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Palaeolandforms and morphotectonic evolution around the Baie des Chaleurs (eastern Canada) [1]

Jean-Pierre Peulvast [a], Mireille Bouchard [b], Serge Jolicoeur [c], Guillaume Pierre [d], Jacques Schroeder [b]

[a] *Université de Paris-Sorbonne, 191 rue Saint-Jacques, 75005, Paris, France*
[b] *Département de Géographie, Université du Québec à Montréal, C.P. 8888, succ. Centre-Ville, Montréal, Qué. H3C 3P8, Canada*
[c] *Département d'Histoire et de Géographie, Université de Moncton, Moncton, N.B. E1A 3E9, Canada*
[d] *Université de Lille 1, 59655 Villeneuve d'Ascq Cedex, France*

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Abstract

A morphological study of the Baie des Chaleurs area, between northern New Brunswick and the Gaspé Peninsula (eastern Canada), leads to the identification of several types of palaeolandforms in the landscapes of the northeastern Appalachians. One of them, the exhumed sub-Carboniferous palaeosurface, was recognized along the shores of the Baie des Chaleurs, around the western part of the Carboniferous basin — the Maritimes Basin — which underlies the Gulf of Saint Lawrence. By analyzing the conditions of its exhumation and its relationships with escarpments limiting the higher planation surfaces of inner Gaspésie and western New Brunswick, it was possible to identify recent deformations. These are en bloc tilting and uplift, flexuring, and faulting; they partly reflect the reactivation of Carboniferous or older structures. The study of palaeolandforms has already proved to be an appropriate method for reconstructing the morphological evolution of basement areas. In this paper, it is applied to the study of the evolution of an emerged part of the eastern Canada rifted margin after the opening of the North Atlantic Ocean.

1. Introduction

Reconstructing the morphological evolution in uplifted basement areas, such as rifted margins, is generally difficult because of the removal of large volumes of rock by erosion. Post-orogenic sediments and old weathering formations that might be correlated with significant stages of the morphological evolution are generally missing or scarce. Nevertheless, the study of the morphological development in basement areas such as the Appalachian Range (Gardner and Sevon, 1989) and other North Atlantic regions, even glaciated areas (Scotland: Godard, 1965; Scandinavia: Gjessing, 1967; Peulvast, 1985a; Lidmar-Bergström, 1982) is a classical theme of geomorphology.

The methods that can be used for such investigations include:

(1) Identification, and dating, if possible, of palaeolandforms — planation surfaces and differentiated palaeolandscapes of tectonic or denudational origin —; evaluation of the nature, number, geographical,

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geometrical and chronological relationships (Lidmar-Bergström, 1988).

(2) Morphostructural analysis, which allows an evaluation of the respective roles of tectonics, differential erosion and drainage evolution in the morphological development. This analysis is also a source of data for understanding the evolution of the tectonic and environmental conditions of the landform development (Peulvast, 1986).

(3) Interpretation of minor landforms and weathering products, and analysis of the relationships with the major (often inherited) landforms. This approach allows a discrimination of the features that are correlative with the shaping of identified palaeolandforms (Peulvast, 1985a).

(4) Reconstruction of the morphological development, based upon use of the results of (1) and (2), and of other sets of data:

(4.1) Analysis of tectonic events (style, intensity, chronology, geophysical meaning) (Lidmar-Bergström, 1991; Peulvast, 1985b, Peulvast, 1991).

(4.2) Evaluation of erosion rates (Clément, 1990) and correlation with sedimentological history of adjacent areas of deposition (Poag and Sevon, 1989).

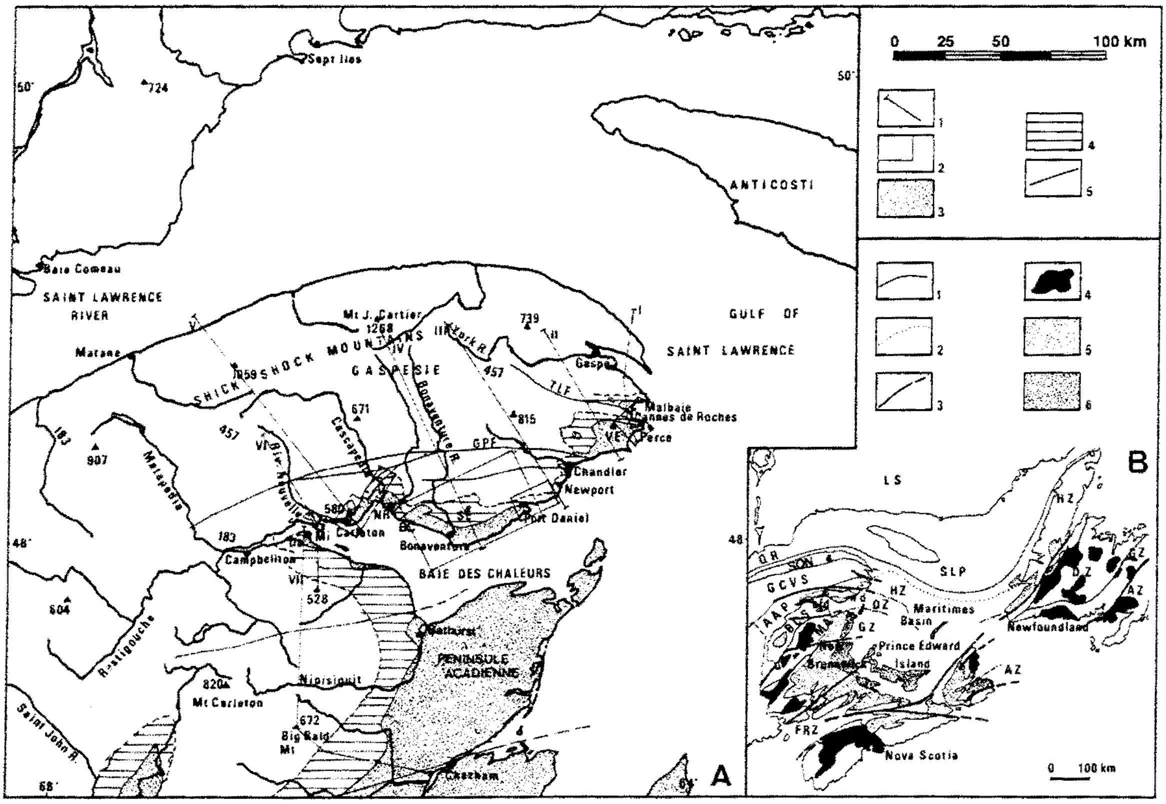

Fig. 1. Location map and geological sketch map. (A) 1: cross sections (see Fig. 2); 2: boxes showing the location of the main block-diagrams (Figs. 9, 11, 12 and 17); 3: Carboniferous–Permian rocks of the Maritimes Basin; 4: probable minimum extent of the sub-Carboniferous exhumed palaeotopographies; 5: faults along which faulting may have occurred during Carboniferous or later. TLF: Troisième Lac Fault; GPF: Grand Pabos Fault; Da: Dalhousie; Ma: Miguasha; NR: New Richmond; BC: Black Cape; SE: Saint Elzéar; VE: Val d'Espoir. (B) 1: NW limit of Appalachian deformation; 2: N limit of the Carboniferous Maritimes Basin; 3: main faults; 4: Appalachian and Caledonian plutonic rocks; 5: Carboniferous sediments; 6: Upper Carboniferous–Permian sediments. LS: Laurentian Shield; HZ: Humber Zone; DZ: Dunnage Zone; GZ: Gander Zone; AZ: Avalon Zone; SQN: Saint Lawrence–Québec Nappes; GCVS: Gaspé–Connecticut Valley Synclinorium; AAP: Aroostook–Percé Anticlinorium; BCS: Baie des Chaleurs Synclinorium; MA: Miramichi Anticlinorium; FRZ: Fundy Rift Zone; QR: Québec Reentrant; SLP: Saint Lawrence Promontory. Compiled from different sources cited in the text.

(4.3) Gathering of palaeoenvironmental data.

Such an approach to landscape analysis requires multidisciplinary investigations, although morphological observations (field work, construction of profiles and block-diagrams) should remain the first and main source of data. Although the observations reported in the present paper correspond only to (1) and (2), the implications allow us to propose a preliminary version of (4), especially some elements for a morphotectonic reconstruction.

The study area is part of the northeastern Appalachians, in Québec and New Brunswick (Canada). Whereas many recent studies give a precise account of the morphological evolution of the central Appalachian Mountains (Battiau-Queney, 1989; Gardner and Sevon, 1989), the structural morphology and the palaeolandforms of the Canadian part of the range have not yet been the object of thorough investigations. The available data remain allusive or general (Grant, 1989) because they were collected only in nearby regions (Estrie, Beauce: Birot et al., 1983; Clément, 1990). The close surroundings of the Baie des Chaleurs were chosen for the first phase of a morphotectonic study of the mountains, plateaus and basins around the Saint Lawrence River and the Gulf of Saint Lawrence. The conjunction of several favorable factors justifies this choice. These factors are a localized and relatively weak glacial action (Grant, 1989), the easy identification of well-differentiated morphostructural patterns and recognizable palaeotopographies, and the presence of unconformable Carboniferous conglomerates, the most recent cover rocks in the region. The study is part of more general investigations on palaeosurfaces (IGCP 317) and on landforms related to passive margins (especially around the North Atlantic).

2. Structural and topographic outlines

2.1. Location and relief

Centered on 48°N and 65°30′W, the Baie des Chaleurs area is located south of the Saint Lawrence estuary, on the northwestern side of the Gulf of Saint Lawrence. It is 400 km inland relatively to the Atlantic coast of Nova Scotia (Fig. 1). In this area, the Appalachian Mountains gently lower eastwards on both sides of the Baie des Chaleurs between the Gaspé Peninsula, to the north, and the New Brunswick plateau and lowlands, to the south. This shallow bay is a widened continuation of the Restigouche River and extends from W to E with sinuous outlines. The bay itself is 130 km long. Its width increases from 3 km near Campbellton to 38 km between Port Daniel and Miscou Island.

On the northern side of the bay, the WSW–ENE Gaspé Peninsula is 200 km long. It appears mainly as a 130 km wide area of forested plateaus between 350 m and 600 m a.s.l., surmounted to the north by a narrow ridge of flat topped summits, the Shickshock mountains (1262 m at Mont Jacques-Cartier). The general asymmetry of this peninsula is underlined by the hydrographic pattern, since the main rivers flow to the south (Matapedia, Cascapedia, Bonaventure rivers).

Northern New Brunswick also comprises a system of plateaus (300 to 600 m) in its western part, whereas lowlands form a peninsula and archipelago that taper northeastwards, east of Bathurst (Péninsule acadienne). The plateaus are part of the north central New Brunswick Highlands. The highlands extend along a SW–NE direction, east of the Restigouche and Saint John rivers. The hydrographic system forms a radial pattern around the higher ridges and summits (Mount Carleton, 820 m). A narrow fringe of lowlands extends along the shore on both sides of the Baie des Chaleurs.

2.2. Main geological features

2.2.1. Part of the Appalachian range

The Baie des Chaleurs area, which is part of the Acadian orogen (Devonian) (Schenck, 1978; Williams, 1979; Keppie, 1985), is characterized by thick series of sandstones, shales and mudrocks of Ordovician to Late Devonian age (Potter et al., 1979; Brisebois et al., 1991), within which several intercalations of more resistant rocks have a strong morphostructural influence. These are mostly limestones (Ordovician Matapedia Group, Silurian Chaleurs Group, Lower Devonian Upper Gaspé Limestones) and volcanic rocks (Chaleurs Group). Outcrops are controlled by a structure of tight or open folds,

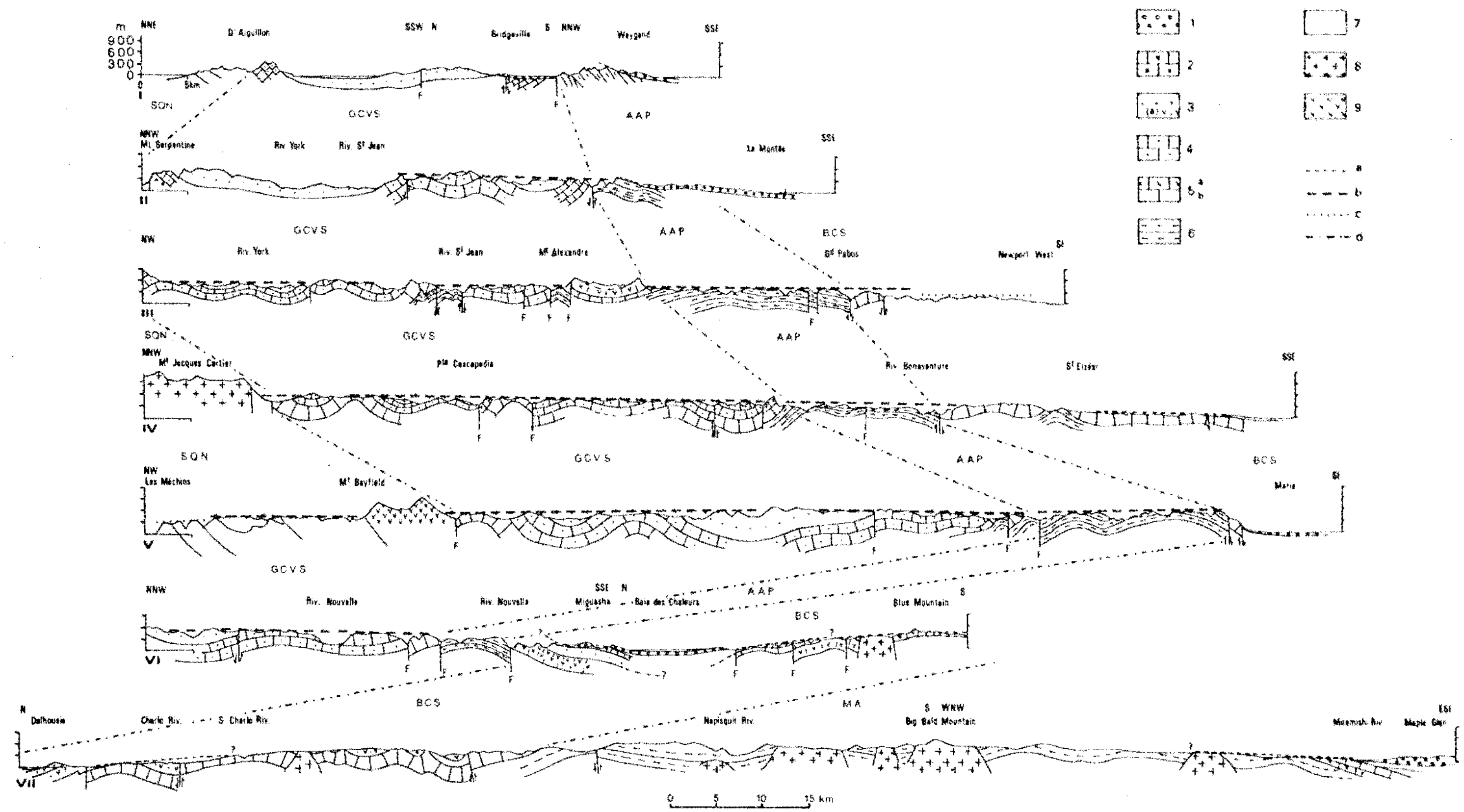

Fig. 2. Cross sections in the Baie des Chaleurs area. Location and explanation of abbreviations: see Fig. 1. 1: Bonaventure Conglomerate (Carboniferous); 2: Escuminac Formation (Upper Devonian, sandstones, mudstones, conglomerates); 3: Gaspé Sandstones (upper and mid-Devonian; sandstones, conglomerates, mudrocks, limestones); 4: Upper Gaspé Limestone (Lower Devonian); 5: Chaleurs Group (Silurian–Upper Devonian; mudrocks, limestones, sandstones; basalts and other volcanic rocks: v); 6: Matapedia Group (Upper Ordovician–Lower Silurian; limestones, mudrocks, sandstones); 7: undifferentiated Ordovician, Cambrian and Precambrian rocks; 8: granitic intrusive rocks; 9: volcanic rocks. a: sub-Carboniferous surface; b: Main Surface of Gaspésie; c: intermediate surface of uncertain origin; d: limits of the main structural units.

generally symmetric or slightly asymmetric, whith axes gently curved from N 35° (New Brunswick) to N 110° (eastern Gaspésie). These structures are arranged in a system of broad anticlinoriums and synclinoriums, which in turn are often separated by vertical faults. This is the case of the Aroostook–Percé Anticlinorium, which is bound by the Grande Rivière and Grand Pabos faults on its northern and southern sides (Fig. 2).

From the north to the south, the study area comprises:

- The Gaspé–Connecticut Valley Synclinorium (GCVS), part of the Appalachian Miogeocline (Marillier and Verhoef, 1989)
- The Aroostook–Percé Anticlinorium (AAP; Malo, 1987), part of the Piedmont Terrane
- The Baie des Chaleurs Synclinorium (BCS), a continuation of the Dunnage Terrane defined in Newfoundland (Rogerson, 1981)
- The Miramichi Anticlinorium (MA), part of the Gander Terrane that extends from central Newfoundland to New England.

2.2.2. The Devonian–Carboniferous basin of the Baie des Chaleurs

The Baie des Chaleurs and the New Brunswick lowlands are part of the Maritimes Basin (Marillier and Verhoef, 1989), which extends below the central and southern parts of the Gulf of Saint Lawrence, and in the adjoining lowlands (Prince Edward Island, Nova Scotia, southwestern Newfoundland). According to Gibling et al. (1992), this basin is "a structural and erosional remnant of a larger depocentre of unknown original extent, originated in the mid-Devonian following the Acadian orogeny."

The western part of the Baie des Chaleurs Carboniferous basin lies approximately along the axis of the Acadian Baie des Chaleurs Synclinorium. The New Brunswick Platform, which bounds the southeastern side of the bay (Péninsule acadienne), lies along the southeastern flank of the Miramichi Anticlinorium. The floor and a narrow coastal fringe of the bay are covered by the same detrital Carboniferous rocks that form the Péninsule acadienne (Syvitski, 1992). In the study area, they are represented by the Cannes de Roches Formation, which may be Visean in age (Rust, 1981), and mainly by the Bonaventure Formation, which was probably deposited during the mid Carboniferous (Mississippian, or Westphalian), and even during the Stephanian and Lower Permian in eastern Péninsule acadienne (Pictou Group: Gibling et al., 1992).

The Carboniferous rocks lie unconformably on the folded rocks of older ages, even on the Devonian terrestrial conglomerates deposited in basins between broad regional upwards during the Acadian orogeny

Fig. 3. Bonaventure conglomerate overlying unconformably Cambrian–Precambrian Maquereau sandstones near Chandler. Rough bedding and coarse size of blocks and pebbles (fanglomerate deposit).

(Rust, 1981). The basal unconformity is often well exposed along the coasts of the Baie des Chaleurs, for instance near Miguasha, New Richmond, Port Daniel, Newport and Chandler (Gaspésie; Seguin, 1976) or between Dalhousie and Pointe Verte (New Brunswick: Armstrong Brook). It may be a simple angular unconformity, but at many places the deposits were laid on strongly differentiated topographies (Fig. 3). The facies of the Carboniferous rocks confirm this observation. North of Gaspé, the Cannes de Roches Formation is composed of breccias with blocks of 2 to 50 cm in size, conglomerates, sandstones and mudstones. They were deposited in semi-arid environments, at the foot of active fault scarps, as a system of alluvial fans on both sides of a palaeovalley filled with alluvial deposits of a trunk river (Rust, 1981). The Bonaventure Formation, which interdigitates with the Cannes de Roches formation in the Percé area, shows similar facies: red to greyish conglomerates or fanglomerates, sandstones and mudstones, and locally a basal layer of massive limestone that may be several meters thick (Alcock, 1935; Kirkwood, 1989).

Block lithology and palaeoflow data (Gibling et al., 1992) suggest that the Bonaventure conglomerates and sandstones were deposited in a Carboniferous valley or elongated basin "with transverse marginal drainage and eastward axial palaeoflow", i.e., from the Appalachian orogen and from nearby escarpments, probably in a context of active tectonics (McCutcheon and Robinson, 1987). The original extent and thickness of these deposits are unknown in the study area. Small outliers located 5 to 15 km off the main outcrops (Saint-Elzéar, Saint-Gabriel de Gaspé) suggest that erosion may have significantly reduced the extent. Some outcrops display thicknesses up to 180 m near the present limits (Percé). According to Ryan et al. (1991), they might have covered most of southeastern Gaspésie 290 Ma ago.

By contrast with the older rocks, the Carboniferous rocks are mainly flat-lying — dips are less than 3° — or gently warped in shallow synclines whose axes are oriented subparallel to the Baie des Chaleurs axis (Syvitski, 1992). Stronger deformations, such as faults, were nevertheless recognized in places. Because they bear significant morphotectonic implications, an analysis of these deformations was completed.

3. Morphological analysis

3.1. Systems of stepped planation surfaces

On both sides of the Baie des Chaleurs, most of the previously described structures are truncated by flat surfaces into which most landforms are inset. The wide dissected plateaus of central Gaspésie correspond mainly to a single planation surface surmounted to the north by the narrow remnants of one or two high surfaces in the Shickshock mountains (800 to 1200 m; Fig. 2). The main surface may correspond to the "Saint Quentin–Dorchester–High Valley Surface" of the Atlantic Canada (Grant, 1989). Whereas the Shickshock mountains correspond to the ophiolites and to the granitic intrusions that lie along the southern limit of the Taconic range, this main surface is restricted to the sedimentary rocks of the Acadian orogen. Nevertheless, residual hills and narrow longitudinal ridges overlook the plateau in places where resistant limestones and volcanic rocks outcrop along the strike of the eroded folds. This surface lowers gently southwards from 600 m to ca. 400 m above the coastal lowlands of the Baie des Chaleurs, 50 to 100 km south of the Shickshock mountains. Its average slope angle is, therefore, 0.2 to 0.4%.

No other continuous surface could be identified below the level of the main surface inside the Gaspesian plateau. Shallow basins are excavated down to 300 m and lower along soft Devonian mudrocks. These have been preserved in synclines of the Gaspé–Connecticut Valley Synclinorium, at the head of transverse rivers (Cascapédia) and around the eastern longitudinal rivers (York River, Malbaie River). Other narrow compartments may be identified below the main surface. They are limited by parallel faults and a few steps of irregular altitudes. Such features have been observed along the main E–W faults of southern Gaspésie (Fig. 2: V, VI) and above the coastal platform, e.g., above Carleton (300 m) and in the Saint-Jogues–Huard area. Most of these steps are structural benches that are delimited by outcrops of Silurian or Ordovician limestones, rather than true planation surfaces. The superimposed river system, that is mainly transverse to geological structures, shows only minor adaptations to fault lines and outcrops of soft rocks leveled by the main surface.

The uplands of New Brunswick are more uneven. To the west, however, the wide SW–NE Restigouche corridor appears as a dissected planation surface that lowers gently northeastwards from 380 m to 250 m. On both sides of the anticlinorium and around its northeastern end (Fig. 2: VII), the Miramichi Highlands also show a surface of similar altitudes. It is probably a continuation of the Restigouche surface and may be an equivalent of the main surface of Gaspésie (Grant, 1989). The summits of the upper hills, structural ridges (Mount Carleton) and wide granitic plateaus (Big Bald Mountain) bear the remnants of a higher surface between 600 and 800 m. It can be recognized between corridors, valleys and basins that belong to the main surface. The lower parts of the radial valleys that drain these uplands are incised in the plateaus.

Discontinuous elements of a low surface surround the Baie des Chaleurs below the Gaspésie and New Brunswick plateaus. Limits of this surface (Fig. 1) coincide in places with those of the present outcrops of Carboniferous sediments (Carleton–Maria) or stand several km beyond them, and more infrequently inside the basin (Percé). This surface is generally uneven and sloping, and it presents at least two types of topographic patterns and relationships with the inner plateaus. South of the bay, between Campbellton and Bathurst, it is indistinctly inset below the main surface, because no significant escarpment overlooks it (Morvan-type: Baulig, 1970). It appears as a weakly dissected sloping plane that connects to the main surface through a steeper angle of slope (2.4%). The main surface is then bordered to the coast by a narrow terrace edged by a low cliff and only locally widened as a coastal plain (Eel River). Steep residual hills or ridges overlook it in places (Dalhousie Hill, 120 m). East of Bathurst, the lower surface widens considerably in the Péninsule acadienne, where it forms a low plateau between 60 and 150 m. On the southern coast of Gaspésie, the Paspébiac–Saint-Jogues and Maquereau areas also show wide and low plateaus gently sloping from the main surface to the sea.

The other parts of the low surface are clearly limited by escarpments of variable height and steepness, located 2 to 20 km from the coast. The profiles are generally sloping to the coast, from 180 m (Saint-Elzéar) to 10 m or less, with straight or slightly concave outlines (Fig. 2: II, IV, V, VI). Flat areas (Miguasha, Carleton, Maria, Bonaventure) are juxta-

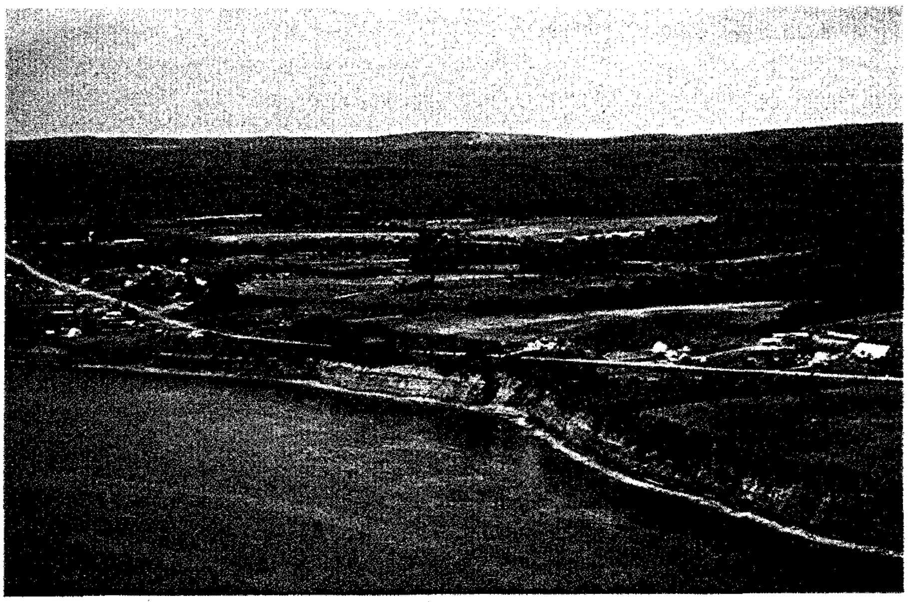

Fig. 4. Bonaventure conglomerate sea cliff and raised wave-cut platform (left) near Shigawake, SW of Port Daniel; Saint Jogues low plateau and Garin escarpment in the distance.

posed with more uneven topographies, with low hills or ridges (Grande Cascapédia, Paspébiac, Port Daniel). This type of contact with the plateaus occurs mainly in southern Gaspésie, where the low surface forms a nearly continuous fringe, with a maximum width (22 km) in the Bonaventure–Paspébiac salient of the coast. A narrow coastal terrace is often inset in its edge, between 10 and 15 m, at the top of the nearly continuous cliff that overlooks the bay (Fig. 4). The low surface disappears to the west in the Restigouche–Campbellton area, i.e., in the western closure of the Baie des Chaleurs basin. The mouth of the Restigouche River is directly incised within the main plateaus, which are here dissected in parallel, structural ridges and valleys (SW of Campbellton).

3.2. A regional datum: exhumed sub-Carboniferous topographies

Whereas no dated post-Acadian structure or deposit can afford dates for the main planation surface of Gaspésie and New Brunswick, the stratigraphic relationships exposed on the low surface allow a more precise evaluation of the nature and age of some regional palaeolandforms. As was mentioned above, this surface is not a simple planation surface. Parts of it clearly truncate the tilted Carboniferous conglomerates, e.g., near Caplan (Fig. 5), but other parts are developed between low cuestas of conglomerate and the edge of the interior plateaus. The topography of such parts of the low surface coincides mainly with exhumed parts of the sub-Visean or sub-Westphalian surface.

The width of the well identified exhumed palaeosurfaces is generally small — a few meters on the coasts (Fig. 3) to a few tens of meters. Nevertheless, cross-sections suggest that exposed unconformity surfaces extend probably on hundreds of meters and even on several kilometers off the present limits of the Carboniferous sediments. This implies that such surfaces form significant elements of the present landscape, for instance south of Dalhousie (Fig. 2: VII), or in the Cascapédia reentrant. Because of the presence of an outlier north of Saint-Elzéar, the outcrop of the exhumed surface could be 12 km in width in the Bonaventure area. Other outliers, west of Port Daniel and southwest of Saint-Gabriel de Gaspé, show widths of several kilometers as well.

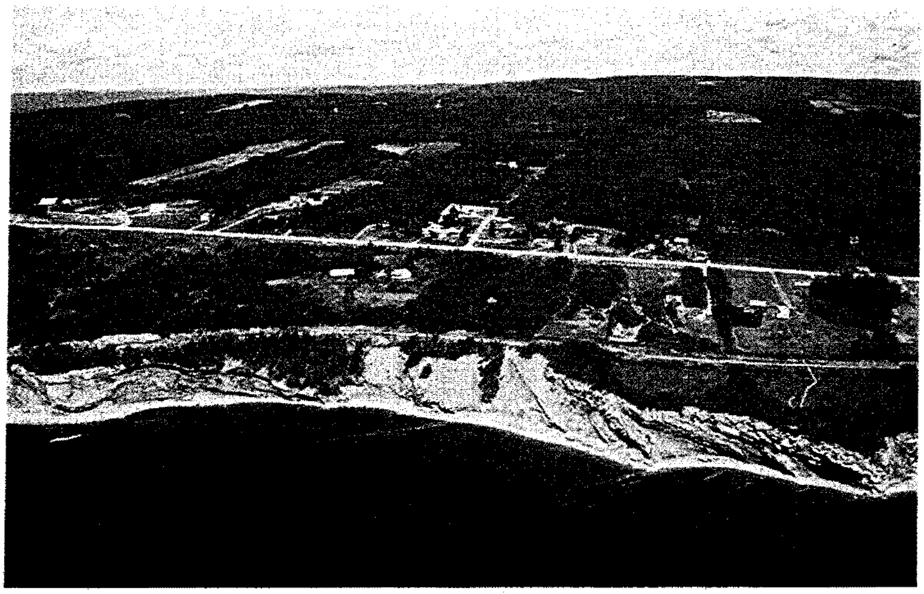

Fig. 5. Contact between the tilted Bonaventure conglomerates (right) and the folded Silurian rocks of the Chaleurs Group (center and left) between Caplan and Black Cape, at the southwestern end of the Robidoux–Black Cape bevelled ridge (in the distance). See also Fig. 8 for morphostructural setting (right-hand part).

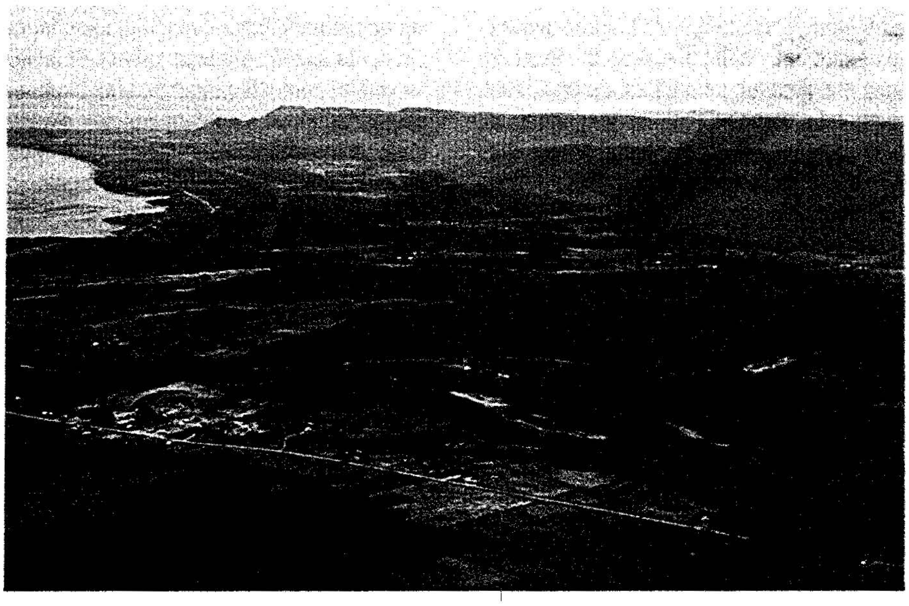

Fig. 6. The Grande Cascapedia valley, the Saint Jules cuesta and quarry (behind the river, right), the Maria low surface and the Mont Maria (right) and Mont Saint Joseph (left, in the distance) escarpments, as seen towards SW. See also Figs. 17 and 18 for the geological features.

Fig. 7. Exhumed palaeokarst in the Saint Jules quarry. Thin remnants of the overlying Bonaventure conglomerates and sandstones are preserved near the pit and in the open cracks between the limestone karrens. Glacial scouring is obvious on the limestone as well as on the conglomerate, and is partly responsible for the exhumation. Structural platform of Bonaventure conglomerates in the distance.

The nature of the exhumed sub-Carboniferous landforms is not uniform. It is possible to observe and analyze it at the foot of coastal cliffs and in a few road sections and quarries. The best exposure in Gaspésie was found in a quarry located on the western side of the lower Cascapédia valley, 2 km south of Saint-Jules de Cascapédia (Fig. 6).

This quarry, at an altitude of 60 m, is located in the northern part of a reentrant of the low surface (the Cascapédia reentrant), 3 km east of the SW–NE Mount Maria escarpment (240–360 m). It is excavated into a layer of massive or breccia limestones of the Chaleurs Group (Silurian), at the foot of a northeast facing cuesta of Bonaventure conglomerates. The limestones, which dip 16°SSW, form a low monoclinal escarpment above the Cascapedia valley, whose floor is excavated down to 10 m or less. In the working face that was visible in 1992, limestone strata were truncated by a planar surface dipping 10°S. They were covered by a very thin layer (1 m or less) of red Bonaventure conglomerate and basal sandstone. Quarrying had partially removed a veneer of till from the bedrock surface (Fig. 7). Glacial scouring by ice coming from N350°, N20° and at last N320° (the local direction of the nearby valley) has partially removed the conglomerate as well, and exposed the underlying surface on ca. 250 m^2 at the date of observation. This exhumed surface carries lapies or karren whose grooves and open joints are still filled with Bonaventure sandstones, as could be observed on the stripped surface and in the working section. One of these widened joints, or grikes, is 50 cm wide and 6 m deep at least. It is filled with a red to purple sandstone containing some small pebbles of quartz, similar to those of the overlying conglomerate. The intervening crests were partially polished by ice during the process of exhumation.

Similar palaeokarstic features, caves filled with red clay and sandstones, were found on structural ridges of Silurian limestones around Port Daniel, up to 130 m above other exhumed parts of the sub-Carboniferous topography. They were developed in protruding limestone ridges, which implies sufficiently low base levels. The buried topographies were far from being flat. The sub-Carboniferous landscape around the Baie des Chaleurs was a landscape of strong differential erosion.

Flat surfaces, often gently sloping, were identified on several coastal sections, e.g., between Dalhousie and Bathurst. Some of them seem to extend on distances of several km, but all of them are only imperfect planation surfaces, possibly pediments, formed around residual hills or ridges (Dalhousie: Fig. 2: VII) or at the foot of escarpments of tectonic (Malbaie: Kirkwood, 1989) or erosional origin (Caplan: Fig. 5). In many sites, the sub-Carboniferous topography appears as a dissected surface, with buried palaeochannels, gullies and structural ridges, hollows or furrows of metric to hectometric scales (Newport: Fig. 3; Black Cape: Fig. 8). Practically no weathering products were found at the contact between the Bonaventure formation and the underlying

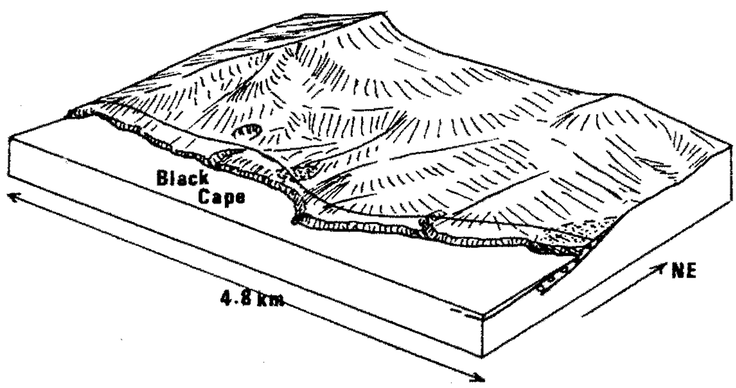

Fig. 8. The Black Cape (7 km SE from NR: New Richmond) outlier of Bonaventure conglomerate (dotted area in the center of the block-diagram). Note its location between low ridges shaped by differential erosion into the volcanic and sedimentary rocks of the Silurian Chaleurs Group.

structures, except small pockets of moderately weathered material of uncertain significance (Port Daniel). The debris flows or torrential outflows that have deposited the conglomerates (Rust, 1981) have probably stripped and incorporated the preexistant regoliths or saprolites, unless they were already thin or lacking.

3.3. Relationships between the low surface, the exhumed sub-Carboniferous topographies, and the other landforms

3.3.1. The New Brunswick type (east of Campbellton)

Four different types of relationships may be defined between the low surface that surrounds the Baie des Chaleurs, the exhumed sub-Carboniferous topographies and the plateaus. In the first, the New Brunswick type, the low surface corresponds mainly to the exhumed and tilted sub-Carboniferous surface, which is a true, yet incomplete, planation surface. It is best represented on the southern side of the Baie des Chaleurs between Campbellton and Bathurst.

Cross-sections (Fig. 2: VI, VII) show that the exhumed planation surface is locally overlooked by structural ridges of Devonian sandstones or limestones (Dalhousie). It probably extends southwards to the edge of the main surface of the New Brunswick Highlands, 25 to 30 km south from the coast. Its slope reflects the post-Carboniferous tilting and uplift that are responsible for younger events of planation and exhumation. The wide gap that separates this exhumed surface from the Highlands prevents any clear analysis of the geometrical and chronological relationships between these high residual hills and the sub-Carboniferous surface. The nature of the highest surface is, therefore, not clearly established: it is either derived from the uplifted sub-Carboniferous surface, or has formed during a younger planation event.

The sloping surfaces that form the low plateau of southern Gaspésie in the Saint-Jogues area (Fig. 9) and between Chandler and Saint-Gabriel de Gaspé below 200 m belong to the same morphological type.

3.3.2. The Saint-Elzéar–Port Daniel type

This case is best represented on the southern coast of Gaspésie (Fig. 2: III, IV). The low surface mainly

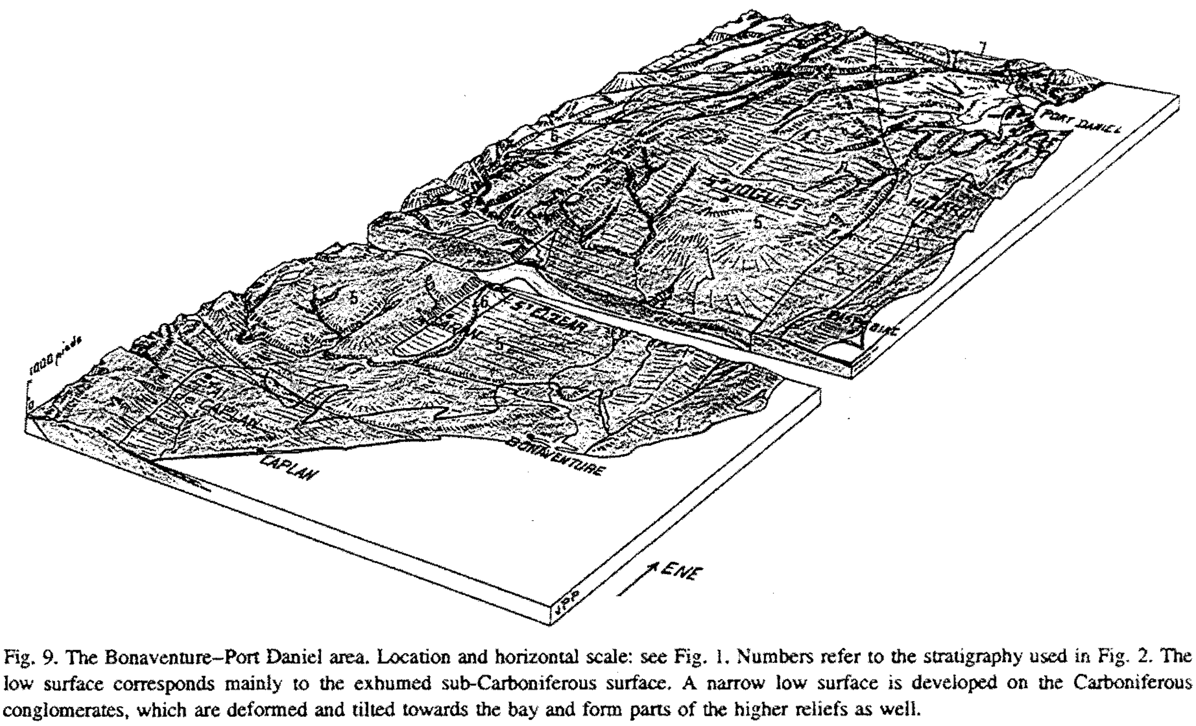

Fig. 9. The Bonaventure–Port Daniel area. Location and horizontal scale: see Fig. 1. Numbers refer to the stratigraphy used in Fig. 2. The low surface corresponds mainly to the exhumed sub-Carboniferous surface. A narrow low surface is developed on the Carboniferous conglomerates, which are deformed and tilted towards the bay and form parts of the higher reliefs as well.

coincides with the exhumed sub-Carboniferous topography, but it is bounded by palaeoescarpments that form the edge of the main planation surface. The presence of flat lying or weakly dipping outliers of Bonaventure conglomerates allows an unequivocal identification of the exhumed surface and an analysis of its morphology.

In the Caplan–Bonaventure–Saint-Elzéar area (Fig. 9), the low surface comprises a narrow coastal, substructural or planation, surface developed between 10 and 90 m on the Bonaventure conglomerate, whose outcrop widens only in the Saint-Alphonse-de-Caplan area. The conglomerate platform is locally bounded northwards by a low cuesta that overlooks the inner part of the low surface, i.e., the exhumed sub-Carboniferous surface. This gently sloping surface truncates folded mudrocks, sandstones and limestones of the Chaleurs Group and of the underlying Matapedia Group (Upper Ordovician).

North of Saint-Elzéar, a straight ENE–WSW escarpment forms the edge of the central plateau of Gaspésie (350–450 m). The Garin escarpment is 10 km long and stands 160 m above a very flat part of the exhumed surface. It contrasts with the more gentle slopes that link the low surface to the plateau around the Bonaventure River embayment to the west, and in the Saint-Jogues area to the northeast (Fig. 10). A 45 m thick remnant of Bonaventure conglomerates is preserved on the exhumed surface and forms the Saint-Elzéar butte, 1.5 km in front of the Garin escarpment. This escarpment is the locally well developed front slope of a hogback of Silurian limestone, on the southern side of a syncline beveled by the main planation surface. The Bonaventure River embayment is a palaeobasin excavated into the mudrocks that outcrop along the axis of the anticline located to the north. Its gently sloping northern flank is the backslope of another beveled hogback whose frontslope overlooks the Cascapedia reentrant to NW, and the flat lying remnants of its conglomeratic cover between New Richmond and Robidoux.

All the escarpments described in this area are identified as palaeoescarpments formed by differential erosion and then partially or completely buried. The basal parts are either still partially buried by Carboniferous deposits (New Richmond–Black Cape) or completely exhumed (Garin). The epigenetic valleys of the Bonaventure Rivers are incised

Fig. 10. The Garin exhumed escarpment (to the left and in the distance) and the Saint Elzéar outlier of Bonaventure conglomerate (the wooded butte on the right), as seen to NE. River Duval in the middle (a tributary of the Bonaventure River). The main planation surface of Gaspésie in the distance. Location: see Fig. 9.

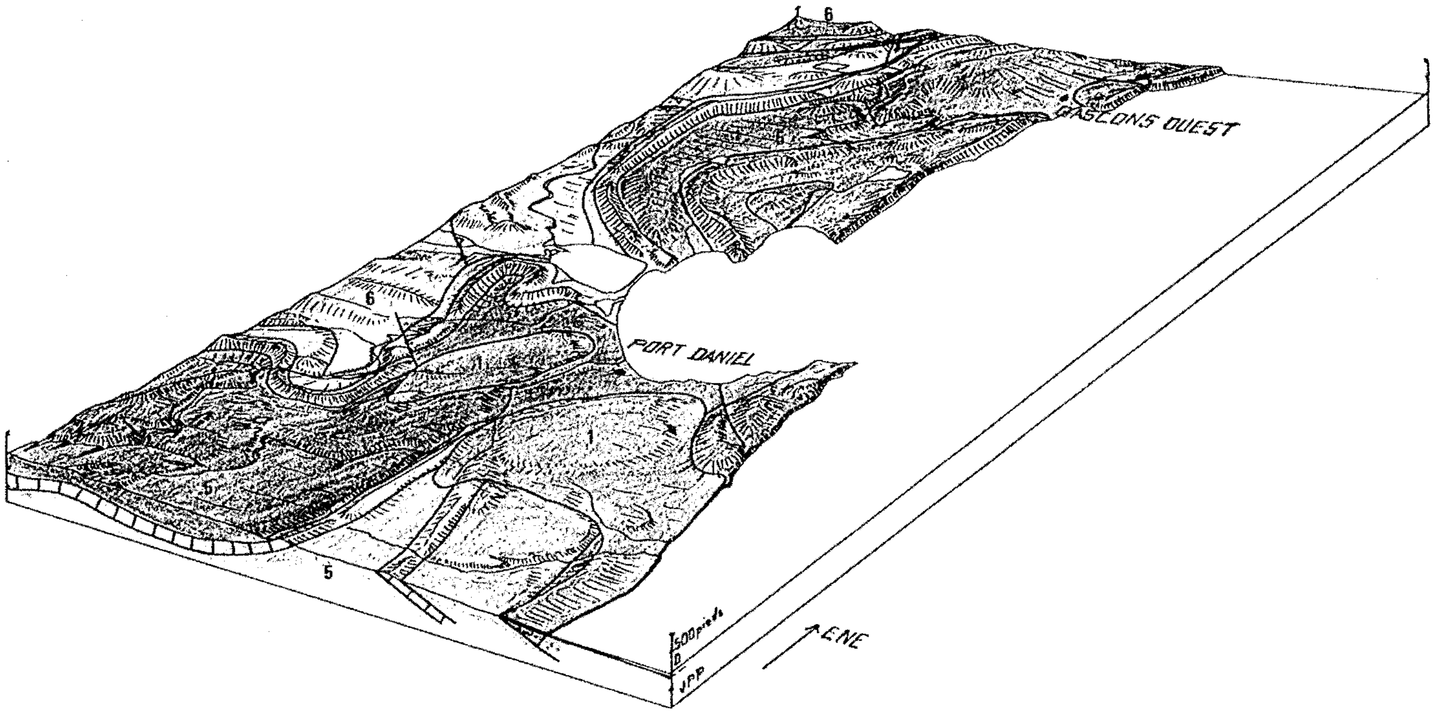

Fig. 11. The Port Daniel area. Most of the folded structures shown on the block-diagram are developed in Silurian limestones and shales of the Chaleurs Group. Numbers refer to the stratigraphy used in Fig. 2. Location and scale: see Fig. 1.

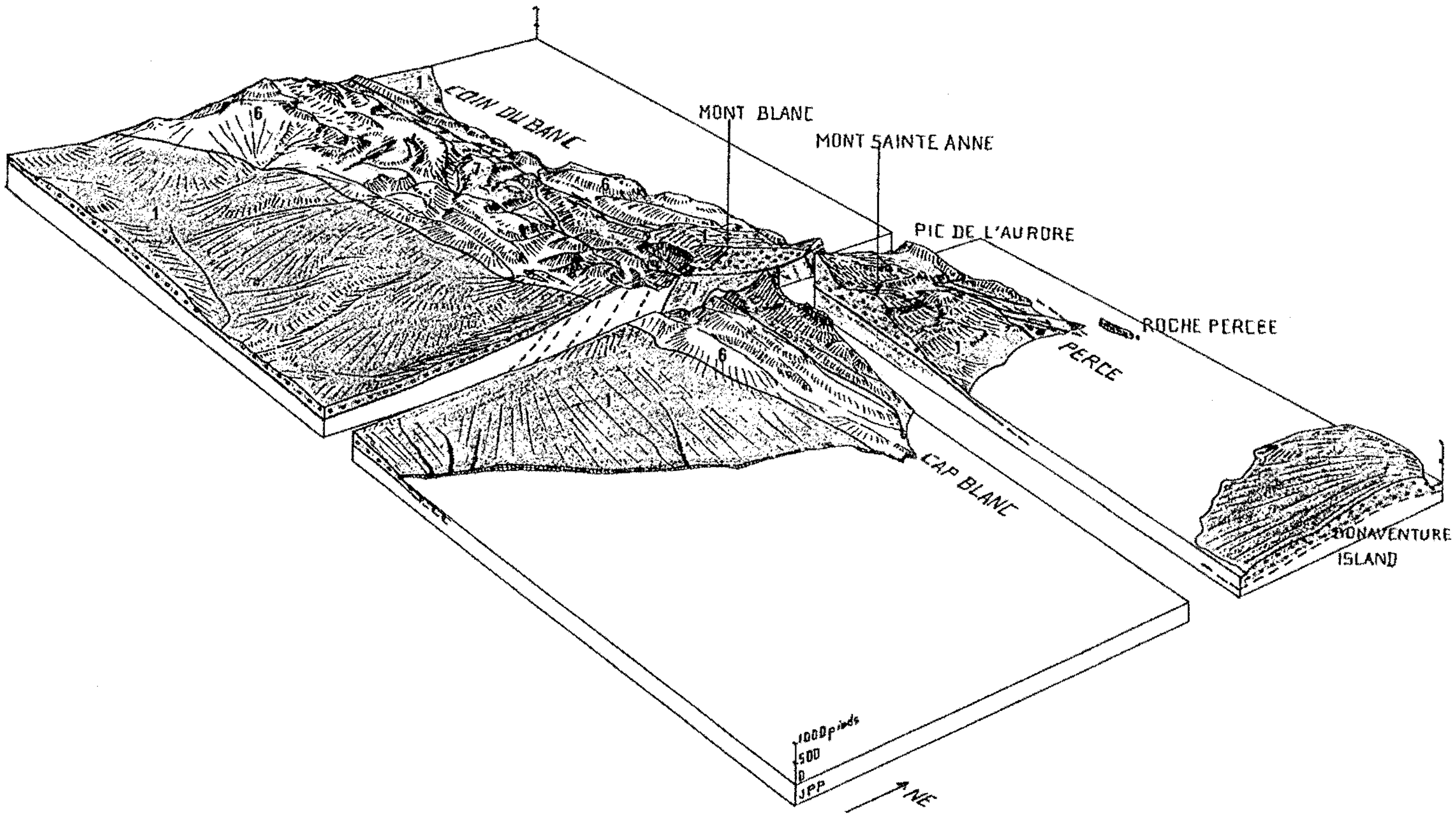

Fig. 12. The Percé area. Numbers refer to the stratigraphy used in Fig. 2. Location and scale: see Fig. 1.

across a low structural ridge that surmount the exhumed surface east of Caplan (Fig. 9). They probably were superimposed on the Carboniferous cover, which in turn probably once covered most of the low topography.

The Port Daniel area displays a more differentiated palaeorelief below the level of the main planation surface of Gaspésie (Fig. 11). West and southwest of Port Daniel, remnants of Bonaventure conglomerates are preserved in depressed areas excavated into mudrocks and sandstones, between and through hogbacks of Silurian limestones. These landforms were shaped by differential erosion along folded structures of the Baie des Chaleurs Synclinorium, on the periphery of the Maquereau eroded dome. The altitude of the karstic cavities filled with Carboniferous deposits suggests that all the presently visible topography was exhumed from the Bonaventure conglomerate. This explains the superimposition of several rivers (e.g., the Rivière de l'Ouest) through the sinuous hogbacks of this area. Northwards and northwestwards, the altitude of the hogbacks progressively rises to 300 m and more, whereas the relief becomes less and less differentiated and the outliers of conglomerate disappear. The transition with the subhorizontal main surface of Gaspésie occurs 8 to 10 km north of the coast.

Most outcrops of Bonaventure conglomerates display weakly inclined strata. Nevertheless, the conglomerate layers may have been tilted toward the Baie des Chaleurs, e.g., west and north of Rivière Caplan. In that area, the dips of some beds reach 20°SE on the backslope of the New Richmond–Robidoux hogback (Fig. 5). The exact amount and the age of this deformation are not known, but such a disposition must be considered in any morphotectonic interpretation of this morphological type.

3.3.3. The Percé–Miguasha type

In this type, a narrow low surface is developed on the Carboniferous conglomerates. These are tilted toward the bay and also form parts of the higher topographies (Fig. 2: I, II, VI).

The Percé area corresponds to the southeastern tip of the Gaspé Peninsula (Figs. 1 and 12). It belongs to a part of the Aroostock–Percé Anticlinorium formed by a WNW–ESE asymmetric anticline with a wide and gently dipping southern limb and a narrow

Fig. 13. The Percé buttes, as seen to NE from Cap d'Espoir. The Mont Blanc in the middle and Mont Sainte Anne (with overhanging walls) to the right. Outcrops of Bonaventure conglomerates in the buttes as well as in the sea cliff (see also Fig. 12). Post-Carboniferous deformation is obvious.

northern flank. This latter is obliquely truncated above Malbaie by the so-called "Faille du Troisième Lac", a NW–SE dextral strike-slip fault (Kirkwood, 1989). These Acadian structures are unconformably covered by wide remnants of the Carboniferous conglomerates.

The relief of this area is one of the most spectacular in Gaspésie (Fig. 13). It is organized around the WNW–ESE Cap Blanc ridge (350–390 m), which bears an extension of the main surface of Gaspésie. This beveled and dissected ridge of Ordovician limestones and mudrocks separates two triangular basins that open eastwards on the Maritimes Basin: the Cannes de Roches Basin, to the north, and the Val d'Espoir Basin to the south. Carboniferous conglomerates form the floors and even parts of the flanks of both basins between the sea level and 150 to 300 m, but they form also parts of the intervening ridge, and even some of its highest summits (Mont Blanc: 370 m).

The exhumed sub-Carboniferous surface outcrops only in a narrow fringe on the southern side of the ridge. It is tilted southwards together with the conglomerates, which are truncated and thinned by the Val d'Espoir Basin surface. The main planation surface of Gaspésie, whose remnants are preserved on the ridge, intersects the tilted sub-Carboniferous surface on the southern edge of this ridge (Fig. 2: II).

North of the ridge, the flat floor of the Cannes de Roches Basin is shaped into the Carboniferous conglomerates. It is also equivalent, however, in part to the exhumed underlying surface that forms the gentle surrounding slopes to the west and to the north (Barachois). On its southern side (Coin du Banc), the basin is abruptly bounded by the straight NW–SE escarpment that continues the complex Rocher Percé–Pic de l'Aurore–Cannes de Roches cliff. This escarpment of Ordovician limestones is parallel to the nearby Troisième Lac fault but it appears as a partly exhumed unconformity surface. This surface is strongly deformed, together with the conglomerates, because dips between 40° and 70°NE have been recorded along the coast (Kirkwood, 1989).

The eroded anticline that forms the ridge itself is covered by thick layers of Bonaventure conglomerates in its easternmost part. The red conglomerates bury a shallow anticlinal valley or half-graben excavated into mudrocks and sandstones of the Murphy Creek Formation (Cambrian). To the southwest, a beveled hogback of Ordovician limestones forms the main part of the ridge (Fig. 12). They are deformed by a shallow synclinal undulation whose axis is parallel to the older fold axes and plunges to ESE (200 m on 2.5 km). On the southern slope of the Pic de l'Aurore, to the north, this structure is bounded by an E–W normal fault along which the conglomerates

Fig. 14. Deformed Carboniferous conglomerates W of the Pic de l'Aurore (Percé) as seen to the West. The conglomerates are locally faulted along an E–W fault with S throw. Limestones and shales of the Matapedia Group on the northern (right) side.

are steeply tilted (Fig. 14). According to Kirkwood (1989) the Post-Acadian tectonics responsible for these structures is mainly synsedimentary. It may explain the important thickness (up to 200 m) of the conglomerates preserved here. Wide buttes with structural inclined tops and vertical or overhanging hillslopes are shaped into the alternatively soft and hard layers of the massive conglomerates (Mont Sainte-Anne, 340 m; Mont Blanc: Fig. 13). They overlook the exhumed and dissected anticlinal palaeovalley. To the east, this paleovalley forms the site of Percé. To the west, it appears as a narrow step between the crest of the ridge — the limestone hogback — and the coastal hills of Cannes de Roches. The Bonaventure Island, SE of Percé, is another remnant of the conglomerates preserved along the same structure.

The morphostructural pattern of the Percé area provides evidence for post-Carboniferous tectonic movements because the thickest remnants of the Bonaventure conglomerates are preserved near the top of the highest structural unit. The structure analyzed from the geometry of the conglomerate layers includes two main eastwards plunging synclines (Malbaie, Val d'Espoir) separated by an asymmetric and possibly faulted WNW–ESE anticline superimposed on the Acadian Percé anticline. Its axis is located on the southern limb of this old structure, and bifurcates to SE around the Mont Blanc–Mont Sainte-Anne plunging syncline (Fig. 12). Though the conglomerates have been deposited on an uneven topography, in a context of active tectonics, it may be suggested that part of this structure was formed later, and even in relatively recent times. This would explain the paradoxical morphological location of the outliers. The presence of exceptionally massive and resistant beds above softer basal beds may be a factor of their preservation (Mont Sainte-Anne). On the other hand, a recent uplift might explain why erosion, which is generally fast in these rocks (see last section of the paper) has not yet destroyed them. Therefore, the stepped pattern of this area would reflect tectonic movements, i.e., differential vertical movements along old Acadian or Carboniferous

Fig. 15. The Miguasha Peninsula, Dalhousie (left) and the Restigouche mouth, as seen to WSW from the Mont Saint Joseph (580 m). The Carboniferous Bonaventure conglomerate underly the peninsula and the Carleton platform (lower left corner), as well as the low surroundings of Dalhousie. Main planation surface of New Brunswick in the distance.

structures and flexuring toward the Baie des Chaleurs and the Gulf of Saint Lawrence. These movements would have been followed by only minor exhumation of the sub-Carboniferous surface in uplifted and in lowered areas.

A similar, yet more simple, conformation may be seen in southwestern Gaspésie, north of Miguasha (Fig. 2: VI). Here, the contact between the low surface — which forms part of the Miguasha peninsula — and the main plateau of Gaspésie (300 m or less in this area) is located on the northern limb of the Baie des Chaleurs Anticlinorium.

The southern edge of the main plateau coincides with the backslope of a beveled hogback of Silurian volcanic rocks, above a longitudinal corridor whose eastern part forms the lower valley of the Rivière Nouvelle. The low surface, which forms the Miguasha Peninsula south of this valley, is underlain by the Bonaventure conglomerates that cover unconformably the folded Devonian series preserved in the synclinorium. Though it clearly bevels the conglomerates, it rises gently westwards and northwestwards, i.e., toward the periclinal ends of two shallow east-plunging synclines that form here the western end of the Carboniferous basin (Fig. 15). Whereas the Devonian substratum is excavated to the south in the Escuminac Bay, the Bonaventure conglomerates are preserved in these synclines. They form a small dissected plateau between 180 and 210 m, with high cliffs (up to 80 m) above the Escuminac Bay. Two or locally three parallel hogbacks of underlying Devonian conglomerates and sandstones separate its northern edge from the Rivière Nouvelle valley and from the main plateau of Gaspésie. These hogbacks and the intervening furrows are shaped into the E–W monocline that forms the northern side of the Carboniferous basin and links the low surface to the main plateau.

Here, and in the Percé area, the preservation of an upstanding syncline of soft Carboniferous conglomerates in the flexure zone suggests that the deformation responsible for the stepped topographic pattern cannot be very old.

3.3.4. *The Maria–Carleton type*

In this type, which is best represented east of the Miguasha Peninsula, the low surface is also developed on the Carboniferous conglomerates, but it is separated from the main plateau by a steep escarpment of tectonic origin (Fig. 2: V).

On the western side of the Cascapédia Bay, the main planation surface of Gaspésie is horizontal or even slightly rising toward southeast and forms a high and tilted compartment of this surface (the Carleton block). Its altitude reaches 570 to 600 m, 5 km only from the sea (Mont Saint-Joseph: Fig. 16A). Its edge over the Baie des Chaleurs is the steepest escarpment of southern Gaspésie (Fig. 17). Its direction is E–W between Robitaille and Carleton, and then N–S after a sharp bend (Mont Saint-Joseph escarpment). It loses steepness and height 7 km north of the bend, as the floor of the low surface rises northwards between it and the Mont Maria block (405 m), in the Rivière Verte reentrant. It is relayed north of Guité by a SW–NE escarpment (the Mont Maria or Grande Cascapédia escarpment) which disappears north of Saint Jules in the northeastern closure of the Cascapédia reentrant of the low surface. These features correspond to the en échelon faults that form the southern limit of the Aroostock–Percé Anticlinorium and bound the limbs of its SW plunging synclines of Ordovician mudrocks, sandstones and limestones (Gosselin, 1988).

Between Robitaille and the Cascapédia mouth, the low surface is 2 to 8 km wide and forms a flat or gently rolling platform below 70 m. It is entirely underlain by Bonaventure conglomerates, though the sub-Carboniferous surface is exhumed at low altitudes, north of discontinuous cuestas, in the Guité, Saint-Jules and Grande Cascapédia areas. It bevels the tilted conglomerates, except a low hogback that parallels the escarpment, 100 to 200 m from it, from Robitaille to the Mont Saint-Joseph bend (Fig. 17). This hogback corresponds to a sharp accentuation of the dip of the conglomerate near the escarpment, up to 70°S.

The conglomerate hogback is developed along the E–W segment of the Mont Saint-Joseph escarpment and along the bend, i.e., at the southern end of the "Carleton block", which is deeply dissected by rivers flowing southwards (Stewart River). This steep and massive part of the escarpment, which lowers to the west because of the lowering of the plateau, corresponds to the continuation of the flexure analyzed in the Miguasha area. However, no remnant of Carboniferous deposit is visible on the uplifted side.

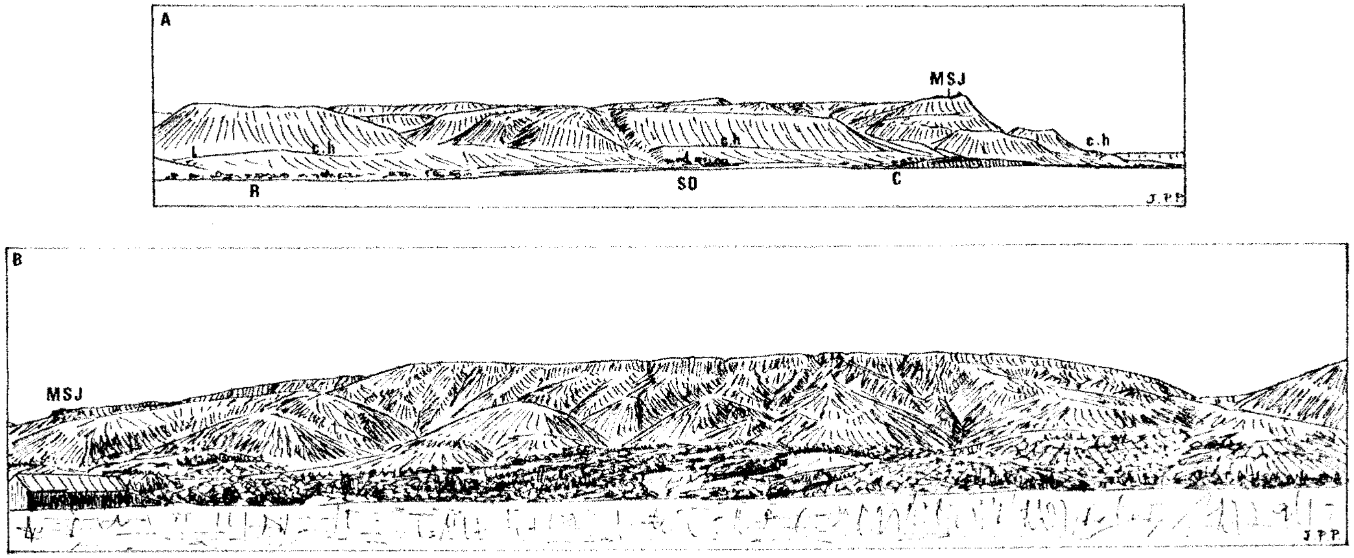

Fig. 16. The Mont Saint Joseph (580 m). (A) As seen to ENE from Miguasha. R: Robitaille; SO: Saint Omer; C: Carleton West; MSJ: Mont Saint Joseph; c.h: conglomerate hogback (Bonaventure conglomerate), separated from the escarpment by a discontinuous furrow excavated along an E–W fault or flexure. (B) As seen to W from Maria West. Fault escarpment with more or less blunted triangular facets in the lowest part, above the Petit montréal Fault, and a steep and nearly straight upper part, controlled by the Mont Saint Joseph Fault (see Fig. 17).

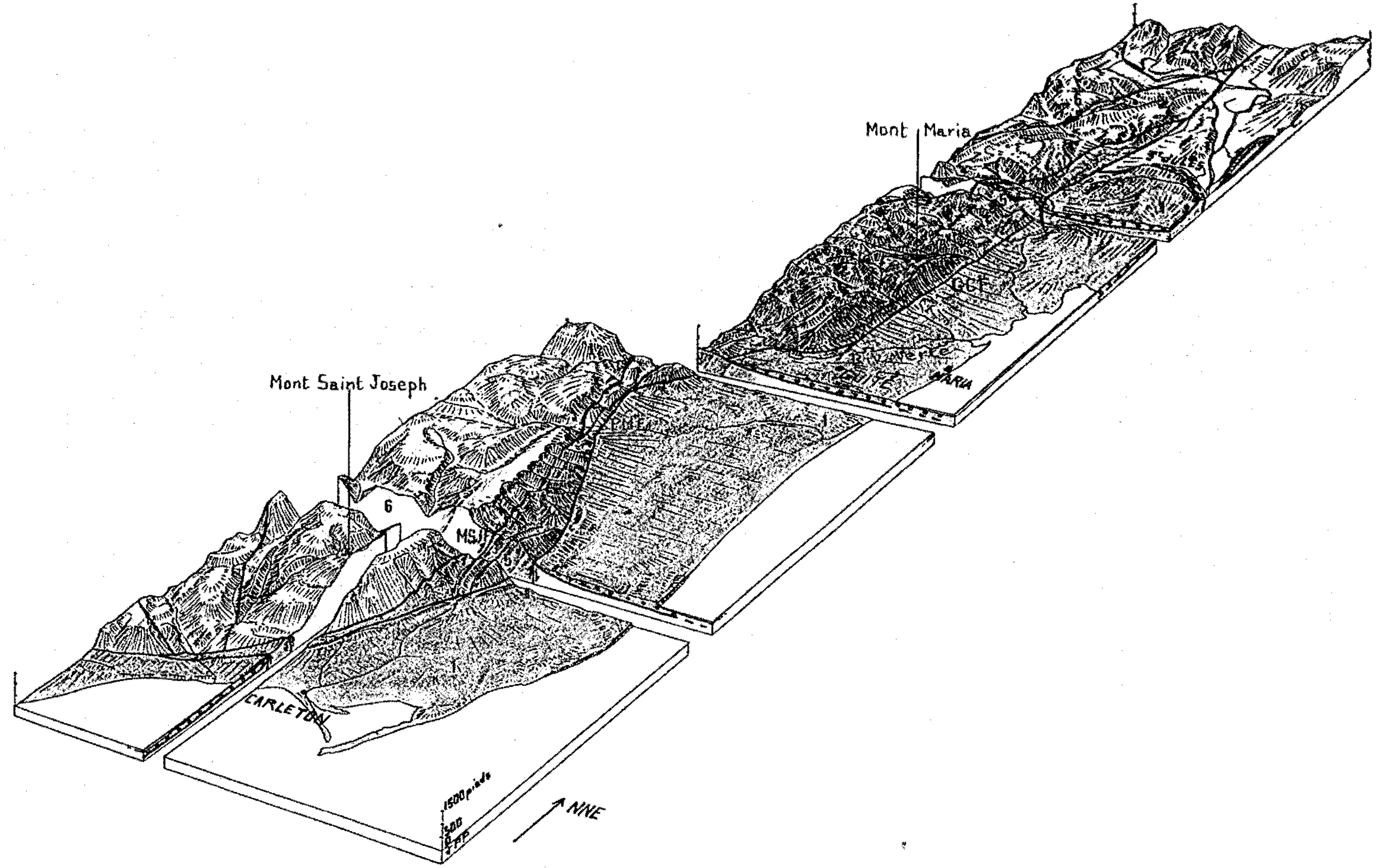

Fig. 17. The Carleton–Maria area. Numbers refer to the stratigraphy used in Fig. 2; location: see Fig. 1. Note the fault escarpment NE of Mont Saint Joseph. MSJF: Mont Saint Joseph Fault; PMF: Petit Montréal Fault; GCF: Grande Cascapedia Fault.

Whereas the escarpment may derive from the strongly tilted and exhumed sub-Carboniferous topography north of Saint-Omer (Fig. 18), it becomes a true fault scarp north of Carleton.The flexure then becomes a fault which trends NE and N: the Petit Montréal Fault (Gosselin, 1988). The Petit Montréal Fault, and the parallel Mont Saint-Joseph Fault identified higher in the escarpment, are interpreted as reverse faults of Acadian age with strong NNW dip (Gosselin, 1988). Nevertheless, the relationships between the fault line and the topography, and the strong tilting of the Carboniferous conglomerates near the fault, suggest that tectonic movements occurred during deposition or later. The weakness zone — mainly the Petit Montréal Fault — was then reactivated as a normal, probably vertical, fault.

The N–S segment of the Mont Saint-Joseph escarpment displays a typical fault scarp morphology, with 10 triangular facets overlooking the narrow undulating pediment that forms the transition with the low platform (Fig. 16B). These somewhat blunted facets are only 100 to 150 m high because they form the edge of a narrow step of Silurian volcanic rocks that divides the escarpment in two parts along the Mont Saint-Joseph Fault. The upper part of the escarpment is steeper as it corresponds to the coalescing headwalls of the short gullies that dissect the step. Whereas this step widens and rises northeastwards and finally merges with the Mont Maria plateau, the upper escarpment progressively lowers to the north and disappears 10 km north of the Rivière Verte reentrant, i.e., where the Mont Saint-Joseph Fault is intersected by the WSW–ENE Grand Pabos strike-slip fault.

The Mont Maria escarpment is steeper and more simple, because it corresponds to a single fault, the SW–NE Grande Cascapedia Fault. This fault is an old Acadian fault with an original NW throw, because Silurian volcanic rocks outcrop in the northwestern compartment, whereas Ordovician mudrocks and limestones of the New Richmond anticline outcrop on the southeastern side. Nevertheless, the presence of Carboniferous limestones on the eroded anticline, at the foot of a 400 meter high escarpment, suggests either that differential erosion had excavated the anticline before the deposition of the

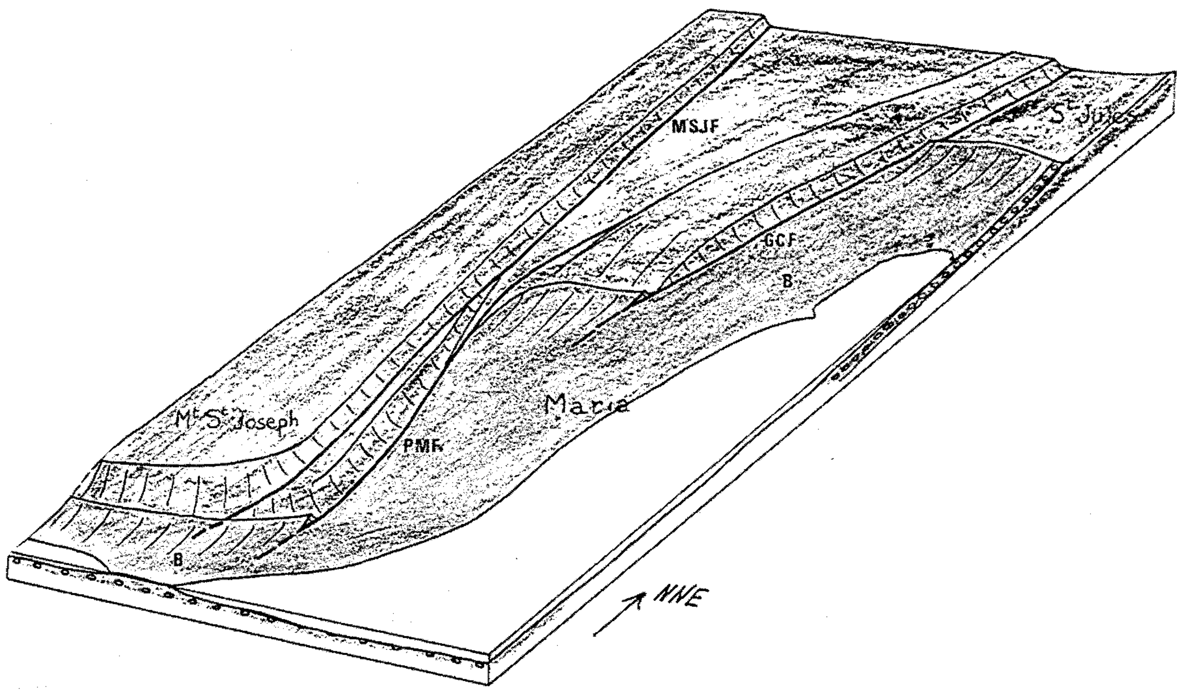

Fig. 18. Tectonic setting of the Carleton–Maria area. B: Bonaventure conglomerate; nomenclature of faults: see Fig. 17.

Bonaventure conglomerates, or that the fault was reactivated later as a normal fault with SE throw. This last hypothesis is not contradictory with the first one and fits well with the observed relief. Lithological factors may explain the steepness of the escarpment because resistant volcanic rocks form part of the uplifted compartment. Indeed, the southern part of the scarp forms two high and wide trapezoidal facets between short NW–SE valleys, whereas the northern part, shaped into less resistant mudrocks, limestones and sandstones, is strongly dissected around the Cascapédia valley (Fig. 17). This morphology suggests relatively recent faulting, although no evidence of presently active tectonics was found, and in spite of the possibility that differential erosion, including stripping of the Carboniferous rocks, could exaggerate the escarpment, north of the Saint-Jules cuesta.

The morphotectonic pattern of the Carleton–Maria area corresponds to a post-Acadian pattern of obliquely faulted blocks whose southern tips are steeply flexured toward the Baie des Chaleurs ("touches de piano": Fig. 18). The present morphology is mainly the result of vigorous post-Carboniferous tectonic movements, although the consecutive exhumation of deformed palaeotopographies from the Carboniferous cover may have an influence as well, especially on the southern end of the tilted blocks or "touches de piano" (systems of cuestas or hogbacks, narrow lowlands and exhumed tilted surfaces or slopes: Fig. 18).

4. Interpretation of the stepped system of palaeotopographies

4.1. The low surface: a composite topography

In spite of its low altitude, the surface which surrounds the Baie des Chaleurs is generally uneven. In every studied case, it includes elements corresponding to exhumed sub-Carboniferous landforms, and plains or platforms beveling the Carboniferous conglomerates. In places where both types of landforms are identified, they are often separated by low cuestas or hogbacks shaped by differential erosion into tilted structures, from a planation surface intersecting the beveled parts of the sub-Carboniferous topographies with low angles (Percé area: Fig. 2: I, II). This conformation, which explains the thickening of the preserved layer of Bonaventure conglomerates toward the Baie des Chaleurs, implies that the planation event occurred after slight tilting of the basin surroundings toward the bay. In eastern New Brunswick, north of Chatham, the post-Carboniferous surface truncates long NE–SW diabase dykes of Triassic or younger age (Potter et al., 1979). Its age is, therefore, post-Triassic.

The low surface truncates some protruding parts of the sub-Carboniferous palaeolandscapes as well, and allowed the superimposition of several rivers through ridges that were successively buried, possibly beveled together with their unconformable cover, and then exhumed (Caplan and Port Daniel areas). Stripping of the Carboniferous sediments and exhumation of the underlying landforms is easy because of the poor consolidation that characterizes most beds of the Bonaventure formation, especially the basal beds. This process is actively going on, as suggested by observations of quick retreat of the coastal cliffs, with frequent rock falls prepared by active undercutting into soft layers. Strong fluvial erosion is shown by the red color of stream and sea water after every significant rainfall. Such an erodible character explains also the Late or post-Glacial formation of fine wave-cut platforms on the conglomerates, now raised to 10 to 20 m, along many parts of the coast.

Differential erosion and partial stripping of the Carboniferous cover were possible around the Baie des Chaleurs because the low planation surface, where identified, is neither connected to the present base level, nor horizontal. Many landforms described here are inset into a sloping surface that shows local transitions with the upper topography, i.e., the main surface of Gaspésie and New Brunswick (Saint-Jogues and Chandler areas, for instance). In such cases, the stepped pattern is only locally well developed, and restricted to areas where once buried palaeoescarpments were present and could be exhumed (Saint-Elzéar, Fig. 9). Nevertheless, uncertainties about the original thickness of the Carboniferous conglomerates make it difficult to know if the whole difference in level between the low surface and the main plateau is entirely the result of exhumation or not.

For instance, the Saint-Elzéar outlier is only 45 m high (altitude of the top: 260 m) whereas the nearby Garin escarpment is 170 m high (altitude of the top: 390 to 450 m). This escarpment bears no evidence of a tectonic origin. Therefore, if exhumation is not the only process of its formation, the hypothesis of the preservation of a never buried Carboniferous escarpment above a low surface restricted to the Carboniferous deposits and ultimately dissected should be proposed. Such an hypothesis does not fit with the fact that the limestone outcrop edged by this escarpment was beveled by the main surface of Gaspésie. No lower topography existed then: the escarpment was buried, and its cover was beveled by the same surface. Moreover, clues for a complete burying of the 150 meter high hogbacks of the nearby Port Daniel area suggest that conglomerate layers of significant thickness might bury parts of the surroundings of the Baie des Chaleurs. This observation is consistent with the maps published by Hendricks et al. (1993), where thick Carboniferous strata are suggested to have covered the whole southeastern Gaspésie during maximum burial, 290 m.y. ago.

4.2. The main planation surface

The main planation surface of Gaspésie and New Brunswick generally remains remarkably even and weakly sloping. Its deep dissection, however, reflects strong uplift, because its altitudes are 300 to 500 m in the close surroundings of the Baie des Chaleurs. The distances between the bay and the plateau are the smallest in places where recent uplift along faults or steep monoclines is inferred (Miguasha, Carleton–Maria, Percé). The corresponding escarpments are only dissected by short valleys. River valleys that were superimposed on the Paleozoic structures, which were themselves beveled by the uplifted planation surface, only show minor readjustments to these structures.

No post-Devonian deposit is known on the planation surface, hence it is difficult to decipher its age. Also, the only dated saprolite occurrences (^{10}Be inventories) do not suggest a Pre-Quaternary age for them (Bouchard and Pavich, 1989). In the Percé and Miguasha areas, this planation surface beveled reliefs that provided elements to the Carboniferous sedimentation, and probably the Bonaventure conglomerates themselves. Therefore, it must be considered as a post-Carboniferous surface, and it is probably much younger, as it is surmounted to the north (Gaspésie) and to the south (New Brunswick) by one or perhaps two higher surfaces. In Gaspésie, its formation below these old surfaces was probably consecutive to a stage of asymmetric uplift along the Saint Lawrence rift, whose faults are the main active structures of this area (Adams and Basham, 1991). The excavation of shallow longitudinal basins into this surface, along the Devonian synclines of inner Gaspé Peninsula, is possibly a result of the continuation of a moderate uplift of these regions. This should have happened before the en bloc uplift which caused the incision of narrow valleys toward the Baie des Chaleurs.

4.3. Relative chronology

Absolute ages can be proposed only for the exhumed elements of Sub-Carboniferous topographies. Only relative ages can be assigned to the other palaeotopographies. The stepped pattern may suggest two different interpretations. In the first one, it may be considered that the low surface is inset into the uplifted main surface, and that it is, therefore, younger, even if it incorporates exhumed sub-Carboniferous topographies. A narrow planation surface would have developed around the Baie des Chaleurs during or after the uplift event. The alternative view is to consider that both levels represent the same surface, deformed by the flexures or faults along which the plateaus of Gaspésie and New Brunswick were uplifted. Most observations suggest that the second interpretation is correct.

According to this interpretation, the present landscape evolved from a single large planation surface surmounted by residual ridges and hills. This horizontal or gently sloping surface probably substituted to previous planation surfaces, beveling most Acadian structures and the Carboniferous cover preserved in a shallow E–W syncline centered on the present Baie des Chaleurs (Fig. 19: 2). Uplift occurred at the periphery of this syncline during "recent" times, in different ways to which the morphostructural types analyzed in this paper correspond respectively.

Along large parts of the bay, the main surface was

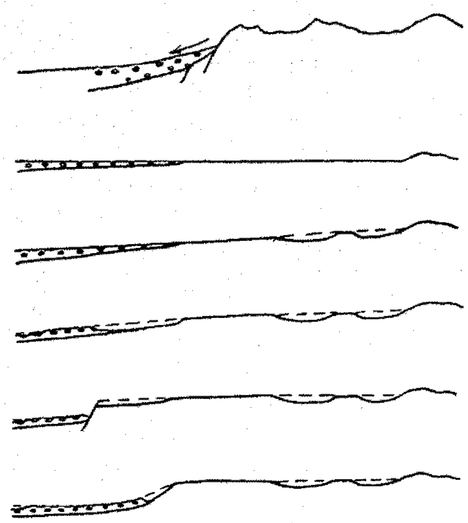

Fig. 19. Tentative sketch cross sections showing the main stages of the landform evolution around the Baie des Chaleurs. 1: Carboniferous (with faulting, erosion, and deposition of conglomerates); 2: Post-Carboniferous planation; 3: gradual uplift and slow degradation of the planation surface (e.g. Central Gaspésie); 4: recent uplift, a: with gentle tilting towards the Baie des Chaleurs and subsequent exhumation of relatively wide parts of the sub-Carboniferous surface (and palaeoescarpments); b: along a normal fault (e.g. Carleton–Maria); c: along a vigourous flexure or monocline (e.g. Miguasha or Percé).

tilted toward the old depressed area. Consecutive differential erosion stripped the soft cover rocks that were present on the uplifted limbs of the wide monoclines (Fig. 19: 4a). Exhumation of the sub-Carboniferous topographies occurred on larger widths as the dips are weak. A low cuesta often forms the edge of the preserved layers of conglomerates. It is then located in front of a gently rising slope which corresponds to an exhumed planation surface. This surface is either intersected at its top by the main surface (New Brunswick, Saint-Gabriel de Gaspé) or abutting against an exhumed escarpment (Saint-Elzéar).

4.4. *The nature of the limiting scarp*

Limited segments of the edge of the main plateau of Gaspésie were formed by strong flexuring. To this may be added a possible exaggeration of the resulting slope by exhumation of more inclined elements of the sub-Carboniferous topography (Figs. 19: 4b). The Miguasha–Saint-Omer and Saint-Jules de Cascapédia areas correspond to this structural type. The Percé area was formed in the same way, but the exhumation process remained incomplete, because thick outliers of well-consolidated conglomerate are preserved in the uplifted part of the structure.

Faulting of the main surface, probably along normal faults, is identified only in the Carleton–Maria area. It resulted in the formation of a high fault scarp above a part of the planation surface preserved on the Carboniferous conglomerates. No remnant of conglomerate is preserved on the uplifted block, but lower compartments in the uplifted plateau may represent exhumed sub-Carboniferous depressed areas (West of the Mont Saint-Joseph: Figs. 16 and 19: 4c). In this case, and also in the flexured areas, partial exhumation of sub-Carboniferous topographies might occur on the low compartment or even in the hinge line of the monocline. This is favored by the weak resistance of the Carboniferous conglomerates compared to most rocks of the substratum, and because of the multiple changes in the base level during the Pleistocene Glacial and Interglacial periods.

5. Morphotectonic evolution of the Baie des Chaleurs area: significance and chronology

5.1. *Lowlands and Carboniferous basin: palaeogeographic coincidence or preservation related to recent tectonics?*

Like many basement areas of Europe (Caledonian orogen of Scandinavia: Peulvast, 1985b; Variscan orogen of France and middle Europe: Klein, 1990) and of eastern North America (Appalachians of the United States: Battiau-Queney, 1989), the Baie des Chaleurs area underwent post-orogenic tectonic movements that could reactivate some of its older structures. These vertical movements could lead to the classical contrast between uplifted areas submitted to erosion and subsiding areas where late- or post-orogenic deposits were laid and ultimately preserved. The morphostructural patterns of the study area, therefore, illustrate some classical types of morphological contacts between a basement plateau, or mountain, and its sedimentary cover.

A good geographical correspondence exists between the boundaries of the Baie des Chaleurs lowlands and the present limits of the northwestern part of the Permian-Carboniferous Maritimes Basin. The problem is to know whether this coincidence is the result of recent tectonics and consecutive differential erosion, leading to a configuration entirely different from the original basin outlines, or whether it remained approximately the same since Carboniferous times. The last interpretation could imply that differential erosion of the basin deposits is the only process responsible for the present morphostructural patterns, after regional "en bloc" uplift (Grant, 1989). It could otherwise imply that tectonic movements occurred mainly along the former margins of the basin or of its deepest parts. The sedimentological data exposed in the first section of this paper suggest that most escarpments separating the main topographical levels are located near the former limits of the basin. Some could even belong to the bounding ridges and tectonic escarpments that provided the Carboniferous sediments (Cannes de Roches). As the morphological study proved the recent reactivation of parts of these structures, the last interpretation seems the most appropriate. It does not rule out, however, the possible stripping of parts of the sedimentary cover that could overlap the present limits.

Like other parts of the Appalachians (Battiau-Queney, 1989; Poag and Sevon, 1989) the study area was probably uplifted as a result of rifting and opening of the Atlantic Ocean, in relationship with the development of the passive margin in eastern Canada. The thermal history of Paleozoic sediments in the Anticosti and Mingan islands, in the northern part of the Gulf of Saint Lawrence, shows that post-Acadian uplift and corresponding erosion reached 2 to 4 km on the Laurentian platform (Bertrand, 1990). The Maritimes basin contains up to 11 km of Carboniferous and Permian sediments in its central parts and shows signs of differential vertical movements in its northwestern parts. It is, therefore, suggested that differences in uplift amplitude, if not true subsidence, may account for the depressed situation of this basin, though a contribution of differential — mainly fluvial — erosion cannot be completely ruled out (Grant, 1989; Syvitski, 1992).

Explanations of the correspondence between lowlands and an old tectonic basin might, therefore, be partly geophysical. For instance, Carboniferous thinning of the crust below the Maritimes Basin resulted in mantle underplating with mafic or ultramafic material which still forms a lower crustal layer about 13 km thick with high density (Marillier and Verhoef, 1989). Moreover, according to the same authors, maximum calculated depths of the Moho (48 km) were recorded below some of the escarpments that surround the Baie des Chaleurs, north of Port Daniel and below the eastern side of the Miramichi plateau. On the other hand, minimal depths (36 km) characterize the intervening part of the Baie des Chaleurs and the Péninsule acadienne. A correspondence exists between these patterns and the distribution of inferred recent tectonic movements in the study area. The seismic activity is presently low in the studied area, but several M3 to M5.7 earthquakes were recorded during the twentieth century on the eastern side of the Miramichi Anticlinorium (Adams and Basham, 1991). Further investigations on the mechanisms of the reactivation of Acadian structures by differential vertical movements should take these facts in account.

5.2. *Timing*

The present study provides no data for a precise timing of the post-Acadian morphotectonic evolution in the Baie des Chaleurs area. Nevertheless, several stages may be inferred, and the ages may be roughly bracketed.

After active Visean, Silesian and Permian tectonics, erosion and sedimentation (Fig. 19: 1), the Maritimes basin and the bounding structures were beveled by a large planation surface. Remnants of this major feature have been identified on mountains and plateaus of many parts of Eastern Canada (Grant, 1989). One or more planation events occurred later, probably after moderate vertical movements such as those recorded in the central Appalachians in Mesozoic times (Poag and Sevon, 1989). They finally formed an incomplete planation surface below the first one, surmounted by residual hills and ridges of resistant rocks (Ordovician and Silurian limestones and volcanic rocks, Devonian granites). No indication occurs in this area of the volumes of rocks removed by these long and complex planation stages, but the process preserved the Carboniferous and Permian conglomerates in the late-Acadian Maritimes Basin (Figs. 19 and 3).

Possibly preceded by slow degradation of this surface, the following stage was characterized by rapid en bloc uplift of central Gaspésie and New Brunswick relatively to the Baie des Chaleurs (Figs. 19 and 4). These movements took place along several types of tectonic structures more or less parallel to Acadian structures. These movements led to the present stepped topographic pattern. They triggered the deep dissection of the uplifted plateaus, the nearly complete stripping of the remnants of Carboniferous sediments that could have been preserved on them, and a moderate shaping of the emerged parts of the lower compartment by differential erosion. Exhumation of sub-Carboniferous topographies by fluvial, marine and possibly glacial erosion is a result of this shaping.

The chronology of these events remains uncertain. Analogies with other parts of the Appalachians provide only hypotheses for further investigations with appropriate methods. Clues for the existence of mountain landscapes, possibly of Andean type with average relief between 3.5 and 4.5 km, are found in the central Appalachian Mountains for Permian and Trias (Slingerland and Furlong, 1989). The bulk of the Carboniferous–Permian sedimentation in the Maritimes Basin took place longitudinally from such mountains. The later planation history is still to be reconstructed. It should be based on correlations with the deposition history of the nearby continental shelf (Keen and Williams, 1989; Poag and Sevon, 1989). The last uplift event is possibly an equivalent of the quick uplift recorded in the central Appalachians and in the highlands of New England by Poag and Sevon (1989) for the Middle Miocene–Pliocene period. Its coincidence with cooling climates and stronger and stronger pulses in sea level may account for the correlative erosion as well. In the nearby region of Estrie (Clément, 1990), few data were found for a long lasting stability in post-Cretaceous times. A high surface was degraded during Oligocene, before a Miocene stage of uplift. As an hypothesis, such a reconstruction might apply to the study area.

6. Conclusion

The analysis of palaeolandforms is an appropriate tool for reconstructing the morphotectonic evolution in basement areas. This is also true of formerly glaciated environments, although it requires a preliminary evaluation of the amount of glacial erosion and modification of the pre-Glacial landscapes. The identification of one surface at least which can be considered as a regional datum for the study of later movements is a necessary basis for any precise reconstruction. The study of the exhumed sub-Carboniferous surface of southern Gaspésie and northern New Brunswick, together with the analysis of morphostructural patterns, allowed such a reconstruction.

According to our observations, we think that the present morphology of the Baie des Chaleurs area may be mainly controlled by recent, possibly Late Cenozoic tectonic movements, though a minor amount of differential erosion must be considered as well. As in other parts of the Appalachians (Battiau-Queney, 1989), these movements occurred along old — Acadian — and possibly deep-seated structures, which were reactivated during epeirogenic events related to the evolution of the North Atlantic margin.

The reconstruction is still incomplete, because it does not include precise timing of the different stages and events. It is, therefore, considered as a set of preliminary data and hypotheses for further investigations on the morphotectonic evolution of regions surrounding the Gulf of Saint Lawrence.

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References

Adams, J. and Basham, P., 1991. The seismicity and seismotectonics of eastern Canada. In: D.B. Slemmons, E.R. Engdahl, M.D. Zoback and D.D. Blackwell (Editors), Neotectonics of North America: Boulder, Colorado. Geological Society of America, Decade Map Volume I, pp. 261–275.

Alcock, F.J., 1935. Géologie de la région de la Baie des Chaleurs. Commission Géologique du Canada, mémoire 183, 165 pp.

Battiau-Queney, Y., 1989. Constraints from deep crustal structure on long-term landform development of the British Isles and eastern United States. In: T.W. Gardner and W.D. Sevon (Editors), Appalachian Geomorphology. Geomorphology, 2: 53–70.

Baulig, H., 1970. Vocabulaire franco–anglo–allemand de géomorphologie. Ophrys, Gap, 300 pp.

Bertrand, R., 1990. Maturation thermique et histoire de l'enfouissement et de la génération d'hydrocarbures du bassin de l'archipel de Mingan et de l'île d'Anticosti, Canada. Can. J. Earth Sci., 27: 731–741.

Birot, P., Godard, A. and Pelletier, J., 1983. L'érosion différentielle dans les reliefs de l'Estrie et de la Nouvelle Angleterre, entre Montréal et le piedmont sud-est des White Mountains. Géogr. Phys. Quat., 37: 3–25.

Bouchard, M. and Pavich, M.J., 1989. Characteristics and significance of pre-Wisconsinan saprolites in the northern Appalachians. Z. Geomorphol. N.F., Suppl., 72: 125–137.

Brisebois, D., Lachambre, G. and Piché, G., 1991. Carte géologique de la péninsule de la Gaspésie 22A, 22B, 22G, 22H et 21O. DV 91-21, Québec.

Clément, P., 1990. Evolution géomorphologique d'un secteur nord-appalachien (Québec, Canada): approche dynamique. Z. Geomorphol. N.F., 34(3): 283–299.

Gardner, T.W. and Sevon, W.D. (Editors), 1989. Appalachian Geomorphology. Geomorphology, 2: 119 157.

Gibling, M.R., Calder, J.H., Ryan, R., Van de Poll, W. and Yeo, G.M., 1992. Late Carboniferous and Early Permian drainage patterns in Atlantic Canada. Can. J. Earth Sci., 29: 338–352.

Gjessing, J., 1967: Norway's paleic surface. Norsk Geogr. Tidsskr., 21(2): 69–132.

Godard, A., 1965. Recherches de géomorphologie en Ecosse du Nord-Ouest. Publications de la Faculté des Lettres de Strasbourg, 701 pp.

Gosselin, C., 1988. Géologie de la région de Maria (Gaspésie). Ministère de l'énergie et des ressources, Québec, ET 87-01, 28 pp.

Grant, D.R., 1989. Le Quaternaire de la région des Appalaches atlantiques du Canada. In: R.J. Fulton (Editor), Le Quaternaire du Canada et du Groenland, ch. 5. Commission Géologique du Canada, Géologie du Canada, Vol. 1, pp. 421–474.

Hendricks, M., Jamieson, R.A., Willett, S.D. and Zentili, M., 1993. Burial and exhumation of the Long Range inlier and its surroundings, western Newfoundland: results of an apatite fission-track study. Can. J. Earth Sci., 30: 1594–1606.

Keen, C.E. and Williams, G.L. (eds), 1989. Geology of the Continental margin of Eastern Canada. Geological Survey of Canada, n°2 (also Geological Society of America, The Geology of North America, v. I-1).

Keppie, J.D., 1985. The Appalachian collage. In: D.G.Gee and B.A. Sturt (Editors), The Caledonide Orogen–Scandinavia and Related Areas. Wiley, Chichester, pp. 1217–1226.

Kirkwood, D., 1989. Géologie structurale de la région de Percé (Gaspésie). Ministère de l'énergie et des ressources, Québec, ET 87-17: 33 pp.

Klein, C., 1990. L'évolution géomorphologique de l'Europe hercynienne occidentale et centrale. Aspects régionaux et essai de synthèse. Mémoires et Documents de Géographie, Editions du CNRS, Paris, 177 pp.

Lidmar-Bergström, K., 1982. Pre-Quaternary geomorphological evolution in southern Fennoscandia. Meddelanden från Lunds Universitets Geografiska Institution, 91: 202 pp.

Lidmar-Bergström, K., 1988. Denudation surfaces and tectonics in the southernmost part of the Baltic Shield. Precambrian Res., 64: 337–345.

Lidmar-Bergström, K., 1991. Phanerozoic tectonics in southern Sweden. Z. Geomorphol. N.F., Suppl., 82: 1–16.

Malo, M., 1987. Stratigraphie et structure de l'anticlinorium d'Aroostook–Percé de l'est de la Gaspésie. Ministère de l'énergie et des ressources, Québec, ET 87-06: 35 pp.

Marillier, F. and Verhoef, J., 1989. Crustal thickness under the Gulf of St. Lawrence, northern Appalachians, from gravity and deep seismic data. Can. J. Earth Sci., 26: 1517–1532.

McCutcheon, S.R. and Robinson, P.T., 1987. Geological constraints on the genesis of the Maritimes Basin, Atlantic Canada. In: C. Beaumont and A.J. Tankard (Editors), Sedimentary Basins and Basin-forming Mechanisms. Can. Soc. Petrol. Geol. Mem., 12: 287–297.

Peulvast, J.P., 1985a. Relief, érosion différentielle et morphogénèse dans un bourrelet montagneux de haute latitude: Lofoten–Vesterålen et Sogn–Jotun (Norvège). Thèse de Doctorat d'Etat, Paris I, 1642 pp.

Peulvast, J.P., 1985b. Post-orogenic morphotectonic evolution of the Scandinavian Caledonides during the Mesozoic and Cenozoic. In: D.G. Gee and B.A. Sturt (Editors), The Caledonide Orogen: Scandinavia and Related Areas. Wiley, Chichester, pp. 979–994.

Peulvast, J.P., 1986. Structural geomorphology and morphological development in the Lofoten Vesterålen (Norway). Norsk Geogr. Tidsskr., 40: 135–161.

Peulvast, J.P., 1991. Structural geomorphology and morphotectonic evolution of an uplifted rifted margin: the Scoresby Sund area, East Greenland. Z. Geomorph. Suppl. Bd., 82: 17–34.

Poag, C.W. and Sevon, W.D., 1989. Record of Appalachian denudation in postrift Mesozoic and Cenozoic sedimentary deposits of the U.S. middle Atlantic continental margin. In: T.W. Gardner and W.D. Sevon (Editors), Appalachian Geomorphology. Geomorphology, 2: 119–157.

Potter, R.R., Hamilton, J.B. and Davies, J.L., 1979. Geological map of New Brunswick. Department of Natural Resources New Brunswick, 2nd ed.

Rogerson, R.J., 1981. The tectonic evolution and surface morphology of Newfoundland. In: A.G. Macpherson and J.B. Macpherson (eds.), The natural environment of Newfoundland, past and present, Department of Geography, Memorial University of Newfoundland, pp. 24–55.

Rust, B.R., 1981. Alluvial deposits and tectonic style: Devonian and Carboniferous successions in Eastern Gaspé. In: A.D. Miall (ed.), Sedimentation and tectonics in alluvial basins. Geol. Assoc. Can. Spec. Pap., 23: 49–76.

Ryan, R.J., Grist, A.M. and Zentilli, M., 1991. The thermal evolution of the Maritimes Basin: Evidence from apatite fission track analysis. In: Mineral Development Division, Report of Activities 1990, Nova Scotia Department of Mines and Energy, Report 91-1: 27–32.

Schenck, P.E., 1978. Synthesis of the Canadian Appalachians. In: E.T. Tozer and P.E. Schenk (Editors), Caledonian–Appalachian Orogen of the North Atlantic Region. Geol. Surv. Can. Pap., 78-13: 111–136.

Seguin, M.K., 1976. L'est du Canada. Basses Terres du Saint Laurent, Appalaches, Bouclier Précambrien. Guides Géologiques régionaux. Masson, Paris, 176 pp.

Slingerland, R. and Furlong, K.P., 1989. Geodynamic and geomorphic evolution of the Permo–Triassic Appalachian mountains. In: T.W. Gardner and W.D. Sevon (Editors), Appalachian Geomorphology. Geomorphology, 2: 23–37.

Syvitski, J.P.M., 1992. Marine geology of the Baie des Chaleurs. Géogr. Phys. Quat., 46(3): 331–348.

Williams, H., 1979. Appalachian orogen in Canada. Can. J. Earth Sci., 16: 792–807.