Stratigraphy, depositional setting, and diagenetic history of the Saint-Jules Formation (Upper Devonian or Mississippian), a newly identified post-Acadian red clastic unit in the southern Gaspé Peninsula, Quebec

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Abstract: The Saint-Jules Formation, a post-Acadian continental clastic unit previously mapped as part of the Bonaventure Formation (pre-Namurian unit), was recently identified in the southern Gaspé Peninsula of Quebec. The Saint-Jules Formation in the study area is confined to a small post-sedimentary graben. The unit is characterized by fault-controlled, oxidized, and poorly sorted detritus that underwent short transportation by fluvial processes. The Saint-Jules Formation is locally overlain by a massive groundwater calcrete several metres in thickness, which is tentatively correlated with the calcretization event that has affected the base of the La Coulée Formation grey clastics (pre-Namurian unit). The calcrete has developed within the karstified upper beds of the Saint-Jules Formation, which brings new insights into the potential hosts of such calcretes and on the potential stratigraphic confusion that such diagenetic overprints can create. Partial erosion of both the La Coulée and Saint-Jules clastic rocks, as well as the massive groundwater calcretes, occurred prior to deposition of the Bonaventure Formation. Like the La Coulée and Bonaventure formations, the Saint-Jules is undated, but unconformably overlies Acadian structures (Middle Devonian) and predates Mabou Group units (Namurian).

Résumé : La Formation de Saint-Jules, une unité clastique continentale post-acadienne auparavant cartographiée comme faisant partie de la Formation de Bonaventure (unité pré-namurienne), a récemment été identifiée dans le sud de la Gaspésie, au Québec. La Formation de Saint-Jules, dans le secteur d'étude, est confinée à l'intérieur d'un petit graben post-sédimentaire. Cette unité est caractérisée par du matériel oxydé et mal trié provenant d'un escarpement de faille et ayant été soumis à un court transport par des processus fluviaux. La Formation de Saint-Jules est recouverte localement par une calcrète d'eau souterraine massive et épaisse de plusieurs mètres, laquelle est considérée comme étant contemporaine à l'événement de calcrétization qui a affecté la base de la Formation de La Coulée (unité pré-namurienne). La calcrète s'est développée à l'intérieur de la partie supérieure karstifiée des lits de la Formation de Saint-Jules, amenant ainsi une nouvelle perspective sur les hôtes potentiels de telles calcrètes, et sur les possibilités de confusion stratigraphique amenées par ces surimpressions diagénétiques. Les formations de La Coulée et de Saint-Jules, ainsi que les calcrètes d'eau souterraine massives, ont été partiellement érodées avant que ne sédimente la Formation de Bonaventure. Tout comme les formations de La Coulée et de Bonaventure, la Formation de Saint-Jules n'est pas datée mais recouvre en discordance les structures acadiennes (Dévonien moyen) et est antérieure au Groupe de Mabou (Namurien).

Introduction

A review of the upper Paleozoic stratigraphy of the southern Gaspé Peninsula of Quebec has led to the identification of a new red bed unit in the Cascapédia Valley (study area on Fig. 1), herein named the Saint-Jules Formation (Appendix A), which was previously included within the Bonaventure Formation (Mississippian) (Logan, 1846; Alcock 1935; McGerrigle 1946; Skidmore 1967; Gosselin 1988; Brisebois et al. 1992; van de Poll 1995). Although the two units contain similar successions of continental red clastics that lack dateable fossils, a few important petrographic differences clearly distinguish the Saint-Jules Formation from the over-

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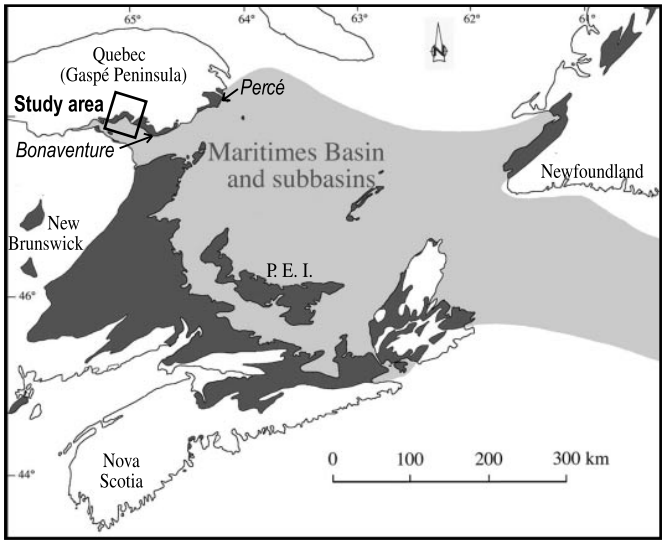
Fig. 1. Study area in the southern Gaspé Peninsula of Quebec. Modified from Gibling et al. (1992). Dark and pale grey fills represent, respectively, the onland and offshore extension of the upper Paleozoic cover.



lying Bonaventure Formation. Moreover, the two units are separated by a significant unconformity.

The Saint-Jules Formation is part of the Carboniferous Ristigouche Subbasin (van de Poll 1995), the northwestern margin of the upper Paleozoic Maritimes Basin. The latter occupies much of southeastern Canada and comprises sedimentary and minor volcanic rocks of Upper Devonian to the Lower Permian age. The Carboniferous strata of Gaspé are relatively undeformed and, where not underlain by the Upper Devonian Miguasha Group (Fig. 2), rest unconformably on Cambro-Ordovician and Siluro-Devonian rocks that were affected by the Taconian (Middle to Late Ordovician) and the Acadian (Middle Devonian) orogenies, respectively, (Alcock 1935; McGerrigle 1950; Rust 1981; Zaitlin and Rust 1983; Rust et al. 1989; Malo et al. 1992 1995; Malo and Kirkwood 1995; Kirkwood et al. 1995; van de Poll 1995).

The Saint-Jules Formation went through a complex post-depositional diagenetic history prior to deposition of the overlying Bonaventure Formation. The unit was cemented, and its upper beds were subsequently karstified prior to being thoroughly calcretized by groundwaters. The thick and massive groundwater calcrete affecting karstified regolith of the Saint-Jules Formation corresponds to a rare calcrete facies that to date has only been documented in recent deposits of Central Australia (Mann and Horwitz 1979; Arakel and McConchie 1982; Jacobson et al. 1988; Arakel et al. 1989; Wright and Tucker 1991) and in grey clastic beds of the Carboniferous La Coulée Formation in the eastern Gaspé Peninsula, which also underlies the Bonaventure Formation (Jutras et al. 1999, 2001). This paper presents the first report of such calcretes developed within karstified regolith as opposed to freshly deposited sediments. This new case history discourages the use of such calcretes as stratigraphic units, as was attempted by Jutras et al. (1999, 2001), because of their observed capacity to transcend time-stratigraphic boundaries. However, other aspects of the calcrete that bear stratigraphic significance are underlined in this paper.

Key sections of the new Saint-Jules Formation are described in an attempt to clarify stratigraphic relationships, depositional environments, diagenetic events and basin geometry. The new stratigraphic data also shed new light on the post-Acadian tectonic history of the area.

Post-Acadian tectonostratigraphy and sedimentology of the Cascapédia Valley and Black Cape Ridge areas

Geological and geomorphic setting

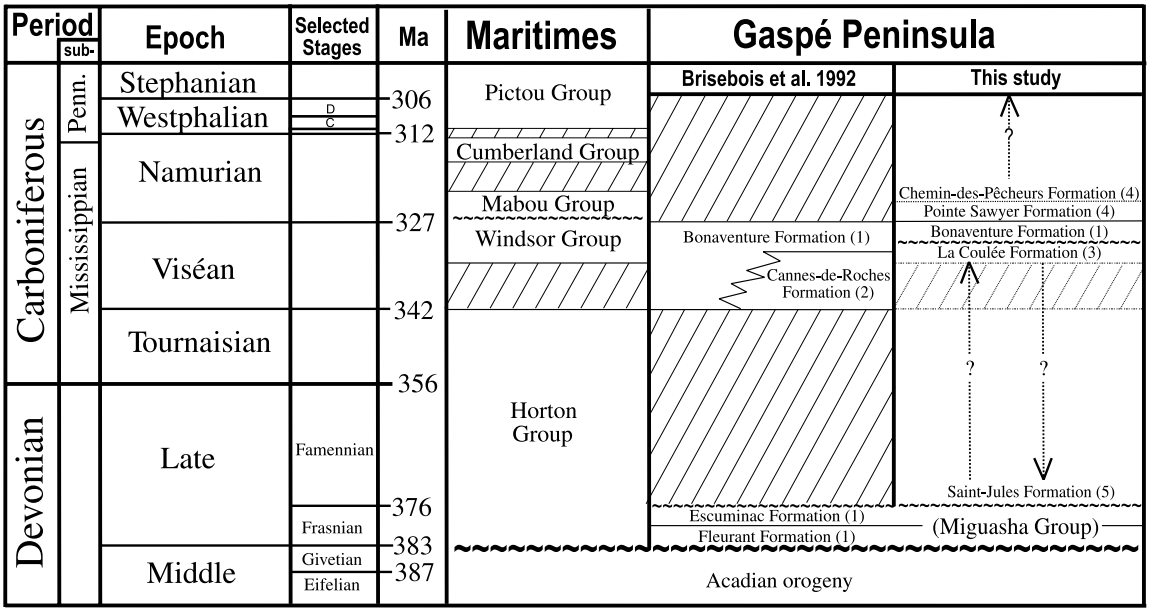
The belt of post-Acadian strata in the southwest Gaspé Peninsula locally ends as a north-facing cuesta < 10 km away from the north shore of Chaleur Bay in the Cascapédia Valley, partly confined by basement highs standing to the northwest (the Grande-Cascapédia fault scarp) and to the southeast (the Black Cape Ridge) (Fig. 3). The exhumed paleosurface that extends immediately to the north of the Carboniferous cover shows a very irregular morphology. It was referred to as an "inherited topography surface" by Jutras and Schroeder (1999) from the observation that it is not exclusively shaped by the currently active river system, in contrast with the dissected peneplain that extends north of the Rivière-Garin Fault and west of the Grande-Cascapédia Fault (Fig. 3). The Carboniferous cover in the Cascapédia Valley rests unconformably on Ordovician mudstones of the Garin and Pabos formations (Gosselin 1988). The Saint-Jules Formation is absent on the Black Cape Ridge, but remnants of the Bonaventure Formation and underlying groundwater calcrete are found on this topographic high, resting unconformably on Silurian rocks of the Chaleurs Group succession (Bourque and Lachambre 1980).

The Saint-Jules quarry section (Fig. 3*a*)

The post-Acadian strata near the town of Saint-Jules abut against the Grande-Cascapédia fault scarp to the northwest (Fig. 3). Contact with the local Ordovician basement is not exposed. The Saint-Jules quarry section shows 7 m of Saint-Jules red clastics overlain by a massive 8 m-thick calcrete hardpan (Fig. 3*a*). The calcrete is unconformably below red clastics of the Bonaventure Formation. The underlying Saint-Jules clastics show high lateral variability within the ~100 m-wide quarry, but are characterized by large lenses of conglomerate, 1 to 3 m thick and up to 50 m wide, cut by small sandstone and siltstone channel fills, up to 1.5 m thick and less than 10 m wide.

The Saint-Jules conglomerates are oligomictic, with a tendency towards a bimodal size distribution. The coarse clasts are typically < 5 cm maximum diameter and exclusively composed of sub-angular to sub-rounded red calcilutite, set in a granular coarse-sand matrix of similar composition. Since no red calcilutite beds are reported among the pre-Carboniferous basement lithologies within a ~20 km radius around the Saint-Jules quarry (Gosselin 1988), it is assumed that the clasts were oxidized during the Saint-Jules weathering and sedimentation event. Similar, but grey calcilutite forms the bulk of the Ordovician to Silurian White Head Formation, which occupies the structural block located north of the east–west-striking Grand-Pabos Fault (Gosselin 1988), < 10 km north of the Saint-Jules quarry (Fig. 3). Although clearly defined

Fig. 2. Upper Paleozoic stratigraphic record in the Maritimes and in the Gaspé Peninsula. Time scale after Okulitch (1999). Wavy lines represent unconformities with no major hiatus and dashed areas represent unconformities with a major hiatus. Stratigraphy of the Maritimes is modified from Bell (1944), Mamet (1970), Howie and Barss (1975), Utting (1987), Utting et al. (1989), and Ryan et al. (1991). Post-Acadian units in the Gaspé Peninsula were introduced by (1) Logan (1846), (2) Alcock (1935), (3) Jutras et al. (1999), (4) Jutras et al. (2001) and (5) this study. Note that only the Miguasha Group and Pointe Sawyer Formation are well dated in the post-Acadian succession of the Gaspé Peninsula. Penn., Pennsylvanian.



clast imbrication is lacking in the chaotic conglomerates of the Saint-Jules Formation, three 1 to 2 m-wide trough channel-fills of sandstone at the Saint-Jules quarry, with the third dimension given by differential erosion of the rock section, indicate paleoflow vectors towards 175°, 182°, and 195°, which also suggest a source to the north.

The red Saint-Jules conglomerates are matrix- to clast-supported and show, in part, chaotic structures typical of debris flows, such as vertically dipping clasts (Heward 1978; Lewis et al. 1980; Harvey 1984). However, channeling, vertical aggradation, partial clast rounding, and the absence of clay clearly suggest that they were deposited by aqueous processes (Harvey 1984; Wells 1984; Miall 1996). The conglomerates are interpreted as high-energy flash flood deposits on an alluvial fan. They are truncated by channel fills of siltstone, sandstone or conglomerate, which show internal stratification (planar- and cross-bedding) and which are interpreted as braided surficial runoff between flash flood events.

The uppermost conglomerate beds of the Saint-Jules Formation in this section are marked by vertical and horizontal endokarstic conduits filled with non-calcareous, lithified gritty red clay, containing rounded quartz grains. In some sectors of the quarry, the conglomerate beds are brecciated into large dislocated blocks floating within the karst fill (Fig. 4). The karst fills, including those within vertical shafts, are sharply truncated by the overlying calcrete and therefore predate the calcretization event (Fig. 5). According to Wright and Tucker (1991), calcrete hardpans thicker than 3 m are non-pedogenetic and can only be formed by saturated groundwaters below the water table.

The contact between the uppermost conglomerate beds of the Saint-Jules and the overlying groundwater calcrete is sharp in some sectors of the quarry, creating the impression of a sedimentary contact between two units. In other sectors of the quarry, the contact is much more irregular, reflecting the post-sedimentary diagenetic nature of the calcrete body. Rare windows of non-calcretized red clastics, identical to those underlying the groundwater calcrete, can be observed within the calcrete mass. Laminated calcrete textures surrounding some of these windows (Fig. 6) suggest that the latter are blocks of host rock conglomerate, such as those floating in the red karst fill below. The fact that matrix within the host rock windows at the Saint-Jules quarry is untouched by calcretization is further indication that the windows consisted of consolidated material at the time of calcrete formation. The groundwater calcrete was also affected by karst formation (Fig. 7), but its cavities are filled with coarser sediments coming from the overlying Bonaventure Formation.

The calcrete–Bonaventure contact, which has been partly exhumed and scoured by Quaternary glaciers, is characterized by several potholes filled with polymictic red clastics, one of them still holding the large rounded pebble that probably served to carve it (Fig. 8). This indicates that the surface was sculpted by a strong turbulent current prior to being buried by fluvial deposits of the Bonaventure Formation.

The exposed calcrete surface shows a stepped topography underneath the Bonaventure Formation. The calcrete has an ~10° dip toward the south with a 095° strike. Its exposed surface dips less steeply south (~5°), which leads to a gradual thinning of the calcrete exposure to the north. The exposed remnants of the overlying Bonaventure Formation never exceed 1 m in thickness within the quarry (Fig. 9), but thicker sections are abundant immediately to the south. The

Fig. 3. Geology of the Cascapédia – Black Cape area, with cross-section A–B and composite columns *a* to *d* (pre-Carboniferous data by Bourque and Lachambre 1980; Gosselin 1988; and Brisebois et al. 1992).

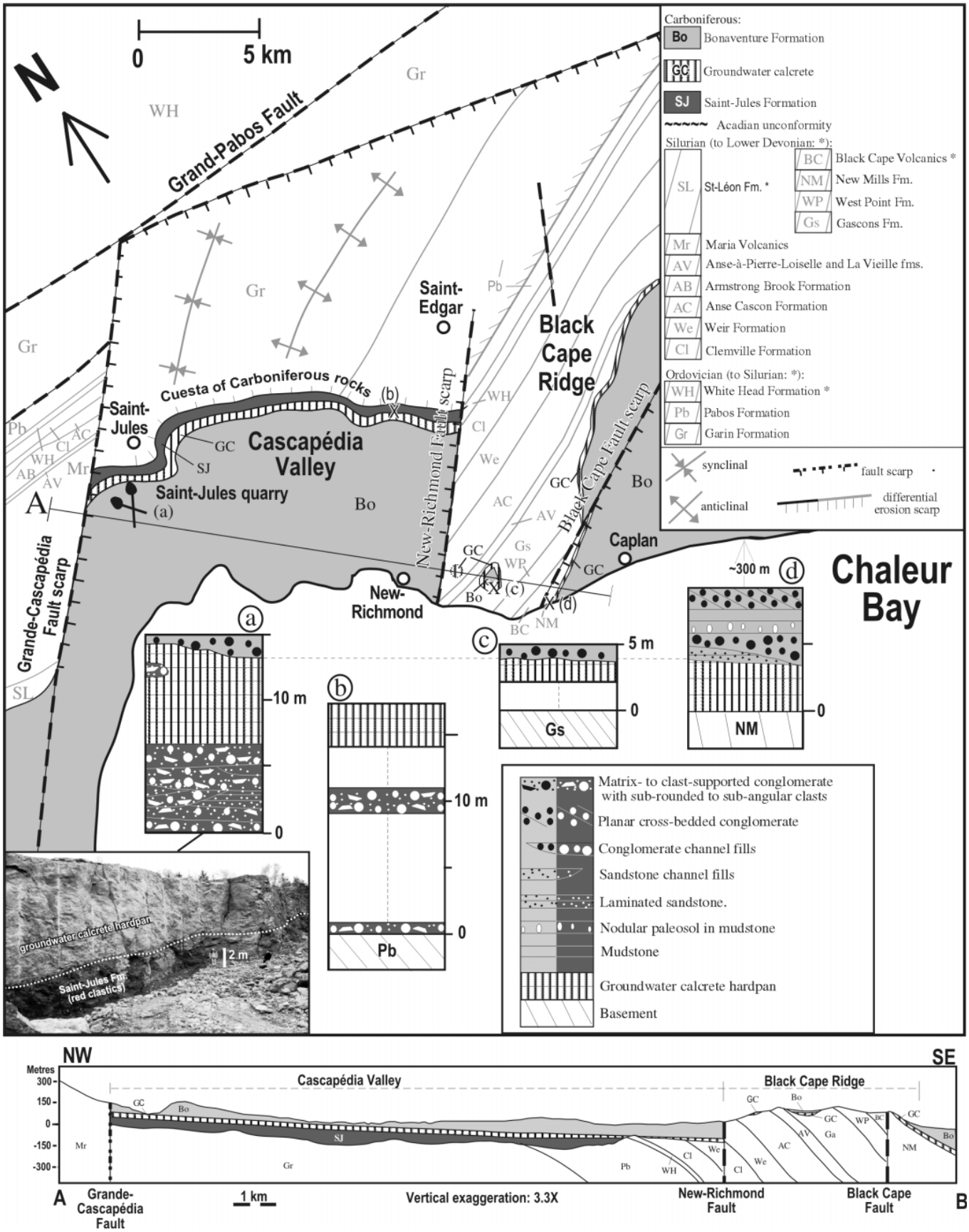


Fig. 4. Densely karstified section of the Saint-Jules Formation (SJ) below the groundwater calcrete in the Saint-Jules quarry, with isolated conglomerate blocks floating in the red claystone karst fill.

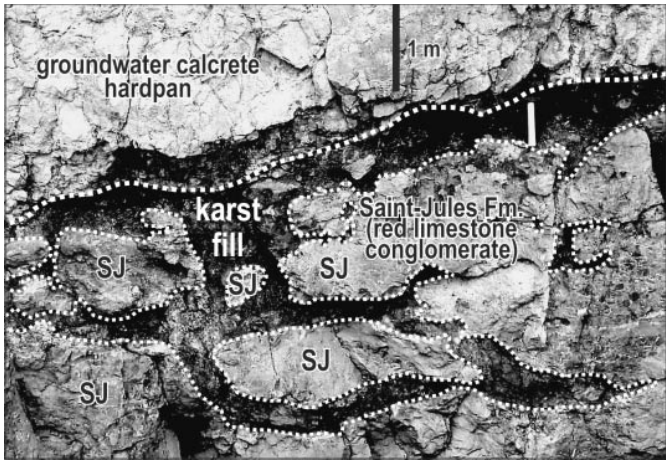
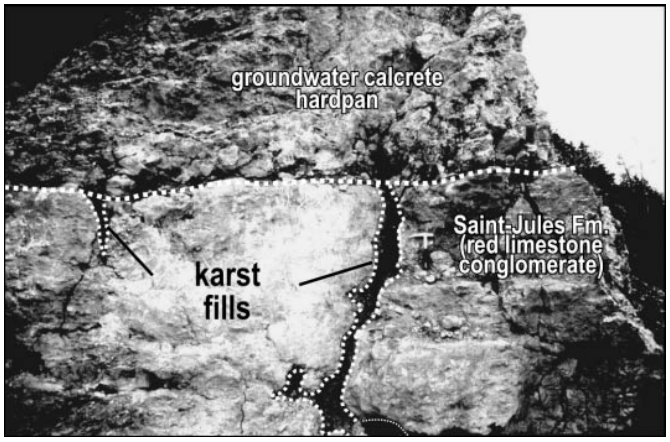


Fig. 5. Truncation of vertical conduit karst fills by groundwater calcrete. Hammer (near center) for scale.



dip of this unit is also to the south but never exceeds 5° in the area.

The Saint-Edgar section (Fig. 3*b*)

The post-Acadian strata, south of the village of Saint-Edgar, abut the Black Cape Ridge to the southeast (Fig. 3). One poor roadside exposure shows 3 m of groundwater calcrete overlying (with a 3 m gap) 2 m of coarse oligomictic conglomerate, identical to that at the Saint-Jules quarry (Fig. 3*b*). This outcrop strongly implies that the groundwater calcrete and underlying Saint-Jules Formation red clastics, observed at the Saint-Jules quarry, are continuous across the Cascapédia Valley.

The succession dips 8° with a 070° strike. The base of the calcrete is ~100 m away from exposures of the Ordovician basement (the Pabos Formation, according to Gosselin 1988 and Brisebois et al. 1992) and, with a ~1° slope between the two outcrops, it can be estimated that the red clastics underlying the calcrete are no thicker than 14 m in this section. However, the depositional surface of the Saint-Jules Formation is very irregular, as suggested by the morphology of the exhumed paleosurface, and thickness may vary considerably across the Cascapédia Valley.

Fig. 6. Uncalcretized block of Saint-Jules Formation conglomerate (SJ), surrounded by laminar calcrete banding features within an overall massive groundwater calcrete (GC).

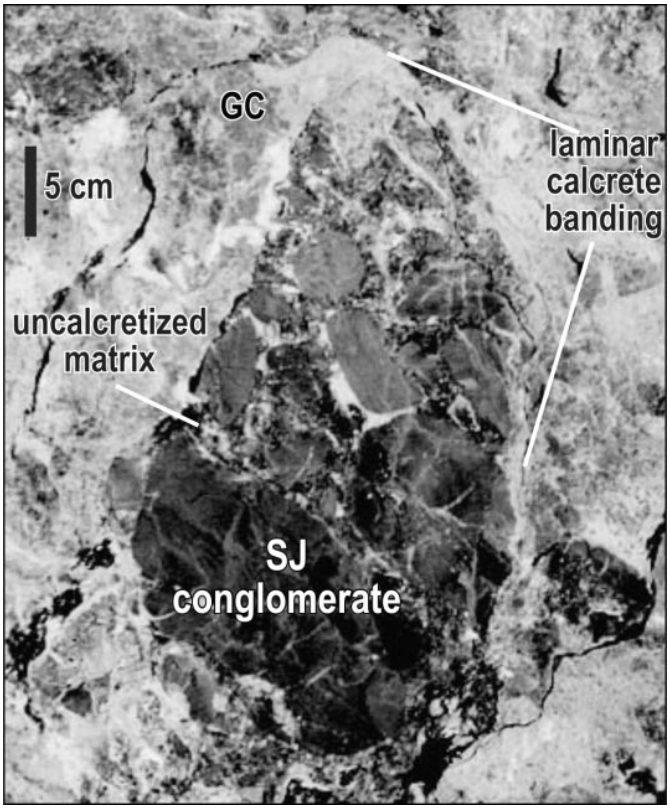
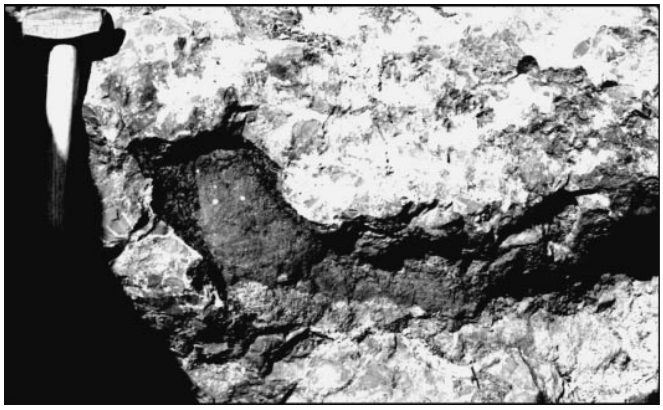


Fig. 7. Endokarstic conduit filled with Bonaventure Formation red clastics within the groundwater calcrete of the Saint-Jules quarry (cross-section view). Hammer for scale.



A few hundred metres to the west of this section, a new quarry was opened in the summer of 2001, revealing the unconformable and irregular contact between reddened Pabos Formation mudstones and the basal metre of overlying Saint-Jules conglomerate.

The Black Cape Ridge section (Fig. 3*c*)

A roadside outcrop on the Black Cape Salient reveals the

Fig. 8. Irregularities in the upper surface of the groundwater calcrete (GC) in the Saint-Jules quarry, including pot-holes filled with red clastics of the Bonaventure Formation (Bo) (plan view). Both the clastic filling and calcrete upper surface are affected by glacial scouring. Hammer for scale.

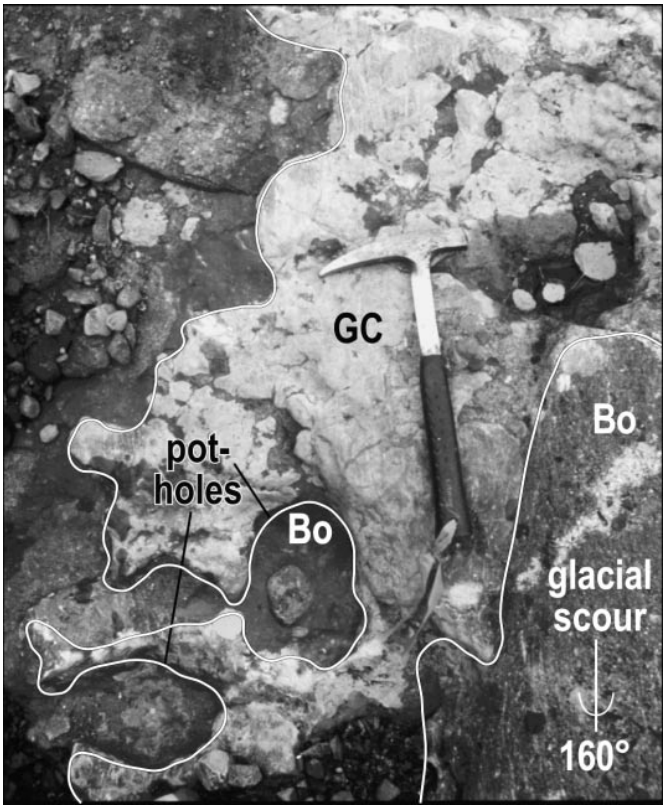
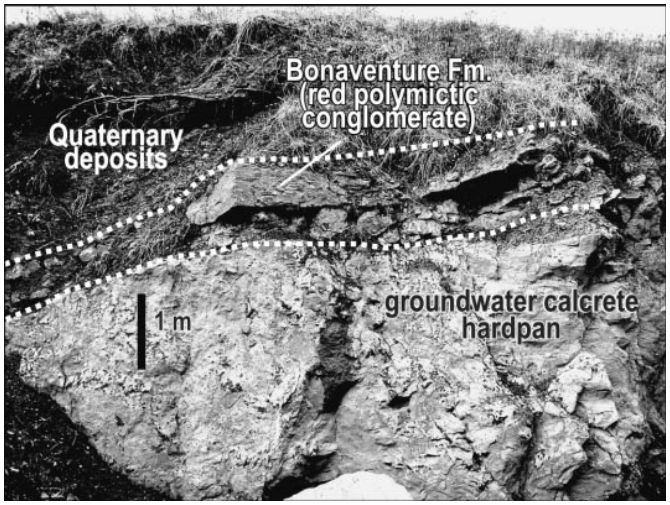


Fig. 9. Contact between the groundwater calcrete hardpan and the overlying Bonaventure Formation in the Saint-Jules quarry.



contact between a flat-lying groundwater calcrete and overlying red clastics of the Bonaventure Formation (Fig. 3*c*). The contact between the basement and the post-Acadian succession is not exposed on this small section, but another groundwater calcrete outcrop, located immediately to the northwest of Location 3c on Transect A–B, shows the incompletely digested contact with sandstone of the Silurian Anse Cascon Formation, suggesting that the Saint-Jules Formation red clastics are absent in this sector.

Beds of the Bonaventure Formation, dipping 5° toward the south (180°), can also be observed at the northwest foot of the Black Cape Ridge near New-Richmond, where they lie less than 2 km to the west and ~50 m topographically below location 3.3c. The southward dip implies that the Bonaventure Formation thickens toward the south. If it is assumed that the 8° dip with a 070° strike of the La Coulée calcrete near Saint-Edgar is constant, the calcrete would lie ~870 m below the surface in the area of New-Richmond. This indicates the presence of an unexposed fault (the New-Richmond Fault) with a post-Acadian vertical displacement of no more than 920 m (870 m + 50 m of altitude correction) separating the Cascapédia Reentrant from the Black Cape Salient (Fig. 3, cross-section A–B).

The Caplan section (Fig. 3*d*)

This section is separated from Location 3.3c by the Black Cape Fault (new name), which strikes northeast-southwest between the towns of Black Cape and Caplan (Fig. 3). Tilted-on-edge red clastics attributed to the West Point Formation or the Indian Point Formation (Silurian) by Bourque and Lachambre (1980), and recently correlated with the New Mills Formation (uppermost Silurian to lowest Devonian) by Bourque et al. (2000), occupy the southeastern foot of the Black Cape Salient. These red clastics are overlain unconformably (60° angular unconformity) by a 3 m-thick groundwater calcrete, which is in turn overlain by a ~300 m-thick section of the Bonaventure Formation (Fig. 3*d*). The nature of the host sediment could not be determined for this mature, clast-free calcrete.

The usually flat-lying Carboniferous succession has a 25° dip and a 035° strike in the vicinity of the Black Cape Fault, which indicates that the fault was active subsequent to Carboniferous deposition. The Bonaventure conglomerates, from their proximity to the Black Cape Volcanics are here dominated by volcanic clasts (72%), while sedimentary clasts, which are usually dominant in this unit, only make up 11% of the gravels. The presence of 17% rounded quartz pebbles and occasional red jasper clasts is, however, typical of this unit.

A continuous section exposing ~190 m of Bonaventure strata between Black Cape and Caplan shows an abundance of conglomeratic beds alternating with sandstones and muddy paleosols with carbonate nodules in the lower ~140 m and almost exclusively sandstone beds in the upper ~50 m (Fig. 3*d*). Extrapolations from discontinuous coastline exposures between the towns of Caplan (Fig. 1) and Bonaventure (about 20 km southeast of Caplan) suggest there are at least 90 more metres of sandstone above the continuous section. The upper exposures include 3 m-thick planar cross-strata with west-dipping cross-laminae, a feature that is found in many sections of the Bonaventure Formation and which Jutras et al. (2001) have associated with large transverse bars. The Bonaventure is disconformably overlain by grey clastics of the Carboniferous Pointe Sawyer Formation (Jutras et al. 2001) at the town of Bonaventure (Fig. 1), giving an approximate

thickness of nearly 300 m for the Bonaventure Formation in this area.

The Cascapédia Valley, bordered by the Grande-Cascapédia and New-Richmond faults, and the Black Cape ridge, bordered by the New-Richmond and Black Cape faults (Fig. 3), can be considered from tectonostratigraphic constraints as, respectively, graben and horst structures that are younger than the Bonaventure Formation. The absence of Saint-Jules clastics on the Black Cape horst leads to the hypothesis that the New-Richmond Fault also experienced pre-Bonaventure displacement, either limiting Saint-Jules deposition to the Cascapédia graben, or possibly causing erosion of the Saint-Jules on the horst. However, the Cascapédia – Black Cape valley and ridge system may not be entirely fault-controlled. Air photos show that the inferred New-Richmond Fault scarp cuts the stratigraphic contacts of the Silurian succession at 25° and intersects a second scarp about 1 km south of the village of Saint-Edgar (Fig. 3). The second scarp is parallel to stratigraphic contacts and most likely developed from recession of the incompetent Pabos Formation mudstones by differential erosion. The Saint-Jules clastics in the Cascapédia graben were, therefore, possibly confined to a differential erosion valley prior to activity of the New-Richmond Fault, which has possibly been active only during post-Bonaventure time. The absence of Saint-Jules clastics on the Black Cape area could then result from non-deposition.

Discussion

Sedimentary and diagenetic environments of the Saint-Jules Formation

The red beds of the Saint-Jules Formation are best differentiated from the overlying Bonaventure Formation by the absence of distantly derived clasts, such as quartz pebbles, which systematically make up 10–20% of the Bonaventure conglomerates, and occasional red jasper clasts within their coarse fraction (Jutras et al. 1999, 2001). Polymictic fluvial gravels of the Bonaventure Formation are also better sorted and more rounded than the oligomictic gravels of the Saint-Jules Formation. These observations suggest that the Saint-Jules detritus was subject to shorter transportation before deposition than that of the Bonaventure Formation.

The lenticular and poorly sorted beds of the Saint-Jules Formation, with coarse sub-angular to sub-rounded clasts, are typical of fault-related alluvial fans as defined by Rust (1981, 1984). The oligomictic character of the conglomerates, amid a lithologically diversified regional basement geology, also suggests a very localized source area, such as a fault scarp. Fluvial deposits and deep oxidization of the entire sequence clearly define the depositional environment as continental. The few available paleocurrent indicators combined with the lithology of the clasts, which are tentatively correlated with the White Head Formation, suggest that the red clastics were derived from flash floods issuing from the Grand Pabos Fault escarpment located to the north.

The upper Saint-Jules beds in the Saint-Jules quarry had to have been already cemented when karstification took place, because karstic conduits can only develop in an aquiclude that forces groundwater circulation to concentrate along joints and bedding planes (Ford 1965). The non-calcareous red gritty claystone that infills the karstic cavities, and which is locally replaced by the invading groundwater calcrete, can be regarded as the insoluble karst residue migrating from above. As this insoluble material only makes up a few percent of the Saint-Jules conglomerate composition, a significant volume of calcite was dissolved from the upper Saint-Jules beds to account for the large volume of red gritty claystone infills that is observed immediately below the calcrete. In some areas, the claystone volume is comparable to that of the collapsed conglomerate blocks that it surrounds.

As non-calcretized blocks of Saint-Jules red clastics are found disseminated throughout the groundwater calcrete profile, it can be inferred that the calcrete developed entirely within the karst-related regolith of the Saint-Jules Formation. To our knowledge, this is the first report of a groundwater calcrete developed within a regolith. The latter can be regarded as a similar host for the calcrete, in terms of porosity, to the very coarse sedimentary breccia of the La Coulée Formation near the town of Percé (Fig. 1; Jutras et al. 1999). In both cases, the calcretization was incomplete, leaving "undigested" oversized clasts (unweathered blocks of Saint-Jules breccia, in the case of the regolith), which remain as floating windows within the calcrete mass.

Thick and massive groundwater calcretes, such as those observed in the Carboniferous succession of the Gaspé Peninsula, are only found around evaporitic basins and are thought to be genetically linked to them, forming specifically in the zone where fresh and saline groundwaters mix (Mann and Horwitz 1979; Arakel and McConchie 1982; Jacobson et al. 1988; Arakel et al. 1989; Wright and Tucker 1991). It is, therefore, inferred that evaporitic basins must have occupied the Chaleur Bay depression sometime after deposition of the Saint-Jules Formation, leading to the formation of such calcretes in the upper Saint-Jules beds of the Cascapédia Valley, and perhaps in regolith developed within Silurian rocks on the Black Cape Ridge. Unfortunately, the stratiform groundwater calcrete at Caplan (Fig. 3*d*) is so mature that it leaves no clue as to the nature of its host sediment.

Stratigraphic relationships

The groundwater calcrete problem

Erosion occurred prior to sedimentation of the Bonaventure Formation and completely removed the remaining host material (sediments or regolith) that overlay the groundwater calcretes from the Gaspé Peninsula, except in the Percé area (Fig. 1), where a 50 m section of La Coulée Formation grey clastics is preserved above the groundwater calcrete hardpan (Jutras et al. 1999). The groundwater calcretes were preferentially preserved due to their high resistance to erosion under the arid climate that then prevailed (Jutras et al. 1999).

The Bonaventure Formation typically sits with an erosional or angular unconformity on groundwater calcrete (Jutras et al. 1999, 2001). The erosional surface that separates the groundwater calcrete of the Saint-Jules quarry from the overlying Bonaventure Formation is, therefore, similar to the contact relationship between these two units seen elsewhere in the southern and eastern Gaspé Peninsula. The only observed areas where there is not at least a few centimetres of calcrete

below the base of the Bonaventure is where the latter overlies poorly consolidated and subhorizontal post-Acadian units, such as the Frasnian Escuminac shales (Brideaux and Radforth 1970; Hesse and Sawh 1992; Prichonnet et al. 1996). Extensive preservation of the basal calcretes suggests that the pre-Bonaventure erosion event has not substantially affected pre-Frasnian basement rocks, while the absence of calcrete between the Saint-Jules and underlying basement rocks further differentiates this unit from the Bonaventure.

The fact that groundwater calcrete does not constitute a primary deposit, but a diagenetic overprint poses a stratigraphic problem. Jutras et al. (1999) proposed to consider all the massive groundwater calcretes that are overlain by the Bonaventure Formation as La Coulée Formation, even in places where the nature of the host sediment is unknown. Following identification of one such calcrete developed within regolith of the Saint-Jules Formation, this view no longer stands. The Saint-Jules setting provides proof that the presence of a groundwater calcrete beneath the Bonaventure does not automatically imply the former presence of a La Coulée Formation host sediment.

While it is not possible to affirm that the groundwater calcrete at Saint-Jules is time-equivalent to that affecting the La Coulée clastics in Percé, the presence of the Saint-Jules calcrete bears stratigraphic significance by indicating that there are at least two hiatuses separating the Saint-Jules from the Bonaventure: (1) Prior to being calcretized, the Saint-Jules Formation in the Cascapédia Reentrant underwent cementation and subsequent karstic weathering, which requires a prolonged period of exposure above base-level. (2) Subsequent erosion occurred after the calcretization event, but before sedimentation of the Bonaventure Formation. It is also observed that, synchronous or not, the thick and massive groundwater calcretes of the Chaleur Bay area all occupy the same relative stratigraphic position, which is (*i*) above the Saint-Jules Formation, (*ii*) within the La Coulée Formation, when present, and (*iii*) beneath the Bonaventure Formation.

Because thick and massive groundwater calcrete can only form where the water table is < 5 m from the surface (Mann and Horwitz 1979; Wright and Tucker 1991), sedimentation and groundwater calcretization were demonstrably coeval in the La Coulée Formation of Percé (Fig. 1), where over 30 m of non-calcretized sediments overlie 30 m of calcretized sediments (Jutras et al. 1999). Calcretization was, therefore, only active during the early stages of the La Coulée clastic deposition. If the thick and massive groundwater calcretes of the Gaspé Peninsula are all remnants of the same event, replacement of a post-Saint-Jules Formation regolith by a groundwater calcretization front suggests that the Saint-Jules may be older than the grey clastics of the La Coulée Formation.

To date, there are no data challenging the postulate that all the massive groundwater calcretes of the Gaspé Peninsula are penecontemporaneous with deposition of the La Coulée Formation. Hence, by indirect association, we now propose to informally refer to these calcretes as "La Coulée calcrete," when the host sediment is not demonstrated to be the La Coulée Formation.

Age constraints and tentative correlations with the stratigraphic record in the rest of the Maritimes Basin

Since the Saint-Jules Formation does not seem to have been affected by the mild compressive event that has gently folded the beds of the post-Acadian Miguasha Group (Frasnian) (Zaitlin and Rust 1983; Hesse and Sawh 1992; Brisebois et al. 1992), it is probably no older than Famennian (uppermost Devonian). The upper age of the Saint-Jules is fixed by the dated Pointe Sawyer Formation, which disconformably overlies the Bonaventure Formation and which is the only local Carboniferous unit bearing plant remains and spores. It contains the SM Spore Zone assemblage, which was dated as upper Viséan (Utting 1987), but now considered lower Namurian (J. Utting, personal communication, 2001), and which is shared by basal units of the Mabou Group in the general upper Paleozoic stratigraphy of the Maritimes Basin (Fig. 2).

From stratigraphic constraints, the Saint-Jules is therefore older than the Mabou Group (Fig. 2) and is either time-equivalent to the Horton (Upper Devonian to Tournaisian; sensu Martel et al. 1993) or Windsor (Viséan) groups of the Maritimes Basin (Howie and Barss 1975; Martel et al. 1993; St. Peter 1993; Calder 1998; Pascucci et al. 2000). Having successively undergone cementation, karstification, groundwater calcretization, and erosion prior to deposition of the Bonaventure Formation, which is also pre-Mabou, time correlation with the Horton is more probable than with the Windsor.

East of the study area, the groundwater calcrete lies directly on a paleowave-cut platform that was tentativelly associated with a short incursion of the Windsor Sea in the southern Gaspé Peninsula (Jutras and Schroeder 1999; Jutras et al. 1999). As Subzone A of the Windsor is the most extensive part of this group in New Brunswick (Plint and van de Poll 1983), formation of the groundwater calcretes must be associated to evaporitic basins that were left behind following the first major transgression–regression cycle of the Windsor Sea (Jutras et al. 2001). This further suggests that the Saint-Jules may be a pre-Windsor unit, unless it correlates with the Hillsborough Formation, a clastic unit that conformably underlies Subzone A carbonates in parts of southern New Brunswick and that is assigned to the Windsor Group (St. Peter 1993; New Brunswick Department of Natural Resources and Energy 2000). It should be noted that the latter assignment contradicts the lithostratigraphic definition proposed by Bell (1944), which sets the basal marine Windsor carbonates as the lower limit of this group, and that equivalent units in Nova Scotia would rather be assigned to the Horton Group (P. Giles, personal communication, 2001).

Small graben or half-graben fills of red beds are typical of the Upper Devonian fraction of the Horton Group (sensu Martel et al. 1993), while early Carboniferous depocentres are typically more extensive in the Maritimes Basin (Calder 1998). Some authors consider these Upper Devonian red beds as pre-Horton and include them within the Fountain Lake Group and equivalent units, while constraining the Horton Group to the uppermost Devonian and Tournaisian (Ryan et al. 1991; Calder 1998).

Age constraints for post-Acadian units in the southern Gaspé Peninsula are still too insecure for official group assignments to be established. It is, therefore, proposed to leave the post-Acadian Gaspé stratigraphy undefined at group level at this stage. More work is underway to identify links between the post-Acadian stratigraphy in the northern

margin of the Maritimes Basin with that of its more extensively studied central sections.

Conclusions

Flat-lying post-Acadian red beds that are older than the Bonaventure Formation occupy a small graben in the southern Gaspé Peninsula and are attributed to the newly identified Saint-Jules Formation. This unit comprises a succession of poorly sorted, fault-controlled continental clastic rocks that were deposited by high-energy ephemeral events. The coarse fluvial strata that characterize the Saint-Jules Formation are matrix- to clast-supported, not well rounded, and exclusively derived from a proximal source.

Original thickness of the Saint-Jules Formation is unknown because its upper beds successively underwent karstification, groundwater calcretization, and erosion. Such thorough calcretization of a regolith by groundwaters had not previously been observed in the geological record. From this, it can be concluded that groundwater calcretes can transcend stratigraphic boundaries and be significantly younger than the units that they digest.

Being visually similar to the unconformably overlying Bonaventure Formation, the Saint-Jules Formation may have been mistakenly mapped as this unit outside of the study area. Post-Acadian red beds in the Chaleur Bay area should not be systematically assigned to the Bonaventure Formation anymore, as was the common practice. The most diagnostic petrographic criteria to differentiate the two units is the presence or absence of distally derived quartz pebbles, which are observed in the Bonaventure Formation but not in the Saint-Jules. The contact between the two units is unconformable and the Saint-Jules Formation could, therefore, be significantly older than the Bonaventure Formation. The presence of a thick groundwater calcrete separating the two red bed successions suggests that the Saint-Jules Formation may also be older than the La Coulée Formation of eastern Gaspé, which is considered to be time-equivalent to the Lower Windsor (Jutras et al. 2001). This suggests that the Saint-Jules Formation may be as old as units assigned to the Horton Group in more central sectors of the Maritimes Basin and underlines the stratigraphic significance of thick and massive groundwater calcretes as peripheral relicts of Windsor Group evaporitic basins.

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Appendix A: The Saint-Jules Formation

Authors

Jutras, P., and Prichonnet, G.

Age

Post-Middle Devonian and pre-Namurian.

History

This unit was previously assigned to the Bonaventure Formation by Logan (1846), Alcock (1935), McGerrigle (1946), Skidmore (1967), Gosselin (1988), Brisebois et al. (1992) and van de Poll (1995).

Original thickness

The original thickness is unknown, because the uppermost beds of this unit were digested by groundwater calcrete and were partly eroded subsequently, but present thickness below the calcrete was estimated as < 15 m near the town of Saint-Edgar-de-Cascapédia.

Distribution

The most significant Saint-Jules Formation exposures, in terms of stratigraphic relationships, are in a quarry located south of the town of Saint-Jules-de-Cascapédia in the southern Gaspé Peninsula of Quebec (Universal Transverse Mercator Zone 22A, 5347500 m N, 282000 m E), which is taken as the type section. In this sector, an 8 m thick groundwater calcrete developed within karstified upper beds of the Saint-Jules Formation separates this unit from the Bonaventure Formation, which unconformably overlies the calcrete. Only two other exposures of this unit are known in the study area. Further investigation is underway outside of the study area to see if other exposures of this unit were mistakenly mapped as the Bonaventure Formation.

Lithology

Red continental clastics, including some sandstone and siltstone, but mainly conglomerate. The coarse fractions only include locally derived sedimentary clasts. The conglomerates are poorly rounded and poorly sorted.

Stratigraphic relationships

The Saint-Jules Formation unconformably overlies rocks that were deformed by the Middle Devonian Acadian Orogeny. It does not bear the folds that affect the Miguasha Group (Frasnian), which also has exposures in the southern Gaspé Peninsula. Hence, it probably postdates these rocks. It is older than the Bonaventure Formation, which underlies the earliest Namurian Pointe Sawyer Formation (basal Mabou Group unit) (Jutras et al. 2001). If the thick and massive groundwater calcrete that digested its karstified upper beds is coeval to that affecting the La Coulée Formation (Jutras et al. 1999), the Saint-Jules Formation is also older than this unit.