Significance of paleosurfaces in interpreting the paleogeographic and stratigraphic evolution of the late Paleozoic Paspébiac graben, a recently identified basin in the southern Gaspé Peninsula of Quebec, Canada

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ABSTRACT

The remote-sensing study of an exhumed upper Paleozoic surface in the southern Gaspé Peninsula of Quebec has provided indirect evidence for the presence of a previously unidentified post-Acadian (post–Middle Devonian orogeny) graben-fill unit. Subsequent work on stratigraphic sections in that area confirms that the graben-fill unit, the new Saint-Jules Formation, is indeed petrographically distinct and older than previously documented upper Paleozoic strata in that area, which were collectively assigned to the Viséan (Upper Mississippian) Bonaventure Formation. Paleogeographic reconstruction from sedimentary facies, paleocurrent, and provenance studies concurs with the geometric detail that was provided by the preliminary geomorphic study. The present paper therefore presents the case study of an upper Paleozoic stratigraphic unit that was first inferred by geomorphic constraints prior to being recognized in the field through the study of stratigraphic sections. The study underlines the stratigraphic relevance of analyzing exhumed paleosurfaces at the margins of ancient sedimentary basins.

Keywords: exhumed paleosurfaces, Saint-Jules Formation, upper Paleozoic stratigraphy, structural geomorphology, paleogeographic reconstruction, Paspébiac graben.

INTRODUCTION

Paleosurfaces have been extensively studied to derive information regarding Cenozoic tectonics and landscape evolution (see compilations of articles edited by Widdowson, 1997, Thiry and Simon-Coinçon, 1999, and Smith et al., 1999). In some cases, especially if they are hardened by the formation of duricrusts, remnants of paleosurfaces have been preserved since the Mesozoic without ever having been buried (Twidale et al., 1976; Twidale, 1994, 1999, 2000; Ollier, 1995; Simon-Coinçon et al., 1997; Battiau-Queney, 1997; Gunnell, 1997; Beard, 1998; Lidmar-Bergstrom et al., 1999; Simon-Coinçon, 1999; Valeton, 1999; Widdowson and Gunnell, 1999). More rarely, exhumed paleosurfaces from the Proterozoic and the Paleozoic have been documented, providing data on paleoenvironments, paleotectonics, and long-term landscape evolution (Chrobok, 1967; Twidale et al., 1976; Bail, 1983; Lidmar-Bergstrom, 1993, 1995, 1996, 1999; Finkl, 1994; Peulvast et al., 1996; Lidmar-Bergstrom et al., 1997, 1999; Dix and Molgat, 1998; Johansson, 1999; Dilliard et al., 1999; Jutras and Schroeder, 1999; Puura et al., 1999; Johansson et al., 2001; O'Beirne-Ryan and Zentilli, 2003).

This paper introduces a new application for the analysis of paleosurfaces by presenting a case study of the Upper Devonian to Lower Mississippian Saint-Jules Formation in the newly identified Paspébiac graben of eastern Quebec (Figs. 1 and 2). The Saint-Jules Formation was recently identified through the study of stratigraphic sections in the adjacent Cascapédia Basin of southwest Gaspé (Fig. 1; inset) (Jutras and Prichonnet, 2002), but its existence was first inferred by the remote-sensing study of an exhumed upper Paleozoic surface in the present study area of southern Gaspé (Jutras and Schroeder, 1999). Hence, for the first time, a stratigraphic unit is predicted by constraints derived from the study of an exhumed paleosurface prior to being formally identified in the field, providing new insights into the potential contribution of geomorphic analysis as an additional tool for the study of ancient sedimentary basin margins. However, because the stratigraphic application of such geomorphic studies is limited to raising questions and proposing potential solutions, they need to be combined with detailed geologic studies to verify their resulting models, which is the purpose of this paper.

Stratigraphic and geomorphic data are combined in this study to (1) verify the geomorphic model of Jutras and Schroeder (1999) concerning the upper Paleozoic stratigraphy of southern Gaspé, (2) update mapping in that area, (3) identify erosion events, (4) describe depositional environments, (5) determine source areas, (6) delineate basin geometry, and (7) produce a paleogeographic reconstruction of the time when the Saint-Jules Formation was being deposited.

GEOMORPHIC SETTING

The composite morphology of the southern Gaspé Peninsula (Figs. 3 and 4), which includes three unrelated geomorphic units, has been described by Jutras and Schroeder (1999). Hence, it is only summarized here to put it in relationship with the new stratigraphic data.

Most of the Gaspé Peninsula is characterized by a peneplain surface that extends throughout the Canadian Appalachians (Grant, 1989) and is locally referred to as the "Gaspesian Plateau" (Fig. 3) (Gray and Hétu, 1985). Two geomorphic units were recognized within the limits of the exhumed upper Paleozoic surface that stands below the Gaspesian Plateau in the southern end of the peninsula (Fig. 3) (Jutras and Schroeder, 1999). Both units truncate folded rocks of Eoproterozoic to Early Devonian age and are partly covered by erosional remnants of flat-lying upper Paleozoic strata (Fig. 4).

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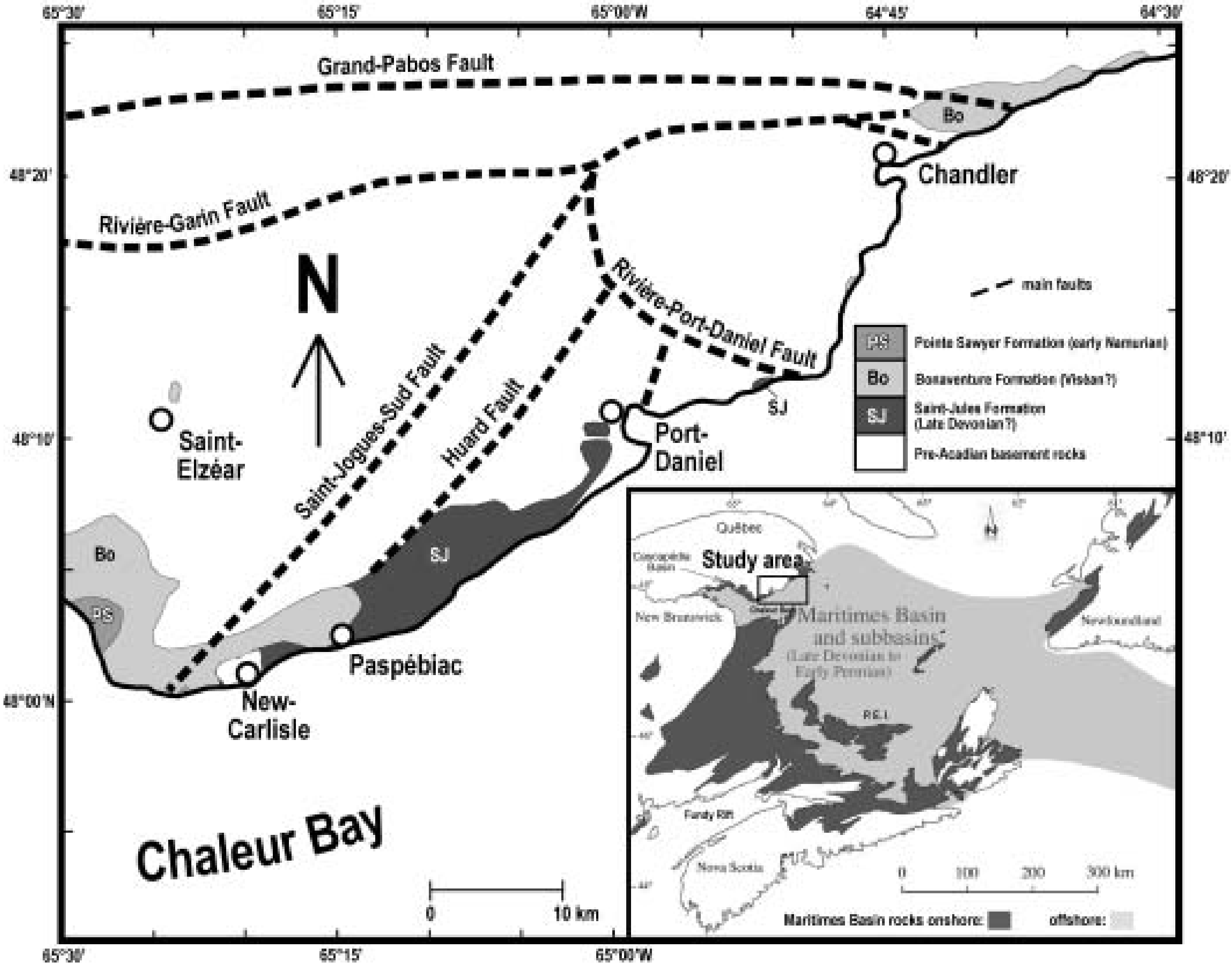

Figure 1. General geology of the study area and localization within the late Paleozoic Maritimes Basin (inset). The main map is modified from Brisebois et al. (1992). The inset is modified from Gibling et al. (1992).

The geomorphic unit referred to as a "perfectly truncated surface" was formed within the same rock units as the adjacent Gaspesian Plateau, from which it is separated by a nonstructural scarp (the "Garin Scarp" of Peulvast et al., 1996) (Fig. 4). Bail (1983) interpreted this truncated surface as a continental pediment, but Jutras and Schroeder (1999) argued that only coastal erosion could so efficiently disregard differential lithologic resistance. These authors therefore considered the surface as a paleo–wave-cut platform and the Garin Scarp as a paleo–sea cliff. The presence of a small residual hill of Viséan (Upper Mississippian) clastic rocks of the Bonaventure Formation (Fig. 2), sitting directly on the postulated wave-cut platform near the village of Saint-Elzéar (Fig. 4), provides an upper age limit for that surface. As is emphasized in the next section, the petrography and age of the basal beds in the residual hill support the theory that they may have been preceded by a brief marine transgression.

The presumably marine "perfectly truncated surface" is separated by the Saint-Jogues-Sud and Huard fault scarps from another surface, which is topographically lower but also partly buried by upper Paleozoic clastic rocks (Fig. 4). These clastic rocks were previously mapped as the Bonaventure Formation, but are here correlated on the basis of petrographic criteria (see below) with the Saint-Jules Formation.

The partly exhumed geomorphic unit that sits topographically below the paleo–wave-cut platform was referred to as an "inherited topography surface" (Figs. 3 and 4) by Jutras and Schroeder (1999), because of the observation that the unit was not sculpted by the currently active climate and fluvial system. This paleosurface is characterized by the presence of limestone hogbacks (the "Clemville hogbacks" of Peulvast et al., 1996), which indicate that it has evolved under an arid, low-latitude climate, for only under such a climate can limestone stand out as most resistant to erosion (Jutras and Schroeder, 1999). The hogbacks are formed by two units, the middle member of the La Vieille Formation and the coral reef complexes of the West Point Formation (Figs. 4 and 5), which are the purest limestones in the local Silurian succession of the dominantly clastic Chaleurs Group (Bourque and Lachambre, 1980). The

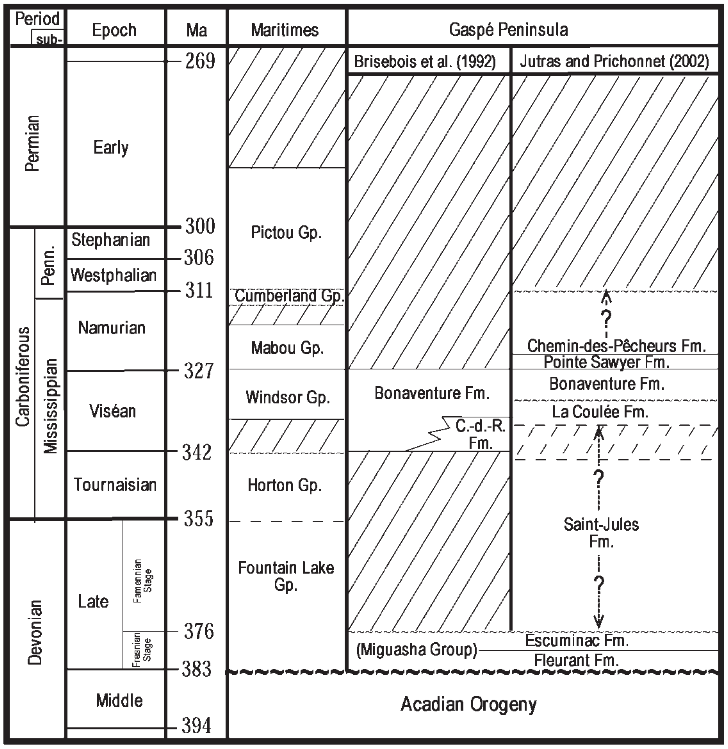

Figure 2. Upper Paleozoic stratigraphic record in the Maritimes and in the Gaspé Peninsula. The time scale is after Okulitch (1999). Wavy lines represent unconformities, and cross-lined areas represent major hiatuses. Stratigraphy of the Maritimes is modified from Bell (1944), Howie and Barss (1975), Utting (1987), Utting et al. (1989), and Ryan et al. (1991).

Saint-Jules Formation abuts one of these hogbacks (cross section B–C in Fig. 5) and was therefore deposited when they were already sculpted by differential erosion.

From the observation of subsurface karst (lapies) filled with lithified red clastic deposits at all levels of the hogback surfaces, Jutras and Schroeder (1999) concluded that karstification took place during the early stages of their eventual exhumation, when the hogbacks were situated in the vadose zone of interfluves and acted as aquicludes amidst more porous upper Paleozoic clastic rocks. Closer study of these karstic features indicated that karstification preferentially took place along Alleghanian (Pennsylvanian deformation) strike-slip fault planes (Jutras et al., 2003). The red clastic karst-fill is also sheared, indicating that faulting, karstification, and clastic infilling occurred simultaneously during the mild Pennsylvanian strike-slip deformation (Jutras et al., 2003).

It is noteworthy that, whereas the La Vieille Formation limestones stand out as hogbacks in the lowermost surface, the same unit is truncated along with all others on the postulated wave-cut platform and is incised between hogbacks on the Gaspesian Plateau (Fig. 4). The composite morphology of the southernmost Gaspé Peninsula therefore shows, from the southeast to the northwest, three unrelated

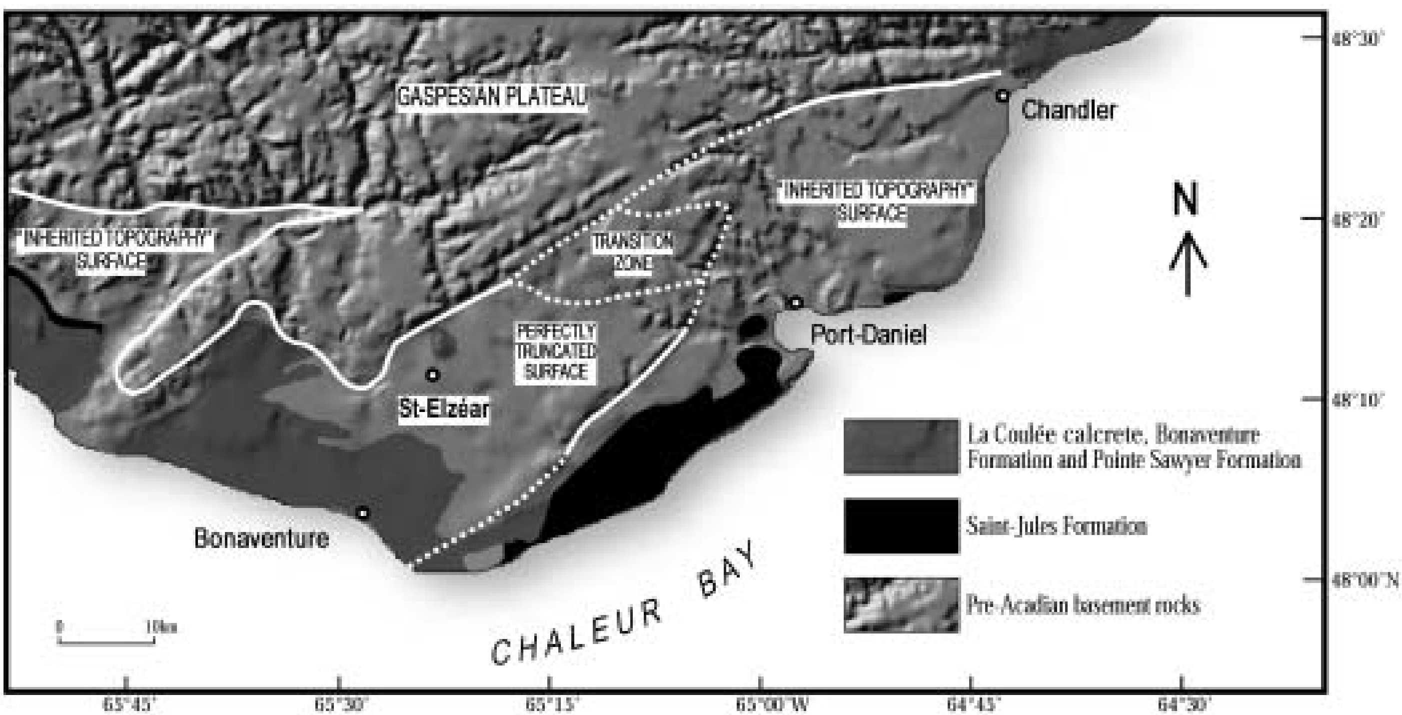

Figure 3. Remnant distribution of the Saint-Jules Formation and other post-Acadian units in relationship to the different topographic domains of the partly exhumed upper Paleozoic surface in southern Gaspé. Modified from Jutras and Schroeder (1999).

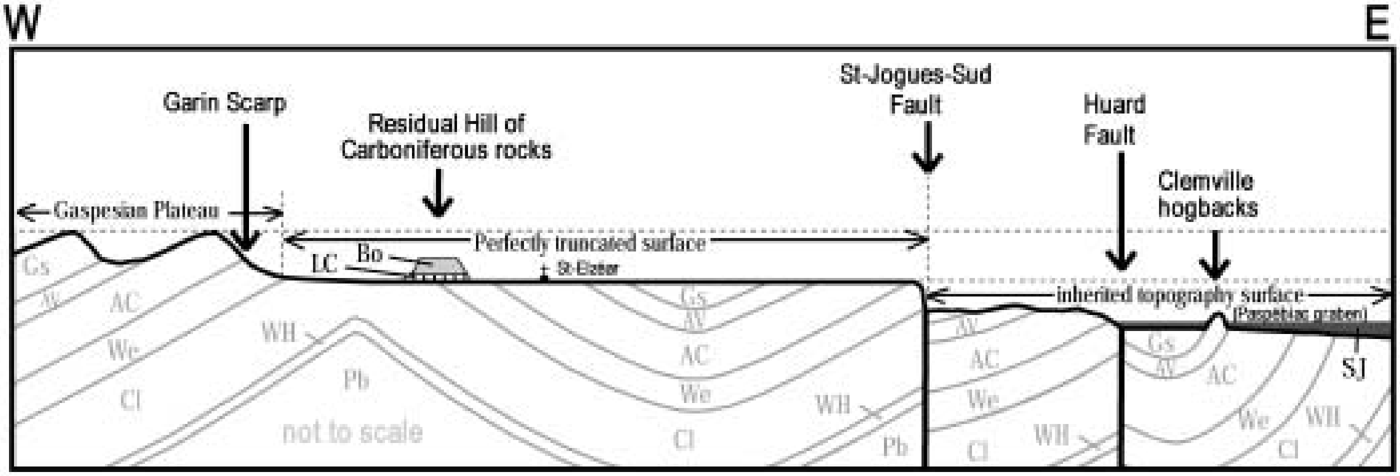

Figure 4. Schematic cross section of southern Gaspé. Refer to legend in Figure 5.

paleosurfaces, although occupied by the same rock successions.

According to Jutras and Schroeder (1999), (1) the inherited-topography surface was formed under a tropical arid climate. (2) It was subsequently buried by a continental clastic graben-fill (in a structure here referred to as the "Paspébiac graben") from the normal splay of the Saint-Jogues-Sud and Huard faults (Fig. 6A), which truncate and are therefore younger than Acadian (Middle Devonian deformation) folds (Fig. 4). (3) The graben fill was then overlapped by a marine transgression, cutting its way to the Garin Scarp and eradicating the local source area of the graben-fill (Fig. 6B). (4) Following marine regression, a second clastic episode buried the wave-cut platform and sea cliff (Fig. 6C). (5) Both surfaces stood below base level during subsequent general peneplanation, which was achieved by Permian time according to the fission-track model of Ryan and Zentilli (1993). The surfaces were therefore preserved underneath upper Paleozoic sedimentary rocks (Fig. 6D). (6) In the process of passive-margin development, during the opening of the Atlantic Ocean in post-Paleozoic time, the peneplain was gradually uplifted and dissected under a generally more humid climate than that prevailing during late Paleozoic time. The increased humidity led to a preferential erosion of the La Vieille Formation limestones, which were deeply incised between more resistant, hogback-forming, siliciclastic rocks, and to the gradual exhumation of paleosurfaces beneath easy-to-erode upper Paleozoic sedimentary rocks (Figs. 4 and 6E).

The model of Jutras and Schroeder (1999) implies that the red clastic rocks that overlie the Paspébiac graben floor belong to a different sedimentary event than those overlying the "perfectly truncated surface" (Fig. 4), the two units having been derived from different source areas and also being separated by a presumably marine erosion event. However, until now, both sets of clastic rocks were mapped as the Bonaventure Formation (Logan, 1846; Alcock, 1935; McGerrigle, 1946; Bagdley, 1956; Ayrton, 1967; Skidmore, 1967; Bourque and Lachambre, 1980; de Broucker, 1987; Brisebois et al., 1992; van de Poll, 1995).

GEOLOGIC SETTING

Upper Paleozoic rocks in the Gaspé Peninsula overlie Neoproterozoic to Middle Devonian rocks that were deformed by the Middle Devonian Acadian orogeny (Malo et al., 1995; Malo and Kirkwood, 1995; Kirkwood et al., 1995). The narrow belt of post-Acadian sedimentary rocks that occupies the southern Gaspé Peninsula delineates erosional remnants of the Ristigouche (van de Poll, 1995) and Cannes-de-Roches (Jutras et al., 2001) Basins, which form the northwestern sectors of the composite late Paleozoic Maritimes Basin (Fig. 1). The latter occupies much of southeastern Canada and includes an Upper Devonian to Lower Permian volcano-sedimentary succession.

Alcock (1935) subdivided the upper Paleozoic rocks of Gaspé into two formations, namely, the Bonaventure and Cannes-de-Roches Formations (Fig. 2). He subdivided the latter unit into three informal members. Rocks equivalent to the upper member were identified in the southern Gaspé Peninsula, disconformably overlying the Bonaventure Formation (Jutras et al., 2001). Consequently, abandonment of the Cannes-de-Roches Formation was proposed, its lower and middle members being correlated with the Bonaventure Formation, and its upper member being included within the newly named Pointe Sawyer Formation (Fig. 2) (Jutras et al., 2001).

The Pointe Sawyer Formation contains the SM Spore Zone assemblage (Jutras et al., 2001), which was dated as late Viséan (Utting, 1987), but now considered early Namurian (J. Utting, 2001, personal commun.), and which is found in basal units of the Mabou Group (Bell, 1944) in the general upper Paleozoic stratigraphy of the Maritimes Basin (Fig. 2). The Pointe Sawyer Formation is the only reliably dated upper Paleozoic unit in the Gaspé Peninsula. Unfortunately, it has only limited exposure in the study area.

The La Coulée Formation was identified beneath the Bonaventure Formation in both the Ristigouche and Cannes-de-Roches Basins (Jutras et al., 1999, 2001). Bearing at the base of its clastic succession a massive, ≤12-m-thick, groundwater calcrete hardpan, the La Coulée Formation is inferred to have been deposited in the vicinity of an evaporitic basin (Jutras et al., 1999), because modern analogues of such calcretes are only known to form in this setting, where saline and fresh groundwaters mix (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson et al., 1988; Arakel et al., 1989; Wright and Tucker, 1991).

The clastic rocks of the La Coulée Formation are absent in the southern Gaspé area, but similar groundwater calcretes occupy the same stratigraphic position, unconformably beneath the Bonaventure Formation. Such calcretes are very rare in the geologic record (Wright and Tucker, 1991), and the Gaspé occurrences are the only ones known in pre-Cenozoic successions. Hence, it is considered probable that all thick and massive groundwater calcrete hardpans that sit unconformably below the Bonaventure are penecontemporaneous.

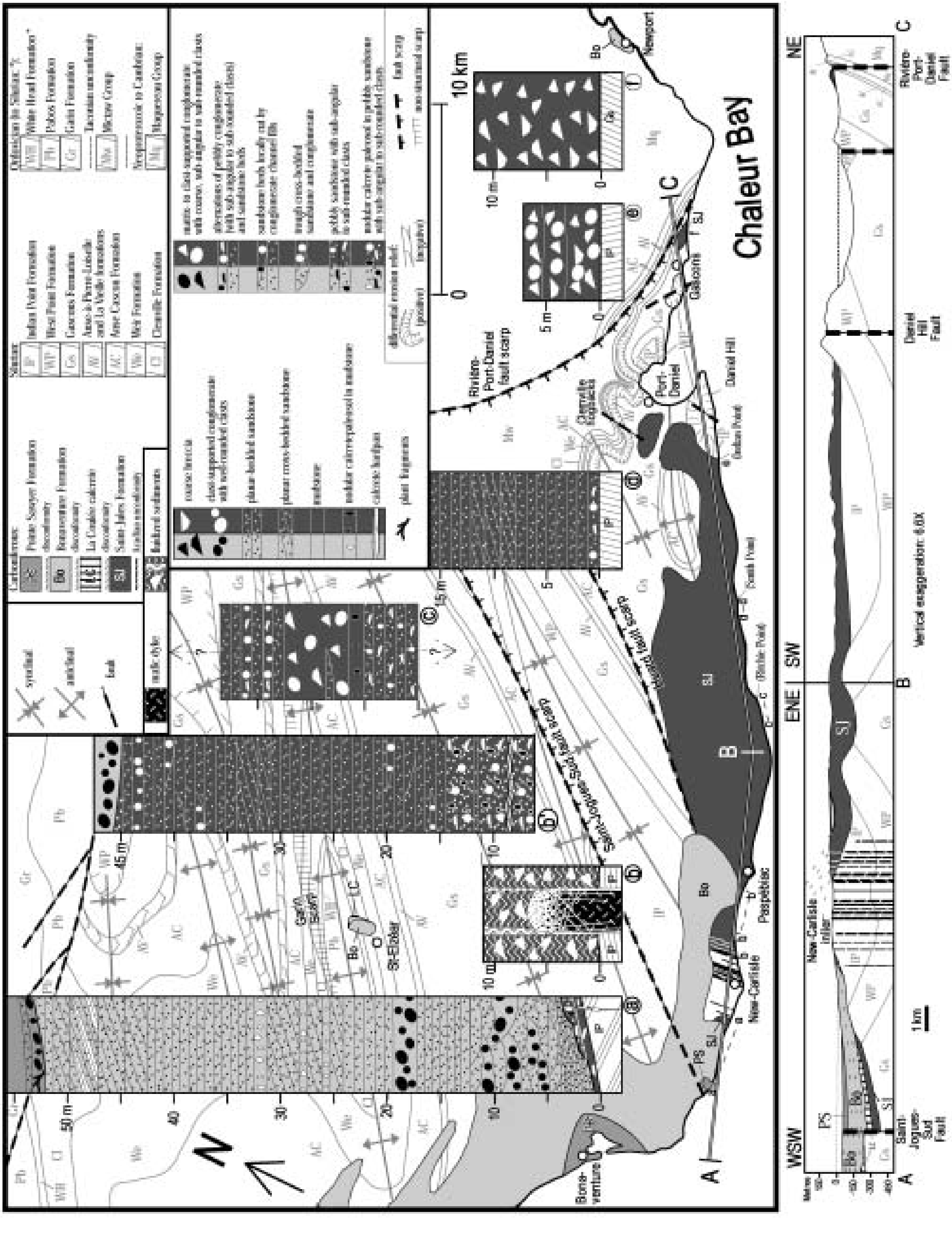

Figure 5. Geology and geomorphology of the New-Carlisle–Port-Daniel area, with cross section A–B–C and composite columns a to f. Pre–Late Devonian data are from Bourque and Lachambre (1980).

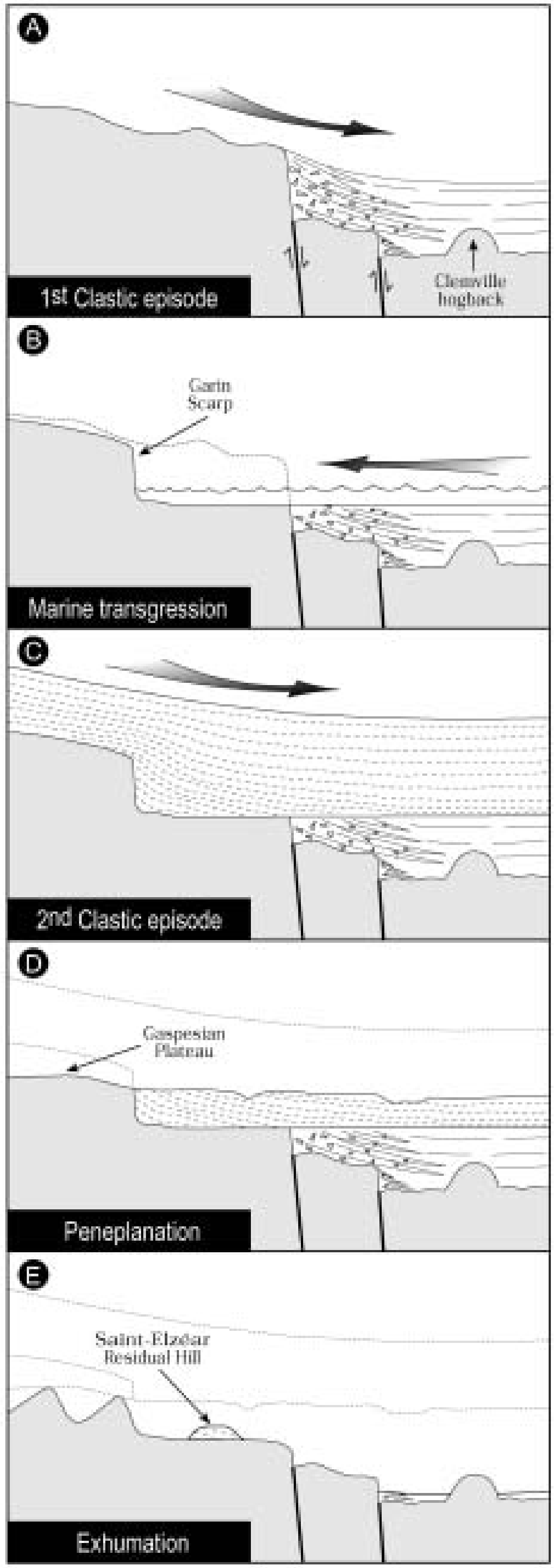

Figure 6. Model for the geomorphic evolution of southern Gaspé. (A) Burial of a mature, low-latitude post-Acadian surface by continental clastic deposits on a graben-floor and erosion of this surface in the source area of the graben-fill. (B) Marine incursion in the graben and erosion of part of its source area by coastal erosion. (C) Burial of the resulting wave-cut platform and coastal scarp (the Garin Scarp) by a second episode of continental clastic sedimentation. (D) Peneplanation of the entire region in Permian time, with several elements of the local upper Paleozoic surface preserved below base level. (E) Mesozoic to Cenozoic uplift and exhumation of the composite upper Paleozoic surface remnant by differential erosion.

In the Saint-Elzéar area, the groundwater calcrete sits directly on the postulated wave-cut platform (Fig. 4). Hence, although the marine wave-cut platform hypothesis can remain controversial in the absence of related marine deposits, it is supported by the presence of this thick and massive groundwater calcrete hardpan on its surface (Jutras et al., 1999), as these are thought to be genetically linked to evaporitic basins. The presence of such basins can be best explained in the context of a transgression-regression cycle, from the abandonment of a sea arm. The wave-cut platform hypothesis is also supported by the probable Viséan age of the Bonaventure Formation, which overlies the calcrete and underlies earliest Namurian gray beds of the Pointe Sawyer Formation. Most of the Maritimes Basin was intermittently invaded by the epicontinental Windsor Sea during this epoch (Fig. 2) (Howie and Barss, 1975; Giles, 1981; Pascucci et al., 2000). The formation of evaporitic basins typically follows each Windsor Sea transgression (Giles, 1981).

In southwest Gaspé, just outside of the study area, the thick and massive groundwater calcrete hardpan that unconformably underlies the Bonaventure Formation was developed within the karstified upper beds of the recently identified Saint-Jules Formation red clastic rocks (Jutras and Prichonnet, 2002). If the massive groundwater calcretes that sit beneath the Bonaventure Formation are truly penecontemporaneous, this observation implies that the Saint-Jules Formation is older than the La Coulée Formation of eastern Gaspé, in which groundwater calcrete formation is demonstrably syndepositional (Jutras et al., 1999). The latter relationship was determined from the observation that groundwater calcretization only affects the basal 30 m of the La Coulée succession in eastern Gaspé, whereas the upper 30 m of the clastic succession is noncalcretized. As groundwater calcretes are only known to form in areas where the water table is less than 5 m below the surface (Mann and Horwitz, 1979; Wright and Tucker, 1991), the upper 25 m of the succession had to be deposited after calcretization of the basal 30 m.

New exposures of the Saint-Jules Formation red beds were recognized in the southern Gaspé Peninsula (Fig. 1) within the newly identified Paspébiac graben. As noted earlier, these red beds were previously included within the Viséan Bonaventure Formation, which disconformably overlies the Saint-Jules Formation in the Paspébiac graben and forms the base of the much wider Ristigouche Basin (Jutras et al., 2001).

POST-ACADIAN STRATIGRAPHY AND BURIED TOPOGRAPHIES OF THE SOUTHERN GASPÉ PENINSULA

Red beds of the Saint-Jules Formation are best lithologically differentiated from the overlying Bonaventure Formation by the absence of distally derived gravel-size clasts such as quartz pebbles and red jasper, which typically form 10%–20% of the content in the latter unit (Jutras and Prichonnet, 2002). The Bonaventure Formation detritus are also better sorted than those of the Saint-Jules Formation. The Saint-Jules clastic rocks were recognized in the Paspébiac graben from these petrographic criteria and from paleogeographic constraints provided by the paleosurfaces that are discussed below.

Thicker sections of the Saint-Jules Formation and a wider variety of clast compositions are present in the Paspébiac graben than in the Saint-Jules type section of the Cascapédia Basin, which was fed by a different source area. The Saint-Jules Formation conglomerate in the Cascapédia Basin is entirely composed of calcilutite clasts of the Ordovician White Head Formation (Jutras and Prichonnet, 2002), which is exposed to the north of the Grand-Pabos Fault (Fig. 1), whereas Saint-Jules Formation conglomerate in the Paspébiac graben includes the diversified lithologies of the Silurian Chaleurs Group, which occupy most of southern Gaspé.

The Saint-Jules clastic rocks in the Paspébiac graben are brownish-red with buff pedogenic nodules and can be visually differentiated from the orange-red Bonaventure Formation, which bears green reduction spheres and greenish pedogenic nodules. Green reduction is absent in the Saint-Jules beds. Several composite stratigraphic columns in the Paspébiac graben are described below.

The New-Carlisle–West Stratigraphic Column (Fig. 5, col. a)

The New-Carlisle–West section is located on the west side of an inlier of Silurian rocks at New-Carlisle (Fig. 5, col. a). Undated intrusions affect the inlier (Bagdley, 1956), which is a Viséan paleorelief that has been gradually onlapped by the Bonaventure clastic rocks. The New-Carlisle–West stratigraphic column exposes a small erosional remnant of Saint-Jules Formation beds, forming a wedge between the overlying Bonaventure Formation and the underlying Silurian calcareous mudstone of the Indian Point Formation (Bourque and Lachambre, 1980). The Saint-Jules Formation forms a stepped topography beneath the disconformably overlying Bonaventure Formation (Fig. 5, col. a). At the east end of the section, the Saint-Jules Formation is 2 m thick. Less than 10 m to the west, it thins out to nothing, and the overlying Bonaventure Formation sits directly on the Silurian basement.

The basal 0.5 m of the Saint-Jules clastic rocks is a red, granular conglomerate with poorly rounded clasts overlain by 1.5 m of nodular, pebbly sandstone. Calcareous nodules in the sandstone are buff in color. A vein of fluidized sediments floating in ankerite cuts the mudstone basement and the Saint-Jules clastic rocks, but is truncated by the Bonaventure Formation (Fig. 5, col. a, and Fig. 7), indicating that the latter unit is younger than the ankerite veining event.

The disconformably overlying beds, above the thin wedge of Saint-Jules Formation clastic rocks, is typical of the Bonaventure Formation; ~15% quartz pebbles and disseminated red jasper characterize the conglomerates, and green reduction spheres and nodules occur in the finer fractions. In the channel fills that are closest to the New-Carlisle inlier, large clasts of red sandstone, which possibly came from the underlying Saint-Jules Formation, are also abundant, along with porphyritic basalt, dacite, and ankerite clasts that are derived from rocks of the inlier.

The uppermost sandstone beds of the Bonaventure Formation are sharply cut by gray channel fills of the Pointe Sawyer Formation. This disconformable contact, according to lateral extrapolations, is only 50–55 m above the observed Bonaventure/Saint-Jules contact at New-Carlisle–West. However, the observed contact is on the flank of the New-Carlisle inlier. The Bonaventure Formation is therefore probably much thicker than 50–55 m at the area of the Pointe Sawyer channel deposit, 5 km away from the New-Carlisle inlier, as expressed on transect A–B–C (Fig. 5). A thickness of ~300 m is achieved in the Bonaventure Formation between the town of Caplan, a few kilometers to the northwest, and the Pointe Sawyer channel deposit (Jutras and Prichonnet, 2002), giving an approximate height of 250 m for the mostly buried paleorelief that crops out as the New-Carlisle inlier.

The New-Carlisle–Paspébiac Stratigraphic Column (Fig. 5, cols. b and b′)

A continuous section of the Saint-Jules Formation is exposed between New-Carlisle–East and the town of Paspébiac, on the eastern side of

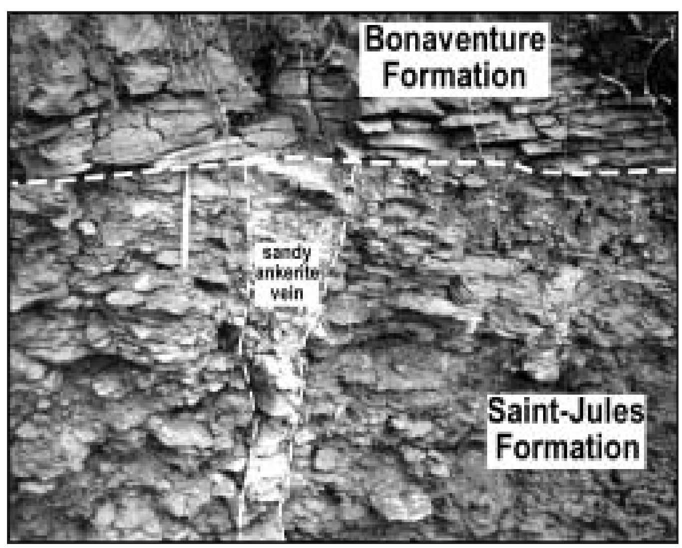

Figure 7. Truncation of a sandy ankerite vein intruding the Saint-Jules Formation by the basal red clastic rocks of the Bonaventure Formation in the New-Carlisle–West section.

the New-Carlisle inlier (Fig. 5, cols. b and b′). In contrast with the overstepping relationship of the Bonaventure Formation with respect to the inlier on the west side, the Saint-Jules beds are tilted away from the inlier and were obviously uplifted along with it (Fig. 5 inset). Large north-trending mafic dikes, ranging from 1.5 to >30 m wide, are concentrated in the New-Carlisle inlier, intrude the base of the Saint-Jules Formation (Fig. 5, col. b), and are most likely responsible for the local uplift.

The basal 12-m-thick section shown in column b in Figure 5 is disturbed by complex interactions between the mafic magma and the Saint-Jules Formation sedimentary rocks (Jutras et al., 2004). Approximately 200 m to the northeast, the lowermost beds of column b′ in Figure 5 are laterally equivalent to the highest beds of column b in Figure 5, but are undisturbed by the intrusions. Column b′ in Figure 5 includes laminated sandstone and poorly sorted and poorly rounded conglomerate. Numerous paleosol overprints, including a calcrete hardpan, partly mask primary sedimentary structures in the 7–15 m interval of column b′ in Figure 5 (first 8 m of this section). The paleosols contain buff calcareous pedogenic nodules.

The 15–30 m interval in stratigraphic column b′ in Figure 5 is dominated by planar-bedded sandstones with a few channels of conglomerate or sandstone in the lower 5 m. The 30–35 m interval shows 0.5–3-m-thick planar cross-beds of sandstone. Their lateral persistency over a few hundred meters and their vertical succession imply that they were deposited on large transverse bars.

The 35–45 m interval in stratigraphic column b′ in Figure 5 is dominated by planar-bedded sandstone with minor mudstone and a few channel fills of pebble conglomerate and sandstone. The conglomerate channel fills, throughout the succession, are exclusively composed of sedimentary and volcanic rock clasts derived from the Chaleurs Group, with no quartz gravels. The planar sandstone beds are laterally persistent for several kilometers, suggesting that they were deposited by sheet floods. Horizontal burrows, desiccation cracks, and abundant adhesion ripple marks indicate that the alluvial-plain sediments were subaerially exposed between sheet-flood events.

A broad channel of orangish polymictic conglomerate with abundant rounded quartz pebbles, red sandstone clasts, and disseminated jasper pebbles disconformably overlies the brownish-red Saint-Jules Formation beds in the west end of the section, near the town of Paspébiac. On the basis of petrographic criteria, this conglomerate is assigned to the Bonaventure Formation (Fig. 5, col. b′).

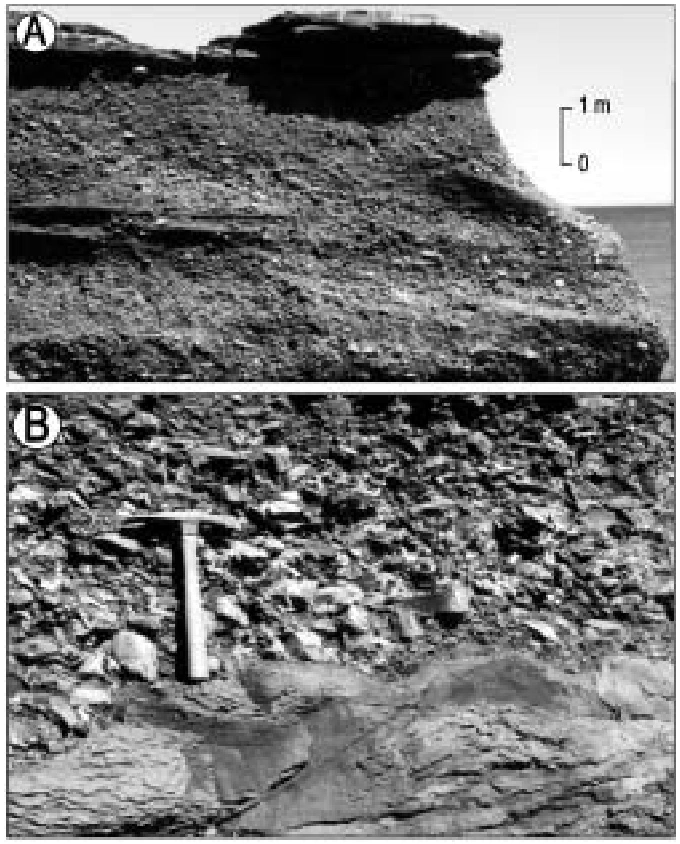

Figure 8. (A) Poorly stratified, poorly sorted, and poorly rounded Saint-Jules Formation conglomerate with a few sandstone lenses at Ritchie Point. (B) Partial destruction of a sandstone bed by a conglomerate-forming event.

The Ritchie Point (Fig. 5, col. c), Smith Point (Fig. 5, col. d), Indian Point (Fig. 5, col. e), and Gascons (Fig. 5, col. f) Stratigraphic Columns

Between the town of Paspébiac and the Rivière–Port-Daniel fault scarp (Fig. 5), the Bonaventure Formation is absent from coastal exposures of upper Paleozoic rocks. The coarse fraction in the red beds is entirely derived from the local Chaleurs Group rocks and exclude quartz gravels. The succession is therefore assigned to the Saint-Jules Formation.

The Saint-Jules Formation beds are lenticular and discontinuous in the Ritchie Point stratigraphic column (Fig. 5, col. c), which results in considerable lateral variability. Column c in Figure 5 is therefore very generalized. The lower and upper parts of the column are similar to the base of column b′, but the middle part is much coarser. Although vertical aggradation (Fig. 8A) and lack of clay-sized particles clearly define the coarse-cobble conglomerate as fluvial, it is in part matrix-supported, which is uncommon to fluvial environments (Miall, 1977, 1996; Wasson, 1977; Ethridge and Wescott, 1984; Harvey, 1984; Kleinspehn et al., 1984; Nemec and Steel, 1984). The poorly sorted nature of the fluvial conglomerate suggests deposition by flash floods engorged with sediment. Sudden high-energy events are also suggested by the penetrative scouring of sandstone beds beneath some of the conglomerate beds (Fig. 8B).

The unconformable contact between (1) the subvertically dipping calcareous mudstone strata of the Silurian Indian Point Formation and (2) the overlying Saint-Jules Formation is well exposed at Smith Point (Fig. 5, col. d, and Fig. 9). The Saint-Jules clastic rocks are resting on a planar surface of relatively unweathered Silurian calcareous mudstone basement. Stratigraphic column d includes ~1 m of pebbly sandstone with subangular clasts at the base of the succession, but gravel-size clasts are absent from the rest of the 15-m-thick succession, which is characterized by sandy sheet-flood and transverse-bar deposits.

The contact between the Saint-Jules Formation and the basement at Indian Point is very similar to that at Smith Point: the red-bed suc-

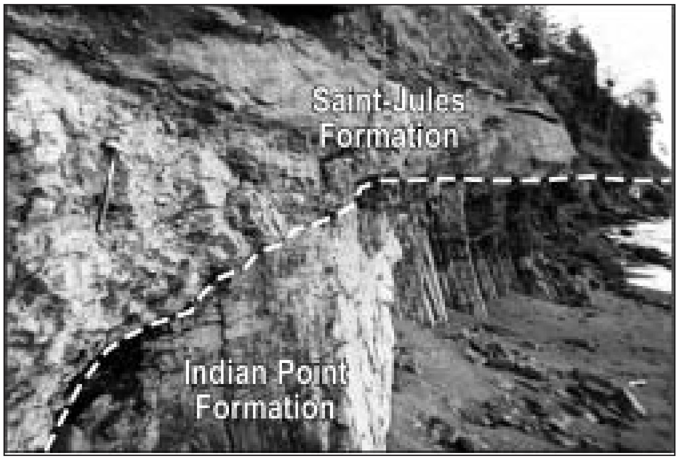

Figure 9. Angular unconformity between the Saint-Jules Formation clastic rocks and the underlying Indian Point Formation, which forms a flat erosional surface at Smith Point.

cession rests on a planar surface that truncates subvertical strata of the Indian Point Formation (Fig. 5, col. e). However, a few hundred meters to the east of the location of stratigraphic column e, the Saint-Jules clastic rocks abut against the basement rocks of Daniel Hill, one of the Clemville Hogbacks (cross section B–C in Fig. 5). This hill is a limestone-reef hogback of the Silurian West Point Formation, which stratigraphically underlies the uppermost Silurian Indian Point Formation (Bourque and Lachambre, 1980) (Fig. 5).

The Indian Point stratigraphic column shows tens-of-meters-wide conglomerate channels of Saint-Jules Formation detritus; the channels cut across each other (Fig. 5, col. e). Sorting is poor and clasts range from fine-sand size to 50 cm blocks, with no clearly defined matrix. From the lack of fine-mud–sized components and from the observed channeling of conglomerate lenses, this matrix- to clast-supported conglomerate is interpreted as torrential, rather than mass flow, related. Poor rounding and sorting suggest that the sediments were deposited by ephemeral flash floods.

Even coarser detritus is found in sedimentary breccia abutting the northern flank of Daniel Hill, with clasts of >50 cm diameter (Fig. 10). The clasts, which are large pieces of coral reef derived from the Silurian West Point Formation, form a lithified talus of rock-fall deposits at the base of the exhumed upper Paleozoic hill.

The easternmost exposure of the Saint-Jules Formation clastic rocks identified to date is in a small outlier near the town of Gascons (Fig. 5, col. f), unconformably overlying subvertical strata of the Silurian Gascons Formation (Bourque and Lachambre, 1980). The Saint-Jules Formation is here composed of over 10 m of coarse breccia. The succession dips ~25° toward the south and away from the Rivière–Port-Daniel fault scarp (Jutras and Schroeder, 1999), which stands less than 200 m north of stratigraphic column f. The coastal cliff exposure is inaccessible and can only be observed from ~10 m below, at the beach level. Modal clast size seems to be 10–15 cm in diameter.

A few kilometers to the northwest of the Rivière–Port-Daniel Fault (Fig. 5), outside the Paspébiac graben, polymictic conglomerate of the Bonaventure Formation with abundant quartz pebbles rests directly on the Neoproterozoic to Cambrian Maquereau Group (Brisebois et al., 1992), which is slightly calcretized at the contact.

PALEOCURRENTS IN THE SAINT-JULES FORMATION BEDS OF THE PASPÉBIAC GRABEN

Paleocurrent measurements were taken from oriented 0.5–10-m-wide trough-shaped channel fills of conglomerate and sandstone in various sections. The measurements indicate that braided streams flowed toward the south in the New-Carlisle–Paspébiac sections and toward the southeast in the Ritchie Point and Indian Point sections (Fig. 11 and Table DR1).[1]

Paleocurrent measurements were also taken from the cross-sets of laterally persistent and 0.5–3-m-thick planar cross-strata. Following the conclusion that these beds are deposits from transverse bars, their cross-sets were interpreted as dipping approximately in the direction of the paleoflow. Transverse-bar structures were identified in three sectors of the study area. They indicate westward flow in the New-Carlisle–Paspébiac section, southwestward flow east of Paspébiac, and west-northwestward flow at Smith Point (Fig. 11 and Table DR1 [see text footnote 1]), averaging as a west-southwestward flow.

DISCUSSION

Sedimentary Environments

The coarse, angular, and chaotic deposits of the Gascons section (Fig. 5, col. f) and of the northern flank of Daniel Hill (Fig. 10) are interpreted as talus deposits derived from local scarps. The coarseness and high lateral variability of fluvial deposits in the Ritchie Point

Figure 10. Massive Saint-Jules Formation talus breccia on the northern flank of Daniel Hill.

[1]GSA Data Repository item 2004xxx, Table DR1, numerical data used for plotting the rose diagrams of Figure 11, is available on the Web at http://www.geosociety.org/pubs/ft2004.htm. Requests may also be sent to editing@geosociety.org.

and Indian Point sections (Fig. 5, cols. c and e) suggest that they are related to an alluvial-fan environment, adjacent to a fault scarp. The New-Carlisle–West (Fig. 5, col. a), New-Carlisle–Paspébiac (Fig. 5, cols. b and b′), and Smith Point (Fig. 5, col. d) are less coarse, but still include conglomerate and show high lateral variability. They also may be as close to the paleoscarp from which they were derived, but farther from the major river outlets that were issuing from it. Hence, the fine succession at Smith Point (Fig. 5, col. d), located between the coarse successions of Ritchie Point (Fig. 5, col. c) and Indian Point (Fig. 5, col. e), indicates that the latter belong to two distinct alluvial fans within a bajada (Fig. 12).

As was noted earlier, the planar-bedded sandstones that overlie the dominantly conglomeratic base of the New-Carlisle–Paspébiac, Ritchie Point, and Smith Point sections (Fig. 5, cols. b′, c, and d) are interpreted as sheet-flood deposits on an alluvial plain. Truncation of some planar beds by sandstone and conglomerate channel fills reflects an alternation between deposition by sheet floods and by channelized sand- or gravel-carrying streams.

The abundance of coarse and chaotic detritus within the Saint-Jules Formation, along with the generally unsorted nature of the sediments, suggests that source relief was frequently rejuvenated by a very active and proximal fault system. The dominantly fluvial succession is deeply oxidized and affected by numerous pedogenic concretions and desiccation cracks, clearly defining the depositional environment as continental and the climate as arid.

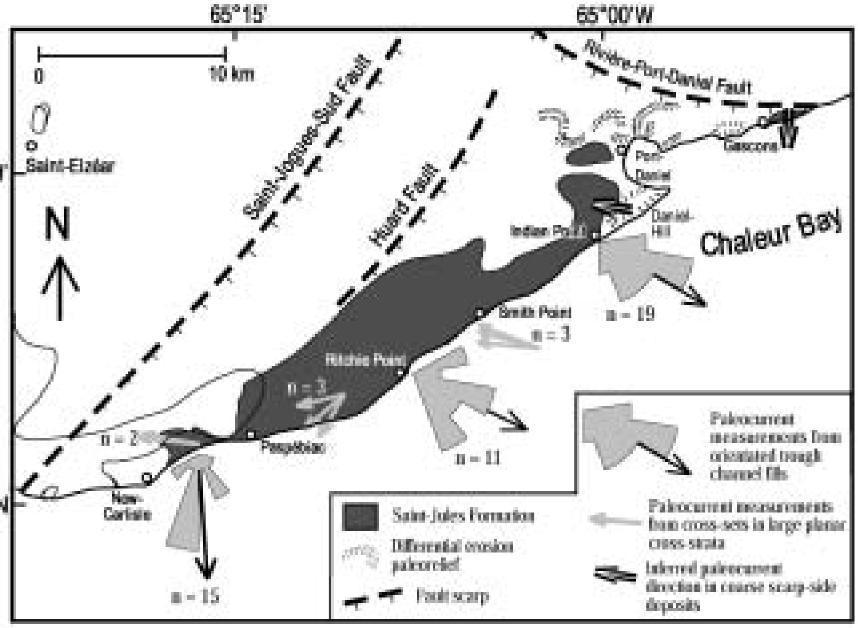

Figure 11. Paleocurrent vectors in the Saint-Jules Formation within the Paspébiac graben.

Paleogeographic Model

As planar cross-bedded sandstones indicate a flow direction that is perpendicular to the flow of channelized deposits, they are interpreted as being related to large ephemeral trunk rivers that were draining parallel to the basin axis and source uplifts. Jutras et al. (2001) suggested that deposits of the Bonaventure Formation were derived from a scarp related to the Rivière-Garin and/or Grand-Pabos Faults in the southern Gaspé Peninsula (Fig. 1). The coarse Saint-Jules Formation detritus in the Paspébiac graben is exclusively composed of sedimentary rock clasts of the Chaleurs Group and was probably derived from closer sources, as these rocks are mainly exposed to the south of the Rivière-Garin–Grand-Pabos fault system. Clast composition, facies distribution, and paleocurrent vectors collectively point to the Huard and Saint-Jogues-Sud Faults as paleoscarps delimiting the source areas of Saint-Jules Formation detritus from New-Carlisle–West to Indian Point (Fig. 11). The coarse breccia at Gascons (Fig. 5, col. f) dips away from the Rivière–Port-Daniel Fault, and its deposition was probably controlled by a paleoscarp associated with movement on that fault.

Observation that the Saint-Jules clastic rocks abut Daniel Hill (Figs. 5 and 10) indicates that the Clemville Hogbacks, features of a tropical morphology unit according to Jutras and Schroeder (1999), formed previously and were subsequently buried by these beds. Part of this tropical surface was buried by the Saint-Jules Formation within two small grabens or half-grabens delimited by (1) the Grand-Pabos Fault in the Cascapédia Basin of southwest Gaspé (Jutras and Prichonnet, 2002) and (2) the convergent Rivière–Port-Daniel and Saint-Jogues-Sud Faults in the Paspébiac graben of southern Gaspé (Fig. 12). According to Jutras and Prichonnet (2002), a differential-erosion scarp confines the Saint-Jules Formation to the southeast in the Cascapédia Basin (Fig. 12). Both the Cascapédia Basin and the Paspébiac graben are confined within the limits of the irregular "inherited topography surface" of Jutras and Schroeder (1999).

A large fault striking parallel to the Saint-Jogues-Sud Fault and affecting upper Paleozoic strata beneath Chaleur Bay was identified by Syvitski (1992) on shallow seismic reflection profiles. This fault, herein referred to as the Chaleur Fault, possibly limited the Paspébiac graben to the southeast (Fig. 12), which would signify that the basin is only 30 km wide. This conclusion is supported by the absence of Saint-Jules Formation beds beneath the Bonaventure Formation to the south, on the New Brunswick side of Chaleur Bay.

Connection of these small continental basins to the ocean was unlikely during deposition. Hence, the west- to southwest-flowing trunk river system (Fig. 11) was possibly connected to an ephemeral recurrent lake located southwest of the exposed sections, beneath present-day Chaleur Bay (Fig. 12), although sedimentary evidence for the presence of such a lake is lacking.

Correlation with the Regional Stratigraphy

The environment of deposition attributed to the Saint-Jules Formation is analogous to that of the Fountain Lake Group and equivalent units (sensu Calder, 1998), which were deposited during the Late Devonian (Famennian) in numerous similarly oriented (southwest-northeast) grabens and half-grabens throughout the Maritimes Basin (Durling and Marillier, 1990, 1993; Calder, 1998; Pascucci et al., 2000). Slightly younger and perhaps partly coeval strata of the Tournaisian Horton Group are less oxidized and did not evolve under a climate that was as arid (Martel et al., 1993; Calder, 1998).

Fountain Lake Group and Saint-Jules Formation red beds are very similar, both being characterized by poorly sorted alluvial-fan conglomerates and buff pedogenic nodules. However, the gray beds of the Horton Group are seemingly absent in the Gaspé area.

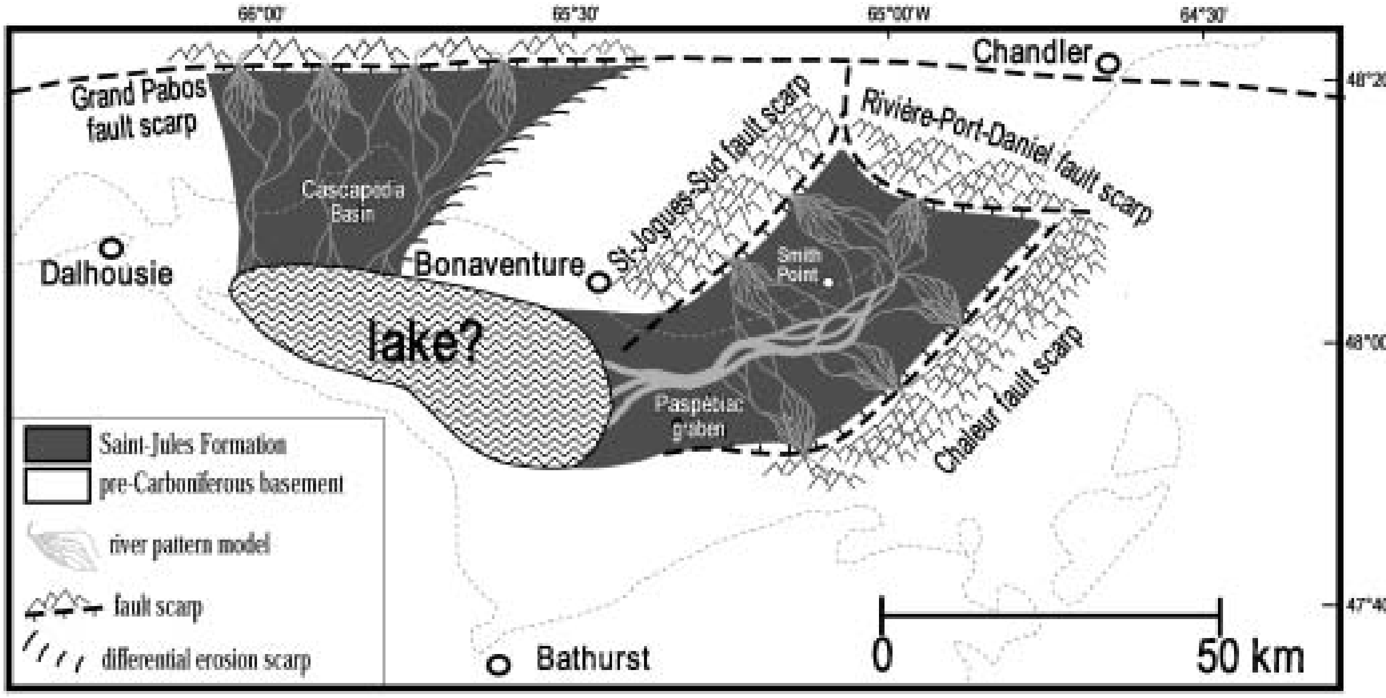

Figure 12. Paleogeography of the Saint-Jules Formation in late Paleozoic (probably Late Devonian) time. Data for the Cascapédia Basin is from Jutras and Prichonnet (2002).

The Post–Saint-Jules Formation Events

The "perfectly truncated surface," whether of marine origin or not, had to form after or at the very end of the Saint-Jules depositional event because it sits in the source area of the Saint-Jules Formation detritus, where high, dissected relief must have once stood to provide such coarse and poorly sorted material. According to Jutras and Schroeder (1999), continental erosion processes such as scarp backwearing, etching, or rock pedimentation cannot justify the straightness of the Garin Scarp and were unlikely to form such a scarp, given the absence of lithologic differences on each side of the scarp. Still, the possibility that the Saint-Jogues-Sud fault scarp may have undergone significant backwearing in the fading stages of the Saint-Jules deposition must be considered. However, partly because of the regional context during the Viséan, which was dominated by marine incursions and by the formation of lowstand evaporitic basins, we conclude that both the geomorphic features and the groundwater calcrete are best explained by the transgression-regression hypothesis.

In the type section of the Saint-Jules Formation in the Cascapédia Basin, west of the study area, the groundwater calcrete sits between this unit and the unconformably overlying Bonaventure Formation (Jutras and Prichonnet, 2002). In the Paspébiac graben, the Saint-Jules Formation is disconformably overlain by the Bonaventure Formation, with no calcrete separating them. Between the two basins, on the postulated wave-cut platform, the Saint-Jules Formation is absent, and the groundwater calcrete sits directly on pre-Carboniferous rocks, disconformably overlain by the Bonaventure Formation.

The erosion event that separated the La Coulée and Bonaventure Formations in eastern Gaspé (Jutras et al., 1999, 2001) and that was also recognized in southwest Gaspé (Jutras and Prichonnet, 2002) was probably responsible for the observed disconformity between the Saint-Jules and Bonaventure Formations in the Paspébiac graben. The calcrete near Saint-Elzéar (Figs. 4 and 5) possibly extended above the Paspébiac graben, but was perhaps more easily removed by pre-Bonaventure erosion where it sat on poorly consolidated upper Paleozoic clastic rocks than where it sat on pre–Upper Devonian basement rocks. Because thick and massive groundwater calcrete hardpans typically evolve laterally into gypsum (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson et al., 1988; Arakel et al., 1989), the possibility that such soft evaporitic material may have once overlain the Paspébiac graben prior to erosion must also be considered. Intrusion of mafic dikes in the New-Carlisle area and uplift of the New-Carlisle inlier was possibly related to the same tectonic event that generated the erosion, unless these dikes were emplaced during late stages of Paspébiac graben development (Jutras et al., 2004).

This regional uplift and erosion was followed by a new episode of fault-controlled sedimentation (Jutras et al., 2001). The related continental deposits of the Bonaventure Formation buried and fossilized the calcrete and the truncated surface that was interpreted as a marine wave-cut platform by Jutras and Schroeder (1999). As indicated by the presence of small remnants around the town of New-Carlisle (Fig. 5), the Pointe Sawyer Formation must have also occupied the southern Gaspé Peninsula toward the end of the Mississippian. Subsequent events of peneplanation, plateau uplift and dissection, and associated exhumation of upper Paleozoic surfaces are only recorded in the geomorphology (Bail, 1983; Peulvast et al., 1996; Jutras and Schroeder, 1999); no related deposits exist within the limits of the study area.

CONCLUSIONS

Geomorphic data are seldom used to help define the stratigraphic record, but are critical to the understanding of the upper Paleozoic geology of southern Gaspé. They provided the first clues that led to the identification of the Saint-Jules Formation, a new stratigraphic unit that is older than the Bonaventure Formation

(Jutras and Prichonnet, 2002). Newly acquired stratigraphic data in southern Gaspé support the model that was proposed by Jutras and Schroeder (1999) to explain the morphogenesis of exhumed upper Paleozoic surfaces in that area. At least one erosional event indeed separates two distinct red clastic units (the Saint-Jules and Bonaventure Formations) that overlie two morphologically distinct and incompatible surfaces of deposition, although both successions were previously included within the same unit (the Bonaventure Formation).

The Saint-Jules Formation—which is separated from the Bonaventure Formation by events of karstification, groundwater calcretization, and erosion in the Cascapédia Basin of southwest Gaspé (Jutras and Prichonnet, 2002)—was recognized in southern Gaspé within a different basin, herein referred to as the Paspébiac graben. The latter occupies the limits of the partly exhumed "inherited topography surface" of Jutras and Schroeder (1999), which includes relicts of a low-latitude arid climate in the form of limestone hogbacks. This tropical geomorphic unit was buried and preserved under red clastic sediments of the Saint-Jules Formation on the Paspébiac graben floor, but was modified by uplift and erosion in the source area of that unit, which was fed by rapidly rejuvenated fault scarps.

An erosion event separated the Saint-Jules Formation from a thick and massive groundwater calcrete in southern Gaspé, the latter sitting on the eradicated source area of the former. As was pointed out by Jutras et al. (1999) and as reemphasized in this paper, the presence of this thick and massive groundwater calcrete supports the geomorphic hypothesis of Jutras and Schroeder (1999) that this erosion could be marine in origin, because formation of the calcrete is best explained by the former presence of a nearby abandoned sea arm.

A second event of erosion separated the calcrete from the Bonaventure Formation, which disconformably overlies the Saint-Jules Formation in the Paspébiac graben, whereas an incompletely eroded calcrete remnant separated the two units in the Cascapédia Basin. Hence, the Saint-Jules Formation is considerably older than the Viséan Bonaventure Formation, from which it was separated by two events of erosion and one event of massive groundwater calcretization.

The Saint-Jules Formation closely resembles Upper Devonian red beds of the Fountain Lake Group of Nova Scotia, whereas Tournaisian beds in the rest of the Maritimes Basin are dominantly gray and seemingly evolved under a less arid climate. Lying above the Middle Devonian Acadian unconformity, the Saint-Jules Formation is probably Late Devonian and therefore separated from the Bonaventure Formation by more than 15 m.y. (Fig. 2).

Without taking a close look at depositional surfaces, the subtle petrographic differences between the Bonaventure and Saint-Jules Formations may have never been seen as relevant, although the differences do support the geomorphic data. The present case study therefore outlines the stratigraphic relevance of relict geomorphic features and calls for a closer look at exhumed paleosurfaces in all peripheral areas of the Maritimes Basin, as well as in those of other ancient sedimentary basins. Preserved features of depositional surfaces add valuable information to that provided by traditional basin analysis methods.

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