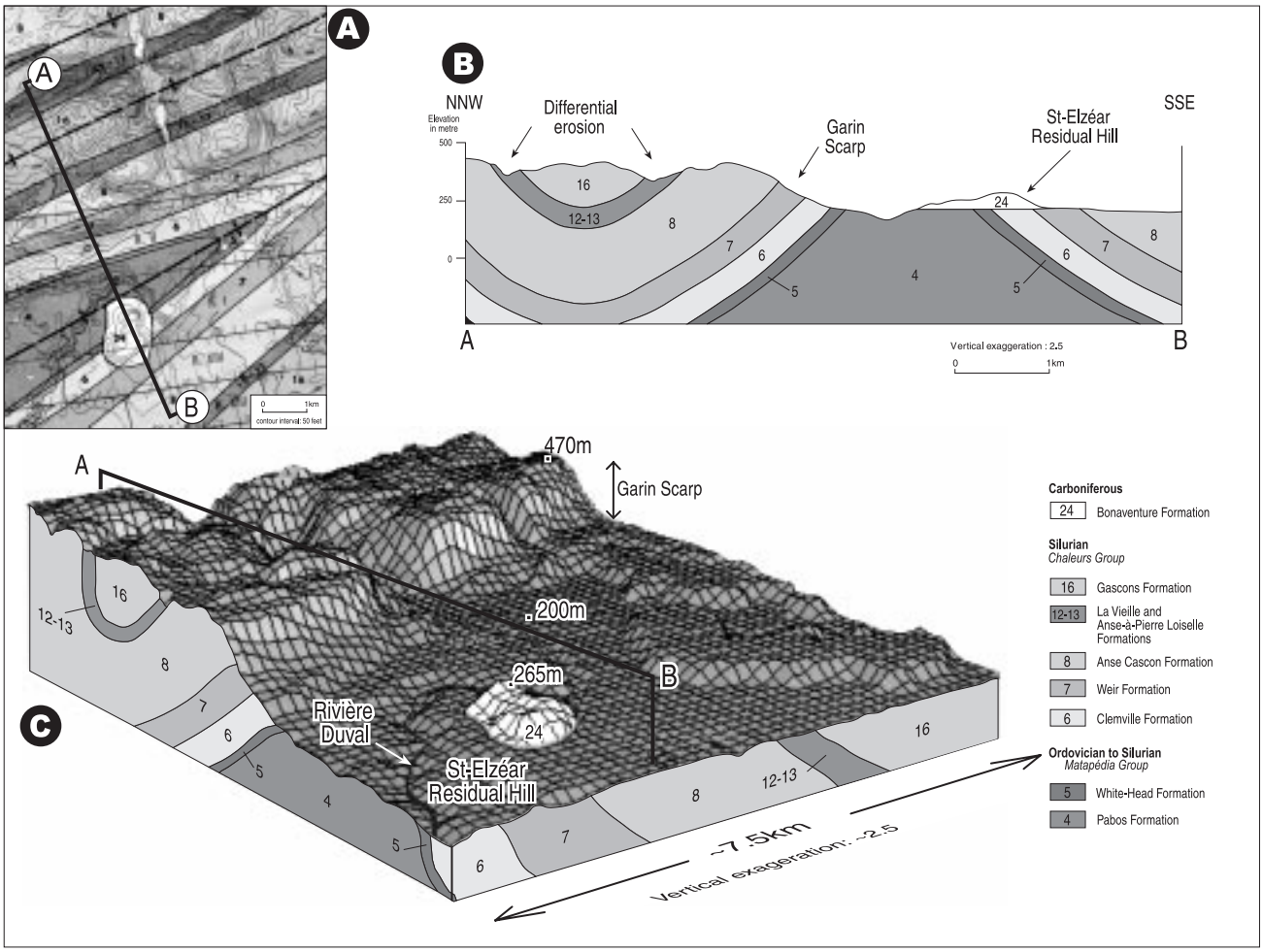

FIGURE 3. a) Plan-view geology of the Saint-Elzéar region modified from Bourque and Lachambre, 1980 ; b) cross-section of the A-B transect of Figure 3a ; c) block diagram of the Saint-Elzéar area (from a topographic model)

a) Vue en plan de la géologie de la région de Saint-Elzéar ; b) coupe A-B ; c) bloc-diagramme de la région de Saint-Elzéar construit à partir d'un modèle numérique de terrain.

Although it has a gradient of less than 1°, it is possible that the Saint-Elzéar surface could represent one of these reportedly levelled rock pediments. However, basing his conclusions on the observation of continental pediments worldwide, Twidale (1983) notes that, in sedimentary rocks, they are always formed on softer rocks than those forming the adjacent highlands. Even in massive igneous rocks, where pediments are most common, the structural control over pediment formation is becoming more and more apparent (Hack, 1960; Denny, 1967; Twidale, 1981, Thomas, 1989). According to this view, continental pedimentation (and/or "etchplanation") is altogether unlikely to explain the morphology of the Saint-Elzéar surface, as had been proposed by Bail (1983), since it is occupied by the same succession of sedimentary rocks as the adjacent Gaspesian Plateau (Fig. 3).

- Coastal erosion in a transgressive context (*i.e.* formation of a wide wave-cut platform): we have favoured this option to explain the genesis of the Saint-Elzéar surface since it is the levelling erosional process that most effectively overlooks structure. According to this model, the Garin Scarp would be a paleosea-cliff and the Saint-Elzéar pediment would represent an horizontally incised marine bedrock terrace. Whitaker (1979) has suggested that the term pediment should not be used when a non-continental genesis is inferred, although he himself points out that paleo wave-cut platforms may currently be confused for continental pediments. Since a marine genesis is proposed, we will simply refer to it as the Saint-Elzéar "surface" rather than "pediment".

Carboniferous sedimentation in the Gaspé Peninsula is regarded as being strictly terrigeneous. We can however point out that it is also considered as being limited to the Viséan (Middle Mississippian) (Brisebois *et al.,* 1992; Van de Poll, 1995) and that the rest of the Maritimes Basin has known a major marine transgression during this period, in which sedimentation of the Windsor Group limestones occured. Figure 4 shows that the estimated limits of the Windsor limestones, in the isopach map of Howie and Barss (1975), come very close to the southern Gaspé Peninsula.

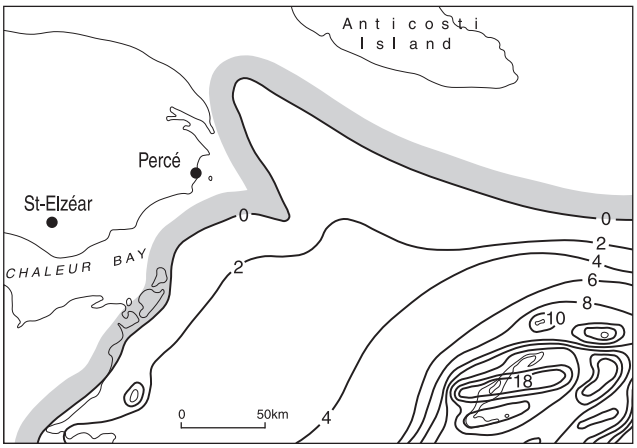

FIGURE 4. Isopach map of the Windsor Group, in thousands of feet. Modified from Howie and Barss (1975).

Carte isopaque du Groupe de Windsor, en milliers de pieds. Modifié de Howie et Barss (1975).

The Garin scarp and platform can be considered as geomorphological evidence that the Windsor transgression may have reached the peninsula, though quickly followed by terrigeneous clastic sedimentation. It can also be noted that the Windsor transgression is described as rapid and related to quick crustal subsidence followed by slow uplift (Geldsetzer, 1977; Carter and Pickerill, 1984; Boehner, 1986; Gibling *et al.,* 1987). If the Garin Scarp locally marks the maximum extent of the Windsor Sea, it is to be expected that the marine presence in the southern Gaspé Peninsula would have been quite short-lived. If marine sediments have been preserved, they cannot be very thick.

An outcrop showing the unconformable contact between the Carboniferous red clastics and the underlying Silurian rocks, directly north of the Saint-Elzéar residual hill, shows no sedimentological evidence for a marine presence preceding terrestrial sedimentation (Bail, 1983). Further south, on the NE flank of the hill, (10 to 12 m-thick) groundwater calcrete separates the red clastics from a mudstone basement (Jutras *et al.,* in press). This discontinuous calcrete is considered to be an erosional remnant of the newly identified La Coulée Formation, which underlies the Bonaventure Formation in the Percé area, 100 km to the NE (Jutras *et al.,* in press).

Groundwater calcretes are reportedly formed in the salty groundwater discharge zone of clastic sequences near salt-lakes or playas (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.,* 1988; Arakel *et al.,* 1989). This groundwater calcrete remnant, beneath the Saint-Elzéar residual hill, may possibly reflect the regressive context that would have quickly followed the maximum transgression.

It is also shown in Jutras *et al.* (in press) that the post-Acadian La Coulée Formation, which is marked by groundwater calcrete formation at its base, has been uplifted and almost entirely eroded prior to deposition of the Bonaventure Formation. In this context, Carboniferous marine sediments in the southern Gaspé Peninsula, if there were any, would have been either calcretized, leaving possibly no clue concerning the nature of the host sediment, or eroded. Field investigations to verify this marine hypothesis have proved futile to date, and it is possible that only drill-holes in the Chaleur Bay graben could provide the much sought-after sedimentological proof that the Windsor transgression had extended into it... or that it had not.

GEOMORPHOLOGICAL CLUES FOR POST-ACADIAN FAULT MOVEMENTS

In an uplifted peneplain, even the scarps associated with fault lines are controlled by differential erosion, the original orogenic fault scarps having long since been eroded. We have identified several fault scarps (Fig. 5) in the southern Gaspé Peninsula that cannot be explained by differential erosion processes and therefore must post-date the last orogenic event.

These fault scarps clearly truncate planation surfaces: the exhumed paleosurface, south of the Gaspesian Plateau hogbacks, is truncated into three steps associated with the previously unnamed Saint-Jogues-Sud and Huard faults (shown as an example on transect C-D of Fig. 5); the smooth surface of the Gaspesian Plateau takes a sudden 100 m drop south of the previously unnamed Lac Blanc Fault; the Raudin fault-scarp separates the Gaspesian Plateau, occupied at this level by the West Point Formation (Silurian), from a lower plateau occupied by the Maquereau Group.

On some fault scarps, surface truncation is observed in rocks of the same formation, which makes a differential erosion explanation even more unlikely: the easternmost section of the Grand-Pabos fault-scarp truncates the Bonaventure Formation; in its westernmost extension, the Rivière-Garin fault-scarp truncates the Garin Formation (Late Ordovician); in its easternmost extension, the Raudin fault-scarp truncates the upper member of the Newport Formation (Cambrian) in the Maquereau Group (Ayrton, 1967; “Newport facies” in De Broucker, 1987); in its southernmost extension, the Rivière Port-Daniel fault-scarp truncates the Anse Cascon Formation (Silurian).

It is also interesting to note that, although rocks of the Maquereau Group are overlooked by rocks of the West Point Formation at the level of the Raudin Fault, the reverse is true at the level of the Rivière-Port-Daniel fault, where the former overlooks the latter. This casts further doubts on attempts, such as in Bail (1983), to explain the stepped topography of the southern Gaspé Peninsula in terms of differential erosion processes.

All the faults identified on Figure 5 have a topographic expression throughout their length, but only the sections that could not be explained by differential erosion are shown as indented. These sections tell us, in each case, that the entire length of the fault must have been the locus of post-orogenic movement. The timings, however, might vary. The Grand-Pabos Fault reportedly cuts through the Carboniferous cover (Ayrton, 1967; Brisebois *et al.,* 1992) and its last activity therefore post-dates it. The Saint-Jogues-Sud, Huard, Rivière-Garin, Rivière Port-Daniel and Raudin fault scarps are

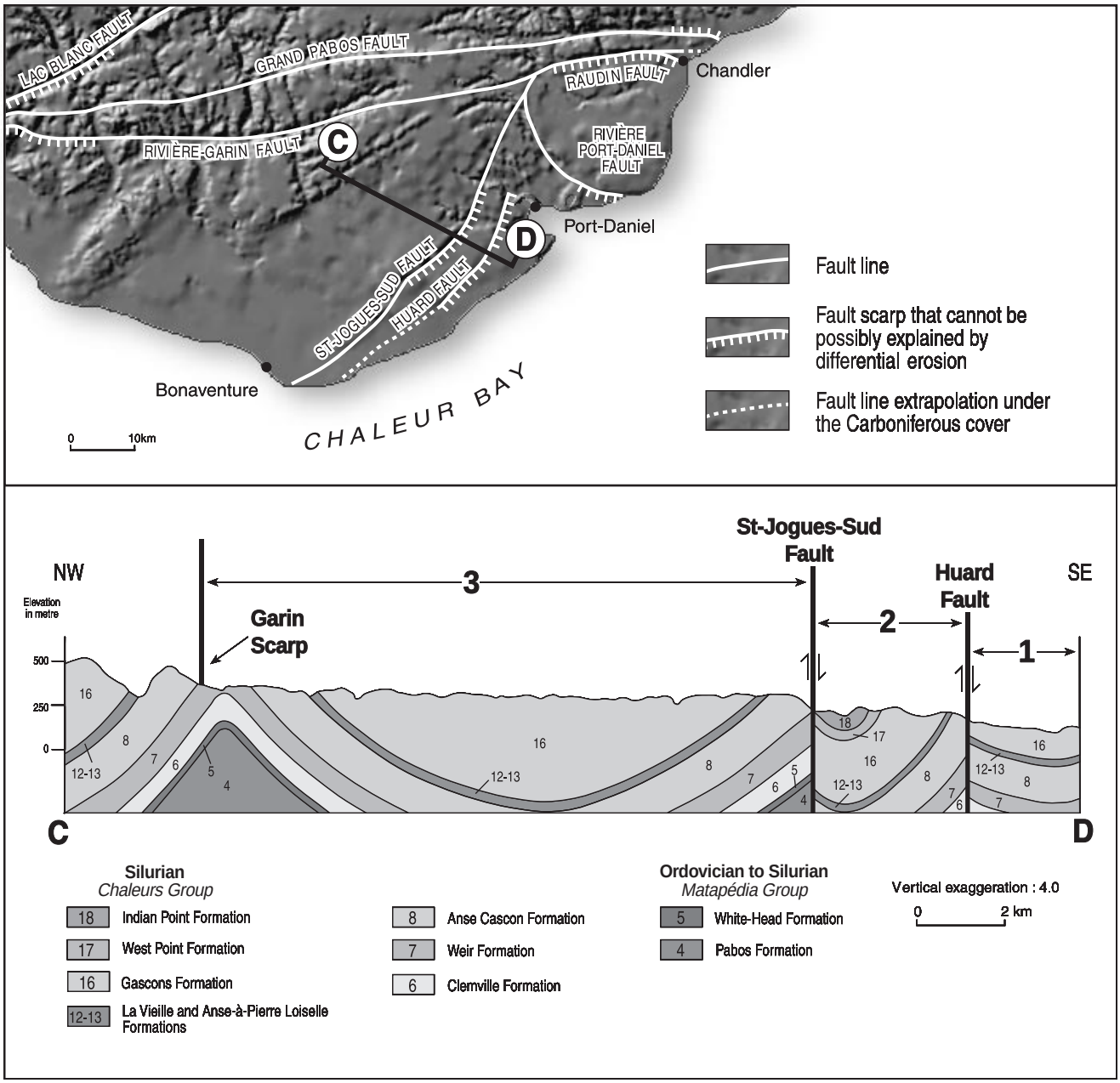

FIGURE 5. Post-Acadian fault-scarps in the study area. Cross-section C-D shows the resultant stepped topography.

Les escarpements de faille post-acadiens dans la région étudiée. La coupe C-D montre la morphologie en escalier qui en résulte.

all under the ~400 m peneplanation line. They could therefore have been protected from the Permian-through-Jurassic erosion event by the Permo-Carboniferous clastic cover and, thus, they are not necessarily related to post-peneplanation tectonics. The Lac Blanc fault-scarp, however, truncates the Gaspesian Plateau and would therefore post-date the Permian-through-Jurassic peneplanation event.

The geomorphological expression is insufficient to determine whether the faults were affected by normal movement or oblique strike-slip. Further work is in progress (Jutras and Prichonnet, in preparation).

THE CLEMVILLE HOGBACKS PROBLEM

The Clemville Hogbacks, formed by the Silurian age La Vieille and West Point limestones, stand directly east of the Huard and Saint-Jogues-Sud faults, in the Port-Daniel area (Fig. 6). In the Saint-Elzéar and Saint-Jogues area (less than 10 km west), on the postulated marine surface, these formations are truncated as are all the other rocks of the Chaleurs Group. North of the Garin Scarp, on the Gaspesian Plateau, the fluvial system is developing preferentially in rocks of the La Vieille Formation, which are therefore deeply incised in between more resistant, hogback forming rocks (see Figs. 4

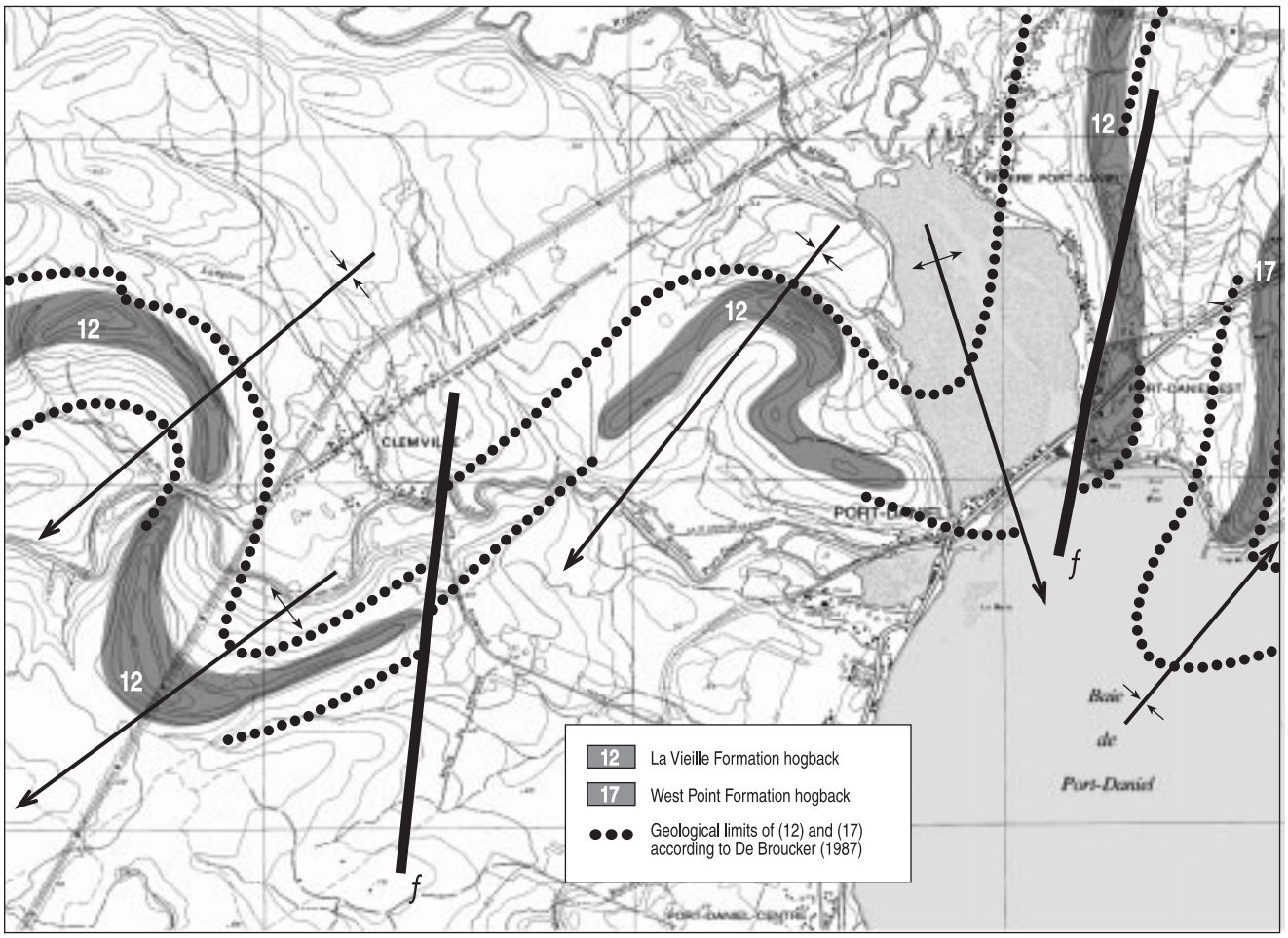

FIGURE 6. Clemville Hogbacks and limits of the La Vieille and West Point formations according to Bourque et Lachambre (1980) and De Broucker (1987). Modified from De Broucker (1987).

Les crêts de Clemville et les limites des formations de La Vieille et de West-Point selon Bourque et Lachambre (1980) et De Broucker (1987). Modifié de De Broucker (1987).

and 5). Both as a negative relief on the Gaspesian Plateau and as a positive relief in the Port-Daniel area, the La Vieille Formation is highly karstified. The karstic features in the Port-Daniel area are filled with red clastics typical of the Bonaventure Formation, which is not the case for the karst north of the Garin Scarp.

The geomorphology of the Clemville Hogbacks, although developed in the same rock formations, corresponds to neither that of the Gaspesian Plateau nor that of the "perfectly truncated" (marine) Saint-Elzéar surface. It corresponds more to the "inherited topography" unit, but its geographic position is problematic: why have they not been cut off by marine erosion? From the tectonic and sedimentological history of the Maritimes Basin and subbasins, two solutions are possible:

- The hogbacks may have been fossilized by pre-Windsor clastics. In the Maritimes, the Tournaisian stage (early Mississippian) was a time of very active clastic sedimentation in an extensional system of horsts and grabens (Howie, 1988; Durling and Marillier, 1989; St. Peter, 1993). The Acadian Huard and Saint-Jogues-Sud faults could have been reactivated as normal faults during Tournaisian time (or possibly Late Devonian or early Viséan), while clastic sedimentation fossilized the Clemville Hogbacks. The Viséan marine transgression would have then cut above them, as the Garin Scarp retreated, forming the almost perfectly truncated planation surface. The wave-cut platform and coastal scarp are then fossilized by a second clastic episode (Fig. 7-Ia, b and c).

- The Clemville Hogbacks may have been displaced by lateral (strike-slip) movements: several post-Acadian deformation episodes have been registered in the Maritimes Basin, the most important having taken place during Westphalian B (Early Pennsylvanian; Ruitenberg and McCutcheon, 1982; Gibling *et al.,* 1987; Yeo and Ruixiang, 1987; St. Peter, 1993). This Westphalian B event is sometimes referred to as the "Maritimes Disturbance", although the term is also used as a reference to the whole Alleghanian (Hercynian) intermittent deformation period in the Maritimes during Permo-Carboniferous time. The major dextral strike-

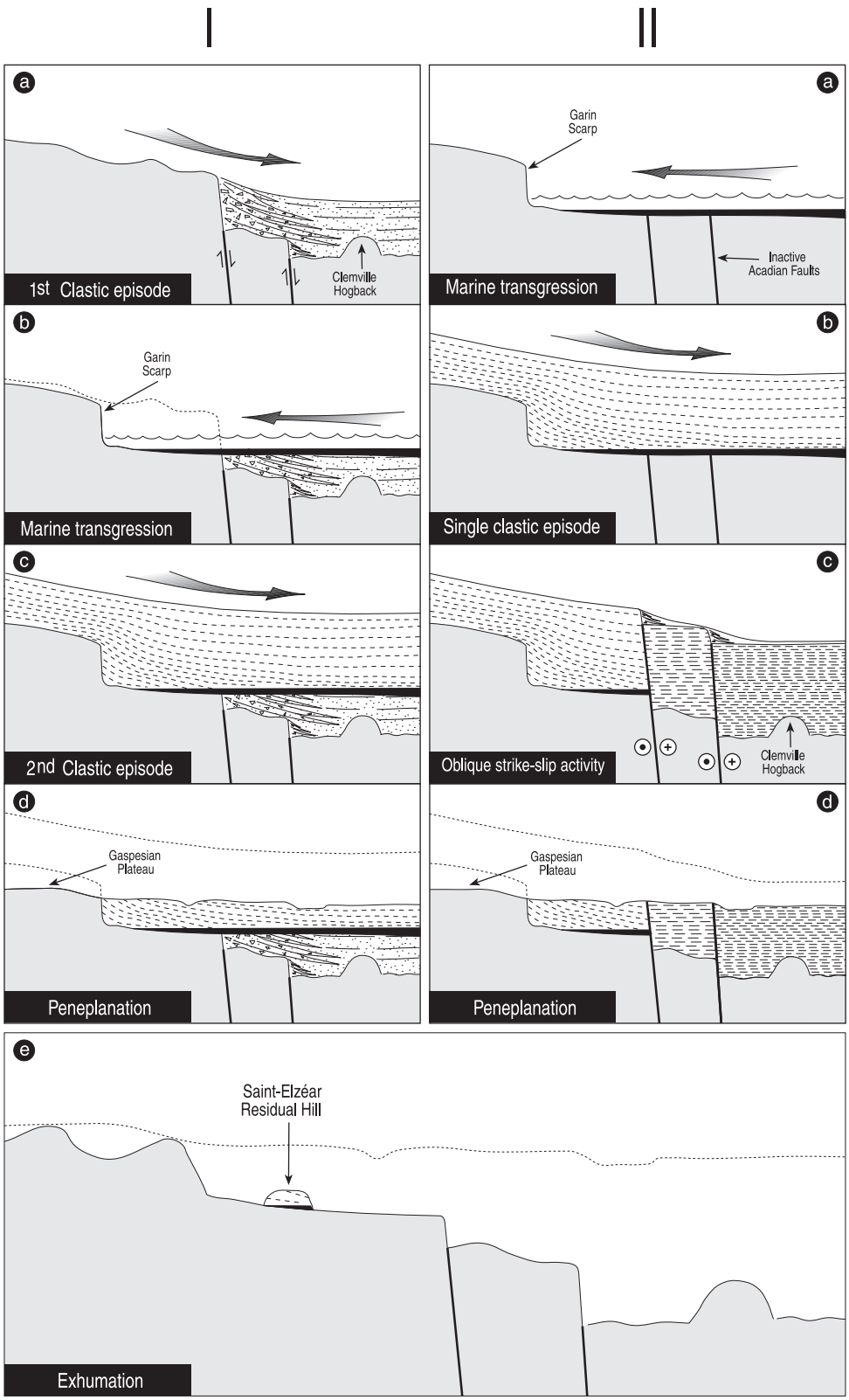

FIGURE 7. **I**. Hypothesis of a pre-Windsor fossilization of the Clemville Hogbacks. a) Pre-Windsor continental clastic sedimentation, controlled by normal faults, and fossilization of the Clemville Hogbacks; b) Windsor marine transgression cutting above the fossilized hogbacks and possibly leaving thin marine sediments (in black); c) New episode of continental clastic sedimentation subsequent to marine regression; d) Permian-through-Jurassic peneplanation event; e) Sketch of the present geomorphic situation in the southern Gaspé Peninsula.
II. Hypothesis of a post-Windsor lateral displacement of the Clemville Hogbacks through dextral strike-slip; a) The Acadian age Saint-Jogues-Sud and Huard faults would have remained passive in Carboniferous Time prior to the postulated Windsor Sea invasion; b) Fossilization of the wave-cut platform and coastal cliff by the continental red clastics of the Bonaventure Formation; c) Lateral juxtaposition of surfaces that were not in contact with the sea in Viséan time with a surface that was, through oblique strike-slip in post-Viséan time; d) Permian-through-Jurassic peneplanation event; e) Sketch of the present geomorphic situation in the southern Gaspé Peninsula.

I. *Hypothèse d'une fossilisation pré-windsorienne des crêts de Clemville. a) Sédimentation clastique continentale pré-windsorienne commandée par des failles normales et fossilisation des crêts de Clemville ; b) transgression marine windsorienne coupant au-dessus des crêts fossilisés et laissant possiblement une mince couverture de sédiments marins (en noir) ; c) nouvel épisode de sédi-mentation clastique continentale subséquent à la régression de la mer ; d) épisode de pénéplanation s'échelonnant du Permien au Jurassique ; e) schéma de la disposition géomorphologique actuelle du sud de la Gaspésie.* ***II.*** *Hypothèse d'un déplacement latéral post-windsorien des crêts de Clemville par des décrochements dextres. a) Les failles acadiennes de Huard et de Saint-Jogues-Sud seraient demeurées passives au cours du Carbonifère avant l'hypothétique invasion marine ; b) fossilisation de la terrasse d'abrasion et de l'escarpement côtier par les « red beds » continentaux de la Formation de Bonaventure ; c) juxtaposition latérale de surfaces qui étaient hors d'atteinte de la mer au Viséen avec une surface qui l'était, grâce à des décrochements obliques post-viséens ; d) épisode de pénéplanation s'échelonnant du Permien au Jurassique ; e) schéma de la disposition géomorphologique actuelle du sud de la Gaspésie.*

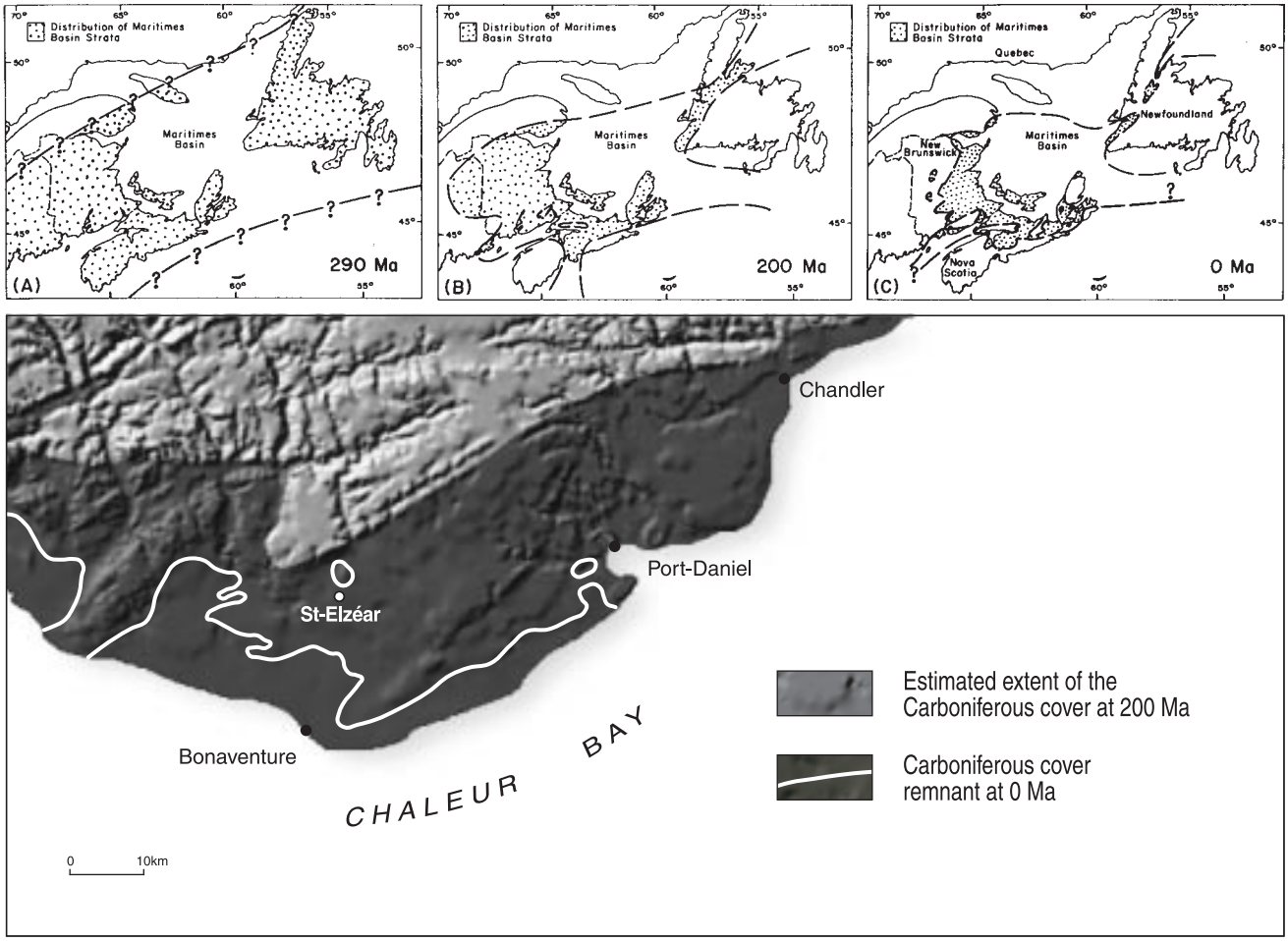

FIGURE 8. Above: estimated extent of the Carboniferous cover at 290 Ma and 200 Ma in relation to the present remnant cover, according to apatite fission track analysis (From Ryan and Zentilli, 1993); Below: estimated extension of the Carboniferous cover in the study area, at the time of maximum peneplanation (around 200 Ma), according to the limits of the exhumed paleosurface.

Au-dessus : extension estimée de la couverture du Carbonifère à 290 Ma et 200 Ma, en relation avec l'actuel, selon l'analyse de trace de fission de l'apatite (de Ryan et Zentilli, 1993). En dessous : extension estimée de la couverture du Carbonifère dans la région étudiée, au temps de la pénéplanation maximale (vers 200 Ma), selon les limites de la paléosurface exhumée.

slip movements that took place during Westphalian B could have possibly reached the northern limits of the Maritimes Basin (*i.e.* the Ristigouche subbasin). In this view, the Clemville Hogbacks could have been outside the limits of the Windsor Sea during Viséan time, and could have been laterally displaced by the Huard and Saint-Jogues-Sud faults during Westphalian B or any other post-Viséan strike-slip deformation event that has affected the Maritimes region (Fig. 7-IIa, b and c).

After the fault-related sedimentation that affected the region from Late Devonian through Early Pennsylvanian times, the Maritimes would have acted as a passive basin from Late Pennsylvanian through Early Permian times, receiving sediments from the Alleghanian mountain chain that was developing to the south (Gibling *et al.,* 1992). According to estimations by Ryan and Zentilli (1993), all of the southern Gaspé Peninsula should have been covered by 290 Ma. The morphologically estimated extent of the exhumed paleosurface suggests that, after the subsequent 270 to 200 Ma peneplanation event, the plan-view geology of the southern Gaspé Peninsula should correspond approximately to that shown on Figure 8. Two alternative cross-section sketches are proposed on figures 7-Id and 7-IId to fit with our previous reasoning.

Most of the paleosurface is eventually exhumed (Fig. 7e), the weakly consolidated horizontal beds or the Carboniferous cover favouring lateral erosion by moving river beds rather than deep incision in the more resistant basement.

Identification of a post-Acadian clastic unit, confined to the triangular graben formed by the Rivière Port-Daniel and Saint-Jogues-Sud faults (Fig. 5), greatly supports our first hypothesis (Jutras *et al.,* in preparation). This unit is stratigraphically under the Bonaventure (for which it has been confused so far) and La Coulée formations. Sinistral, SSW-NNE trending fault planes affecting both the La Vieille

Formation and the red clastics filling its karstic system (Jutras and Prichonnet, in preparation) could be taken as support for the lateral displacement hypothesis. However, the fact that they are sinistral implies too great of a displacement to justify that the Clemville surface would have been out of reach while the sea was transgressing.

KARST IN RELATION TO THE DENUDATION PROCESS

In the study area, karstic features are all located in the more than 85 % pure limestone of the La Vieille Formation middle member (Silurian), the same lithology that stands as hogbacks in the Clemville area. Terrigeneous mud constitute up to 50 % of the lower member and up to 20 % of the upper member (Bourque and Lachambre, 1980).

Only in an arid climate would erosion of less carbonated rocks of the rest of Chaleurs Group be favoured versus erosion of the compact limestones of the La Vieille Formation middle member. However, two types of karstic processes (*i.e.* humid climate features) have affected the rocks of the hogbacks: endokarst conduits, resulting from groundwater circulation, and up to 10 m deep lapiés, resulting from subsurface (immediately under soil) dissolution.

These two types of karst are fossilized by clastic material derived from the Carboniferous cover. In the endokarstic conduits, finer fractions (silt and sand) of this material are deposited in beds intercalated with limestone crusts (Fig. 9a). In the lapiés (Fig. 9b), the same material tends to be less sorted and thus coarser (abundant gravel) (Schroeder and Jutras, in preparation).

The fact that red clastics-filled lapiés, which are near-surface karstic features, are found both on the top and flanks of the Clemville Hogbacks indicates that sculpting of the hogbacks occured prior to karst formation, which most likely occurred during the denudation process.

With the supposed Appalachian *en bloc* uplift accompanying the Atlantic opening, in Jurassic Time, a new phase of erosion begins. The rivers develop an *en treillis* system on the Gaspesian Plateau. The river system probably becomes more dendritic south of the Garin Scarp, on the flat lying Carboniferous cover.

As river incision penetrates into the Carboniferous cover, lateral circulation of groundwater occurs in the highest zone of the porous aquifer held in the clastic material. However, the compact limestone of the hogbacks, surrounded by highly porous material, constitute aquicludes through which concentrated endokarstic circulation can develop (Fig. 10a). Since the karstic conduits are fed by the Carboniferous cover aquifer, once calibrated, they will be fossilized by fine detrital material issued from it.

Being much more resistant to erosion, the hogbacks are being gradually exhumed. It is just prior to final exhumation, when the hogbacks have a very thin cover, that lapiés formation occurs, beginning in the highest levels and gradually passing to lower levels (Fig. 10b). The space produced by dissolution is synchronously filled with unsorted clastic material derived from the Carboniferous cover.

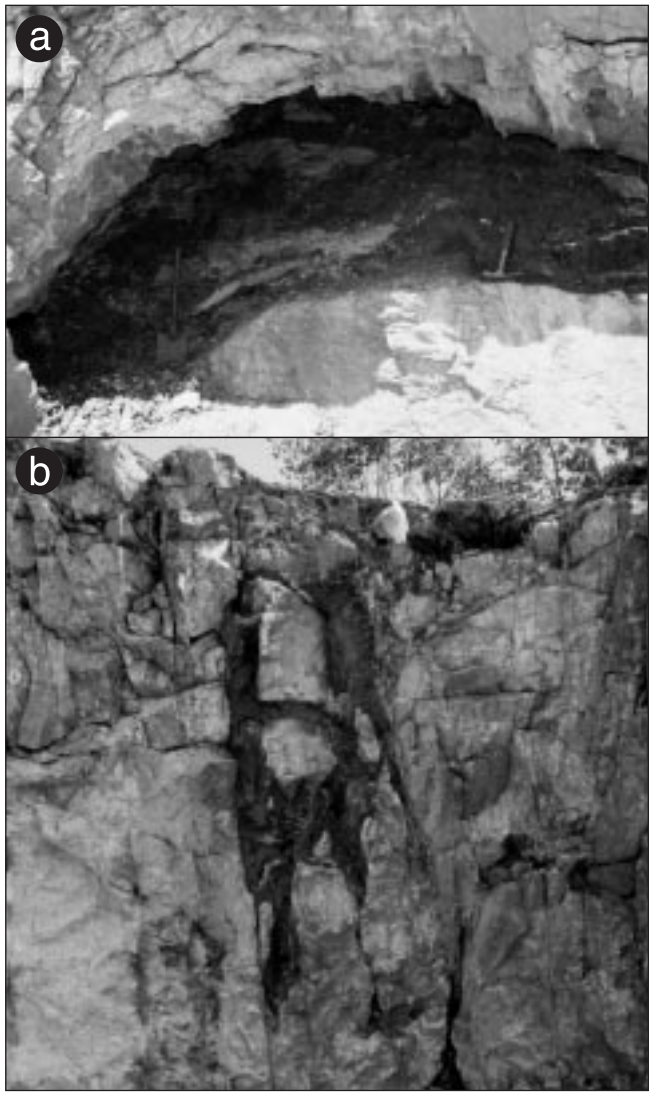

FIGURE 9. a) Endokarstic conduit filled with fine red clastics; b) lapiés filled with coarse red clastics.

a) Conduits endokarstiques remplis de sédiments clastiques rouges à granulométrie fine ; b) lapiés remplis de sédiments clastiques rouges à granulométrie grossière.

A vast karstic network has also developed in the La Vieille Formation middle member on the Gaspesian Plateau (the Saint-Elzéar Caves). This network is not fossilized by red clastics since none or very little of the Carboniferous cover was left at the level of the Gaspesian Plateau after the main peneplanation event. The study of the Saint-Elzéar Caves network is made more complicated due to Quaternary karst having been superimposed on older karst (Schroeder and Jutras, in preparation).

CONCLUSION

Study of the exhumed paleosurface suggests that minor post-Acadian fault reactivation has affected the southern Gaspé Peninsula. This correlates well with the geological con-

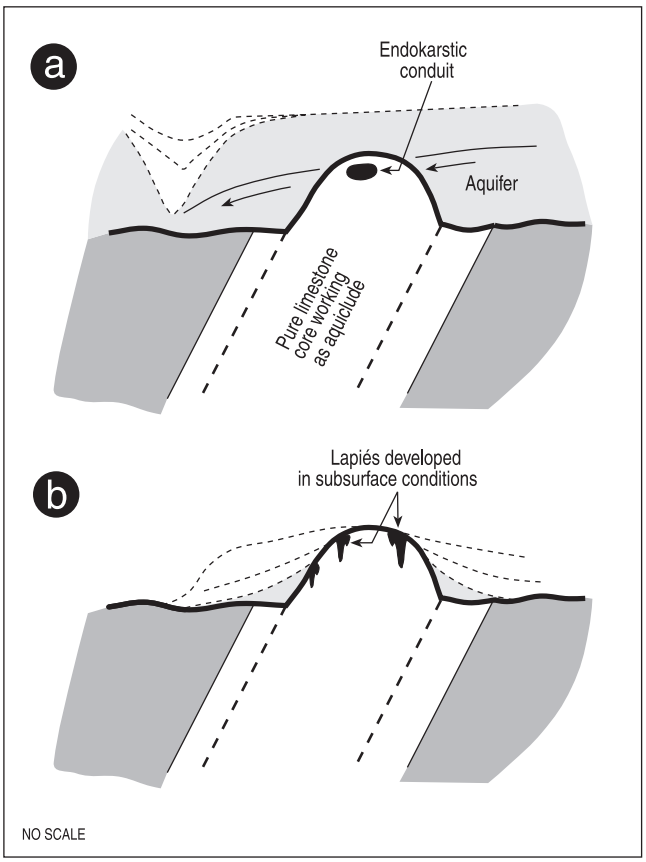

FIGURE 10. a) Postulated scenario for the formation of endokarst in the Clemville Hogbacks in relation to incision in the Carboniferous cover; b) postulated scenario for the formation of lapiés in the Clemville Hogbacks in relation to erosion of the Carboniferous cover.

a) Scénario considéré pour la formation d'endokarsts dans les crêts de Clemville en relation avec l'incision dans la couverture carbonifère ; b) scénario postulé pour la formation de lapiès dans les crêts de Clemville en relation avec l'érosion de la couverture carbonifère.

text of the Maritimes where Alleghanian deformations are recognized as far north as Newfoundland and northern New Brunswick.

The hypothesis of a Viséan transgression reaching the southern Gaspé Peninsula is strongly supported by the fact that no other known erosional process could convincingly explain the geomorphology of the Saint-Elzéar area and that it correlates well in terms of timing with the Windsor episode. The "inherited topography" unit would then simply be the part of the exhumed paleosurface that was not in communication with the Windsor Sea.

The Clemville Hogbacks area consists either of a third morphologic unit that would have been fossilized before the other two, or of a displaced section of the "inherited topography" unit. It seems to have evolved under an arid climate since the purest limestones (the La Vieille and West Point formations) were most resistant to erosion. This is clearly not the case in "post-peneplain" time, when the La Vieille Formation is more easily incised than most other formations of the Chaleurs Group. This suggests a more humid environment for the latter post-Jurassic erosional phase, at the beginning of which karst formation occurred, in the already-sculpted Clemville hogbacks, while they were still buried under the Carboniferous cover.

The many unknowns concerning the Carboniferous environments of the Gaspé Peninsula prevent us from tightly constraining our hypothesis. A more detailed stratigraphic analysis of the Carboniferous formations and an investigation of the structural deformations affecting the Carboniferous strata is in progress.

The geomorphology itself gives us many clues but few solid answers. The fact that it strongly suggests a Carboniferous transgression and a more active than previously estimated post-Acadian fault activity in the area is nevertheless important, notably in regards to the petroleum potential of Chaleur Bay.

ACKNOWLEDGEMENTS

We wish to thank B. Hétu, M. Malo, J.J. Veillette and N. Carette for reviewing the script and giving useful suggestions. We also thank André Parent, map technician, for his precious help with the graphic work, B. St.-Onge for providing numerical data and J. Bourne for proof-reading the english manuscript.

REFERENCES

Alcock, F.J., 1935. Geology of the Chaleur Bay region. Geological Survey of Canada, Memoir 183: 146 p.

Arthaud, F. and Matté, P., 1977. Late-Paleozoic strike-slip faulting in southern Europe and northern Africa: Result of a right lateral shear zone between the Appalachians and the Urals. Geological Society of America Bulletin, 88: 1305-1320.

Ayrton, W.G., 1967. Région de Chandler - Port-Daniel. Ministère des Richesses naturelles du Québec, RG 120: 197 p.

Béland, J. 1981. Analyse tectonique dans les Appalaches québécoises ; le chevauchement acadien de Percé (Gaspésie orientale) affecte un Cambro-Ordovicien non-déformé par la phase taconienne. Comptes rendus des séances de l'Académie des Sciences, série 2, 293, 15 : 1083-1086.

Béland, J., 1982. Geology of the Quebec Appalachians, p. 11-23. *In* R. Hesse *et al*., eds., Excursion 7b; Paleozoic continental margin sedimentation in the Quebec Appalachians, McGill University, Montréal.

Béland, J., Piqué, A., Ringele, H. and Millot, G., 1983. Analyse tectonique dans les Appalaches québécoises ; la région de Maquereau (Gaspésie sud-orientale) : un allochtone taconien charrié vers le sud. Comptes rendus des séances de l'Académie des Sciences, série 2, 296, 18 : 1445-1448.

Bird, J. B., 1972. The denudation evolution of the Maritime Provinces, Canada. Revue de Géographie de Montréal, 26: 421-432.

Boehner, R., 1986. Bromine stratigraphy of Windsor Group Major Cycle 1. A guide to depositional conditions, correlation and structural configuration. Atlantic Geology, 22 (2): 178.

Bourque, P. A. and Lachambre, G. 1980. Stratigraphie du Silurien et du Dévonien basal du sud de la Gaspésie. Ministère de l'Énergie et des Ressources, Québec, ES-30, 123 p.

Bourque, P.A., Gosselin, C., Kirkwood, D., Malo, M. and St.-Julien, P., 1993. Le Silurien du segment appalachien Gaspésie-Matapédia-Témiscouata : stratigraphie, géologie structurale et paléogéographie. Ministère de l'Énergie et des Ressources, Québec, MB 93-25, 115 p.

Bourque, P.A., Brisebois, D. and Malo, M., 1995. Gaspé Belt, p. 316-351. *In* H. Williams, ed., Geology of the Appalachian-Caledonian Orogen, in Canada

and Greenland, Chapter 4. Geological Society of Canada, Geology of Canada, 6.

Briden, J.C., Kent, D.V., Lapointe, P.L., Livermore, R.E., Roy, J.L., Séguin, M.K., Smith, A.G., Van der Voo, R. and Watts, D.R., 1988. Paleomagnetic constraints on the evolution of the Caledonian - Appalachian orogen, p. 35-48. *In* A.L. Harris and D.J. Fettes, eds., The Caledonian - Appalachian orogen. Geological Society, Special Publication 38.

Brisebois, D. Lachambre, G. and Piché, G., 1992. Carte géologique : péninsule de la Gaspésie. Ministère de l'Énergie et des Ressources, Québec, DV 91-21.

Büdel, 1977. (translated by L. Fischer and D. Busche in 1982). Climatic Geomorphology. Princeton University Press, 443 p.

Carter, D.C. and Pickerill, R.K., 1984. Lithostratigraphy of the Late Devonian-Early Carboniferous Horton Group of the Moncton subbasin, southern New Brunswick. Atlantic Geology, 21 (1): 11-24.

Cooke, R., Warren, A. and Goudie, A., 1993. Desert Geomorphology. UCL Press, 526 p

De Broucker, G., 1987. Stratigraphie, pétrographie et structure de la boutonnière de Maquereau-Mictaw. Ministère de l'Énergie et des Ressources, Québec, MM 86-03 : 170 p.

Denny, C.S., 1967. Fans and pediments. American Journal of Science, 265: 81-105.

De Römer, H.S., 1974. Geology and age of some plutons in north-central Gaspé, Canada. Canadian Journal of Earth Sciences, 11: 570-582.

Durling, P.W. and Marillier, F., 1989. Offshore extension of structural trends into the Western Gulf of St.-Lawrence. Atlantic Geology, 25 (2): 157.

Geldsetzer, H.H. 1977. The Windsor Group of Cape Breton Island, Nova Scotia. Geological Survey of Canada, Paper 77-1A: 425-428.

Gibling, M.R., Boehner, R.C. and Rust, B.R., 1987. The Sydney Basin of Atlantic Canada: An Upper Paleozoic strike-slip basin in a collisional setting, p. 269-285. *In* C. Beaumont and A.J. Tankard, eds., Sedimentary basins and basin-forming mechanisms. Canadian Society of Petroleum Geologists, Memoir 12.

Gibling, M.R., Calder, J.H., Ryan, R., Van de Poll, H.W. and Yeo, G.M., 1992. Late Carboniferous and Early Permian drainage patterns in Atlantic Canada. Canadian Journal of Earth Sciences, 29: 338-352.

Grant, D.R. 1989. Quaternary Geology of the Atlantic Appalachian Region of Canada. P. 393-440. *In* R.J. Fulton, ed., Quaternary Geology of Canada and Greenland, Chapter 5. Geological Survey of Canada, K-I.

Gray, J.T. and Hétu, B., 1985. Le modelé glaciaire du centre de la Gaspésie septentrionale, Québec. Géographie physique et Quaternaire, 39 : 47-66.

Hack, J.T., 1960. Interpretation of erosional topography in humid temperate regions. American Journal of Science, 258A: 80-97.

Hacquebard, P.A., 1972. The Carboniferous of Eastern Canada. Seventh International Carboniferous Congress, Compte rendu, 1: 69-90.

Haszeldine, R.S., 1984. Carboniferous North Atlantic paleogeography: Stratigraphic evidence for rifting, not megashear or subduction. Geological Magazine, 121: 443-463.

Howie, R.D., 1988. Upper Paleozoic evaporites of southeastern Canada. Geological Survey of Canada, Bulletin 380, 120 p.

Howie, R.D. and Barss, M.S., 1975. Upper Paleozoic rocks of the Atlantic provinces, Gulf of St.-Lawrence and adjacent continental shelf. Geological Survey of Canada, Paper 74-30, 2: 35-50.

Jutras, P., 1995. Synthèse géomorphologique de la péninsule gaspésienne. Master's thesis, Université du Québec à Montréal, 109 p.

Jutras, P., Prichonnet, G. and von Bitter, P., in press. The La Coulée Formation, a new post-Acadian stratigraphic unit in the Gaspé Peninsula, Québec. Atlantic Geology.

Kent, D.V. and Keppie, J.D., 1988. Silurian-Permian paleocontinental reconstructions and circum-Atlantic tectonics, p. 469-480. *In* A.L. Harris and D.J. Fettes, eds., The Caledonian - Appalachian orogen. Geological Society, Special Publication 38.

Kent, D.V. and Opdyke, N., 1985. Multicomponent magnetizations from the Mississipian Mauch Chunk Formation of the central Appalachians and their tectonic implications. Journal of Geophysical Research, 90 (B7): 5371-5383.

Kirkwood, D., 1989. Géologie structurale de la région de Percé. Ministère de l'Énergie et des Ressources, Québec, ET 87-17, 42 p.

Kirkwood, D., Malo, M., St,-Julien, P. and Thérrien, M., 1995. Vertical and fold-axis parallel extension within a slate belt in a transpressive setting, northern Appalachians. Journal of Structural Geology, 17 (3): 329-343.

Larocque, C.A., 1986. Geochronology and petrology of north central Gaspé igneous rocks, Québec. Master's thesis, McGill University, Montréal, 231 p.

Lefort, J.P. and Van der Voo, R., 1981. A kinematic model for the collision and complete suturing between Gondwanaland and Laurussia in the Carboniferous. Journal of Geology, 89: 537-550.

Lefort, J.P., Max, M.D. and Roussel, J., 1988. Geophysical evidence for the location of the NW boundary of Gondwanaland and its relationship with two older satellite sutures, p. 49-60. *In* A.L. Harris and D.J. Fettes, eds. The Caledonian-Appalachian orogen, Geological Society, Special Publication 38.

Mabbutt, J.A., 1966. The mantle controlled planation of pediments. American Journal of Science, 264: 78-91.

Malo, M. and Béland, J., 1989. Acadian strike-slip tectonics in the Gaspé region, Québec Appalachians. Canadian Journal of Earth Sciences, 26: 1764-1777.

Malo, M., Kirkwood, D., De Broucker, G. and St.-Julien, P., 1992. A reevaluation of the position of the Baie Verte - Brompton Line in the Québec Appalachians: The influence of Middle Devonian strike-slip faulting in the Gaspé Peninsula. Canadian Journal of Earth Sciences, 29: 1265-1273.

Malo, M. and Kirkwood, D., 1995. Faulting and progressive strain history of the Gaspé Peninsula in post-Taconian time: Areview, p. 267-282. *In* J.P. Hibbard, C.R. van Staal and P.A. Cawood, eds., Current perspectives in the Appalachian - Caledonian Orogen. Geological Association of Canada, Special Paper 41.

Malo, M., Tremblay, A., Kirkwood, D. and Cousineau, P., 1995. Along-strike Acadian structural variations in the Québec Appalachians: Consequence of a collision along an irregular margin. Tectonics, 14 (5): 1327-1338.

Mattinson, C.R., 1964. Région du mont Logan. Ministère de l'Énergie et des Ressources, Québec, RG 118, 102 p.

Petit, M., 1990. Géographie physique tropicale: approches aux études de milieu. Karthala-ACCT, 321 p.

Peulvast, J.-P., Bouchard, M., Jolicoeur, S., Pierre, G. and Schroeder, J., 1996. Paleotopographies and post-Orogenic morphotectonic evolution around the Baie-des-Chaleurs (Eastern Canada). Geomorphology, 16: 5-32.

Piper, D.J.W., Pe-Piper, G. and Loncarevik, B.D., 1993. Devonian-Carboniferous igneous intrusions and their deformation, Cobequid Highlands, Nova Scotia. Atlantic Geology, 29 (2): 219-232.

Piqué, A., 1981. Northwestern Africa and the Avalonian plate: Relations during Late Precambrian and Late Paleozoic times. Geology, 9: 319-322.

Rodgers, J., 1967. Chronology of tectonic movements in the Appalchian region of Eastern North-America. American Journal of Science, 265: 408-427.

Ruitenberg, A.A. and McCutcheon, S.R., 1982. Acadian and Hercynian structural evolution of southern New Brunswick, p. 131-148. *In* P. St.-Julien and J. Béland, eds., Major structural zones and faults of the northern Appalachians. Geological Association of Canada, Special Paper 24.

Russel, M.J. and Smythe, D.K., 1983. Origin of the Oslo Graben in relation to the Hercynian-Alleghanian orogeny and lithospheric rifting in the North Atlantic. Tectonophysics, 94: 457-472.

Rust, B.R., 1981. Alluvial Deposits and Tectonic Style; Devonian and Carboniferous successions in Eastern Gaspé, p. 49-76. *In* A.D. Miall, ed., Sedimentation and Tectonics in Alluvial Basins. Geological Association of Canada, Special Paper 23.

Rust, B.R., Lawrence, D.A. and Zaitlin, B.A., 1989. The sedimentation and tectonic significance of Devonian and Carboniferous terrestrial successions in Gaspé, Québec. Atlantic Geology, 25 (1): 1-13.

Ryan, R.J. and Zentilli, M., 1993. Allocyclic and thermochronological constraints on the evolution of the Maritimes Basin of eastern Canada. Atlantic Geology, 29 (2): 187-197.

St. Peter, C., 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, 29 (2): 233-270.

Thomas, M.F., 1989. The role of etch processes in landform development-II. Etching and the formation of relief. Zeitschrift für Geomorphologie, N.F., 33: 257-274.

———— 1994. Geomorphology in the tropics. A study of weathering and denudation in low latitudes**.** John Wiley and Sons, 460 p.

Thornbury, W.D., 1954. Principles of Geomorphology. John Wiley and Sons, 354 p.

Twidale, C.R., 1981. Origins and environments of pediments. Journal of the Geological Society of Australia, 28: 423-434.

———— 1983. Pediments, peneplains and ultiplains. Revue de Géomorphologie dynamique, 32: 1-35.

Van De Poll, H. W., 1995. Upper Paleozoic rocks; New-Brunswick, Prince-Edward-Island and Îles-de-la-Madeleine, p. 455-492. *In* H. Williams, ed., Geology of the Appalachian/Caledonian Orogen in Canada and Greenland. Geological Survey of Canada, Geology of Canada, 6.

Veillette, J-J. and Cloutier, M. 1993. Géologie des formations en surface, Gaspésie, Québec. Geological Survey of Canada, map 1804A, scale 1 : 250 000.

Whalen, J.B., 1987. Géologie du complexe plutonique des monts McGerrigle, péninsule de la Gaspésie, Québec. Geological Survey of Canada, map 1665A.

Whalen, J.B., Mortensen, J.K. and Roddick, J.C., 1991. Implications of U-Pb and K-Ar geochronology for petrogenesis and cooling history of the McGerrigle plutonic complex,Gaspé, Québec. Canadian Journal of Earth Sciences, 28: 754-761.

Yeo, G.M. and Ruixiang, G., 1987. Stellarton Basin, a pull-apart basin, p. 298-309. *In* C. Beaumont and A.J. Tankard, eds., Sedimentary basins and basin-forming mechanisms. Canadian Society of Petroleum Geologists, Memoir 12.

Zaitlin, B.A. and Rust, B.R., 1983. A spectrum of alluvial deposits in the Lower Carboniferous Bonaventure Formation of the Western Chaleur Bay area, Gaspé and New brunswick, Canada. Canadian Journal of Earth Sciences, 20: 1098-1110.