UNIVERSITÉ DU QUÉBEC À MONTRÉAL

TECTONOSTRATIGRAPHIE DU CARBONIFÈRE DE LA GASPÉSIE, QUÉBEC, CANADA

THÈSE PRÉSENTÉE À L'UNIVERSITÉ DU QUÉBEC À CHICOUTIMI COMME EXIGENCE PARTIELLE DU DOCTORAT EN RESSOURCES MINÉRALES OFFERT À L'UNIVERSITÉ DU QUÉBEC À MONTRÉAL EN VERTU D'UN PROTOCOLE D'ENTENTE AVEC L'UNIVERSITÉ DU QUÉBEC À CHICOUTIMI

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RÉSUMÉ

Ce travail de recherche fait suite à un questionnement posé par une étude géomorphologique sur le sujet des environnements tectoniques et sédimentaires du Carbonifère de la Gaspésie. Une révision générale du Carbonifère de la Gaspésie a donc été entreprise.

Plusieurs changements concernant la stratigraphie et l'histoire tectonique du Carbonifère de la Gaspésie sont proposés à l'intérieur de la présente étude. Quatre unités clastiques continentales post-acadiennes sont nouvellement identifiées à partir de discontinuités stratigraphiques et selon des critères d'ordre pétrologique. Deux de ces unités, les formations de Paspébiac et de La Coulée, sont sous-jacentes à la Formation de Bonaventure et étaient autrefois incluses à l'intérieur de cette dernière. Les deux autres unités, les formations de Pointe Sawyer et du Chemin-des-Pêcheurs, sont sus-jacentes à la Formation de Bonaventure et étaient auparavant incluses à l'intérieur de la Formation de Cannes-de-Roches. Des épisodes de déformation, synchrones et postérieurs à la succession stratigraphique post-acadienne, sont aussi nouvellement identifiés.

À la base de la succession post-acadienne en Gaspésie, excluant les formations de Fleurant et d'Escuminac (Dévonien tardif), la nouvelle Formation de Paspébiac se différencie pétrographiquement de la Formation de Bonaventure par le caractère exclusivement local de ses sources clastiques et par le caractère mal trié de ses fractions grossières. Cette nouvelle unité s'est déposée sous des conditions oxydantes à l'intérieur de petits grabens ou demi-grabens continentaux situés dans le sud et le sud-ouest de la Gaspésie. Une épaisseur maximale d'à peine plus de 50 m a été répertoriée. La Formation de Paspébiac est probablement associée au Groupe de Horton des Provinces Maritimes. Une corrélation avec la Formation de Hillsborough, unité clastique à la base du Groupe de Windsor, est également possible.

La nouvelle Formation de La Coulée, également nourrie par des sources exclusivement locales, est en plus différenciée de la Formation de Bonaventure par son caractère non-oxydé et, dans les affleurements connus, par la présence d'une calcrète d'eau souterraine épaisse de plus de 10 m à sa base. La présence de calcrètes d'eau souterraine aussi épaisses, répertoriées pour la première fois dans des unités pré-quaternaires, implique que la Formation de La Coulée a évolué à la périphérie de bassins évaporitiques. La Formation de La Coulée fut légèrement déformée et presqu'entièrement érodée avant que se déposent en discordance angulaire les lits clastiques rouges de la Formation de Bonaventure. La calcrète de base a mieux résisté à l'érosion que les lits clastiques gris sus-jacents et a été plus largement conservée. L'épaisseur de cette unité est inconnue et seul les premiers 60 m sont répertoriés.

Dans le sud-ouest de la Gaspésie, une calcrète similaire à celle affectant la Formation de La Coulée a envahi un manteau d'altération développé dans les lits supérieurs de la Formation de Paspébiac. Une autre recouvre une surface d'érosion, possiblement d'origine marine, dans le sud de la péninsule. Ces calcrètes sont également recouvertes en discordance par la Formation de Bonaventure. Occupant la même position stratigraphique relative que la Formation de La Coulée, elles sont considérées comme contemporaines à cette dernière.

La Formation de Pointe Sawyer, différenciée de la Formation de Bonaventure par ses lits clastiques gris à débris de plantes, recouvre cette dernière en discordance de ravinement. Cette nouvelle unité correspond à l'ancien membre supérieur de la Formation de Cannes-de-Roches par ses faciès et son assemblage de spores, lesquels correspondent à ceux du Groupe de Mabou des Provinces Maritimes. Les lits clastiques rouges des membres inférieur et moyen de l'ancienne Formation de Cannes-de-Roches, quant à eux, ont des faciès équivalents à ceux de la Formation de Bonaventure. Les lits clastiques rouges de la Formation de Cannes-de-Roches, tout comme ceux de la Formation de Bonaventure, recouvrent en discordance les calcrètes d'eau souterraine de la Formation de La Coulée. À partir de ces nouvelles données stratigraphiques, il est proposé d'abandonner la Formation de Cannes-de-Roches, maintenant subdivisée en tant que Formation de Bonaventure et Formation de Pointe Sawyer.

Selon des reconstructions paléogéographiques, les roches autrefois cartographiées en tant que Formation de Cannes-de-Roches n'ont pas sédimenté dans le même bassin sédimentaire que les roches du même âge dans le reste de la péninsule. Le premier bassin est qualifié de Bassin de Cannes-de-Roches et le second de Ristigouche. La Formation de Bonaventure, dans le Bassin de Cannes-de-Roches, n'est épaisse que d'environ 50 m, alors qu'elle excède les 300 m dans le bassin de Ristigouche. La Formation de Pointe Sawyer ne totalise que 20 m dans le premier bassin et seule sa base est reconnue dans le second.

Au-dessus des lits clastiques gris de la Formation de Pointe Sawyer, la Formation du Chemin-des-Pêcheurs marque un retour vers des conditions oxydantes et le début d'une sédimentation provenant de sources beaucoup plus distales que celles qui ont alimenté les unités post-acadiennes sous-jacentes. Cette dernière formation, tout comme la Formation de Pointe Sawyer, est associée au Groupe de Mabou des Provinces Maritimes. Elle est la plus jeune unité sédimentaire pré-quaternaire reconnue en Gaspésie. On lui attribue 15 m de dépôts résiduels sans pouvoir préciser l'importance qu'elle a pu représenter avant érosion.

La succession stratigraphique du Carbonifère de la Gaspésie est affectée par des déformations transpressives post-sédimentaires, probablement associées à la déformation Alléghanienne (Pennsylvanien à Permien). Trois systèmes de failles coulissantes, avec structures compressives subordonnées, ont été répertoriés. D'importants déplacements latéraux post-acadiens sont ainsi identifiés pour la première fois en Gaspésie.

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INTRODUCTION

MISE EN CONTEXTE

Cette thèse constitue une révision générale des environnements sédimentaires et contextes tectoniques du Carbonifère de la Gaspésie, dans l'est du Québec. La Gaspésie est une péninsule orientée est-ouest de 200 km de long et jusqu'à 140 km de large, bordée par l'estuaire du fleuve St.-Laurent, au nord, le golfe du St. Laurent, à l'est, et la baie des Chaleurs, au sud (Fig. 1).

Contexte géologique pré-carbonifère

La Gaspésie est principalement formée de roches du Paléozoïque appartenant aux différentes unités structurales appalachiennes. Les Appalaches sont le résultat du long processus de fermeture de Iapétus, un bassin océanique ayant pris naissance à l'Hadrynien (fin Précambrien) suite au développement d'un rift à l'intérieur des racines exhumées de la chaîne Grenvillienne (~1 Ga). Le rift aurait commencé à s'ouvrir vers 800 Ma dans les structures rocheuses aujourd'hui situées au nord de la zone d'étude, selon Hada (1980), ou vers 723 Ma, selon Kamo *et al.* (1995), mais seulement entre 630 et 610 Ma dans les structures rocheuses de la Virginie, selon Fichter et Diecchio (1986).

Selon certains auteurs, Iapétus a déjà des zones de subduction actives dès la fin du Précambrien et les premières accrétions dites 'appalachiennes' auraient commencé vers 600 Ma (Keppie, 1985; Rast *et al.*, 1988), avant même que la partie sud de Iapétus ne soit ouverte en tant que bassin marin, selon les données de Fichter et Diecchio (1986). Les déformations appalachiennes les plus vieilles observées dans des roches de la Gaspésie datent de la fin du Cambrien-début Ordovicien et sont enregistrées par le Groupe de Maquereau. Ce dernier forme avec le Groupe de Mictaw une boutonnière d'âge Précambrien à Ordovicien moyen dans le sud de la péninsule (Fig. 1) (De Broucker, 1987). Ces déformations furent d'abord attribuées à " l'orogenèse Gaspésienne " (Ayrton, 1967), un terme maintenant abandonné. Elles sont maintenant considérées comme " taconiennes " (Rodgers, 1967; De Broucker, 1987).

Les déformations taconiennes ont pris fin durant l'Ordovicien moyen pour les roches du sud de la Gaspésie, mais se sont perpétuées jusqu'à l'Ordovicien supérieur pour des roches situées à moins de 100 km de là, dans le nord de la péninsule. En fait, selon Piqué *et al.* (1983), De Broucker (1987) et Bourque *et al.* (1993), ces roches étaient beaucoup plus éloignées les unes des autres au temps de l'orogenèse Taconique qu'elles ne le sont aujourd'hui, d'importants mouvements latéraux les ayant rapprochée subséquemment durant le Dévonien, au cours de l'orogenèse Acadienne.

Le sud et le nord de la péninsule ont donc une histoire tectonique légèrement distincte. Au sud, une succession stratigraphique d'âge Ordovicien moyen à Dévonien supérieur repose en discordance sur un socle d'âge fin-Précambrien à Ordovicien moyen. Au nord, une succession stratigraphique d'âge Ordovicien supérieur à Dévonien moyen repose en discordance sur un socle d'âge fin-Précambrien à Ordovicien supérieur. La Faille du Grand-Pabos, un grand décrochement dextre acadien orienté est-ouest (Malo *et al.,* 1992), sépare ces deux successions stratigraphiques (Fig. 1).

L'ensemble de ces roches fut affecté par les déformations transpressives acadiennes (Malo et Béland, 1989; Malo *et al.,* 1992, 1995; Malo et Kirkwood, 1995; Kirkwood *et al.,* 1995). Des études paléomagnétiques (Kent et Opdyke, 1985; Briden *et al.*, 1988; Kent et Keppie, 1988) et des données de terrain (Keppie, 1985, 1989; St-Jean *et al.,* 1993; Murphy *et al.,* 1995) suggèrent que ces déformations soient liées à la fermeture définitive de Iapétus au cours du Dévonien.

La fin du Dévonien moyen correspond à la fin des déformations dites 'acadiennes', mais le Groupe de Miguasha (Frasnien), dernière séquence de molasses nourrie par la chaîne Acadienne en Gaspésie, a été déformée subséquemment, avant le dépôt des unités d'âge Carbonifère (Brideaux et Radforth, 1970; Zaitlin et Rust, 1983; Hesse et Sawh, 1992; Prichonnet *et al.,* 1996). Bien que le Groupe de Miguasha soit en discordance sur les unités siluro-dévoniennes sous-jacentes, les déformations qu'il a enregistrées n'ont jamais été considérées comme 'post-acadiennes'. Les synthèses de Malo et Kirkwood (1995), Malo *et* *al.* (1995) et Kirkwood *et al.* (1995) n'évoquent pas de déformation compressive ou transcourante post-acadienne en Gaspésie.

Contexte géologique mississippien (Carbonifère inférieur)

Les roches d'âge Précambrien supérieur à Dévonien supérieur sont recouvertes en discordance par des dépôts d'âge Carbonifère (Fig. 1) faisant partie du bassin de Ristigouche (van de Poll, 1995), un sous-bassin du bassin des Maritimes. Ce dernier recouvre la majeure partie du sud-est du Canada (Fig. 2). La tectonique d'extension responsable de la formation du bassin des Maritimes et de ses sous-bassins est interprétée par certains auteurs comme le produit d'un 'rift avorté' lié à une compensation post-orogénique (Belt, 1968; Ruitenberg *et al.*, 1973; Howie et Barss, 1975; Poole, 1976; Ruitenberg et McCutcheon 1982; Fyffe and Barr, 1986; McCutcheon et Robinson, 1987; Durling et Marillier, 1993), et par d'autres comme directement liée à une tectonique de cisaillement concentrée sur la géofracture de Minas (faille de Cobequid-Chedabucto) en Nouvelle-Écosse (Ramsbottom, 1973; Arthaud et Matté, 1977; McMaster *et al.*, 1980; Fralick et Schenk, 1981; Bradley, 1982; Keppie, 1982; Gibling *et al.*, 1987; Ryan *et al.*, 1988; Pe-Piper *et al.*, 1989; Rust *et al.*, 1989; Reed *et al.*, 1993; Murphy *et al.*, 1995; Jutras et Prichonnet., soumis-b: Chapitre 4 de cette thèse).

Les premières données sur le Carbonifère de la Gaspésie ont été compilées par Logan (1846). Certaines unités du Dévonien moyen ont été alors confondues avec les unités du

Carbonifère. Alcock (1935) a fait la première cartographie détaillée de la baie des Chaleurs. Ses données tectonostratigraphiques et cartographiques du Carbonifère sont demeurées pratiquement inchangées jusqu'à récemment (Jutras *et al.*, 1999, 2001; Jutras et Prichonnet, soumis-a, b; chapitres 1 à 4 de cette thèse).

Alcock (1935) a subdivisé le Carbonifère en deux unités, les formations de Bonaventure et de Cannes-de-Roches, la seconde étant elle-même divisée en trois membres. La Formation de Bonaventure forme une ceinture discontinue autour de la Baie des Chaleurs (Fig. 3). Zaitlin et Rust (1983) ont démontré que la dépression de la baie des Chaleurs correspond approximativement aux limites de la paléovallée dans laquelle cette formation s'est déposée. Ce bassin sédimentaire sera plus tard nommé 'bassin de Ristigouche' par van de Poll (1995). Cette formation a été définie comme une succession de brèches, conglomérats, grès et mudstones, contrôlée par des escarpements de failles en milieu continental. L'absence de débris ou d'empreintes de plantes, une oxydation rouge pénétrante et une abondance de calcrètes pédogéniques suggèrent que cette formation se soit accumulée sous un climat tropical aride (Zaitlin et Rust, 1983).

Le même type de succession est observé dans les membres inférieur et moyen de la Formation de Cannes-de-Roches, bien que les clastes y soient typiquement plus anguleux. Le membre supérieur se démarque par sa couleur grise et une abondance de fragments de plantes carbonisés, traduisant l'absence de conditions oxydantes. Les affleurements de la Formation de Cannes-de-Roches n'ont été signalés que dans la dépression de la Malbaie

(Fig. 3). Selon Rust (1981), la paléovallée dans laquelle cette formation a sédimenté se serait étendue originellement jusqu'au niveau de Forillon.

Alcock (1935) a proposé que les formations de Bonaventure et de Cannes-de-Roches se soient accumulées à peu près à la même époque, mais dans deux vallées distinctes, une seule offrant les conditions nécessaires à la prolifération des plantes. Cette hypothèse, qui fut retenue par Rust (1981) dans une étude sédimentologique détaillée, n'a jamais été contestée avant la présente étude.

En accord avec les modèles très semblables d'Alcock (1935) et de Rust (1981), Kirkwood (1989) note une alternance de brèches et conglomérats rouges dans la région de Percé et les interprète comme étant le fait d'une interdigitation entre la Formation de Bonaventure et la Formation de Cannes-de-Roches. C'est cette proposition qui a été adoptée dans la synthèse générale de Brisebois *et al.* (1992) (Fig. 4).

Seul le Membre Supérieur de la Formation de Cannes-de-Roches contient des spores pour datation. Hacquebard (1972) a proposé un âge Namurien inférieur et M.R. Barss, dans Rust (1981), a plutôt suggéré un âge Viséen. C'est cette dernière attribution palynostratigraphique qui fut adoptée par Brisebois *et al.* (1992). Considérant la Formation de Cannes-de-Roches comme étant synchrone à la partie inférieure de la Formation de

Bonaventure, ces derniers auteurs ont placé les deux formations dans l'époque ([1]) du Viséen (Mississippien moyen) (Fig. 4).

Les auteurs précédents considéraient donc qu'un seul épisode de sédimentation, entièrement continental et ayant laissé deux formations synchrones, avait été enregistré dans la stratigraphie du Carbonifère de la Gaspésie. Avant la présente étude, ces unités étaient également considérées comme non-déformées, à l'exception de quelques réajustements causés par des failles normales (Bernard et Saint-Julien, 1976; Bourque et Lachambre, 1980; Gosselin, 1988; Rust *et al.*, 1989; Kirkwood, 1989; Peulvast *et al.*, 1996) et quelques micro-failles cisaillantes n'ayant pas causé de déplacements cartographiables (Faure *et al.*, 1996a).

Contexte géologique pennsylvanien (Carbonifère supérieur)

La fermeture de Théïc (extension sud de Iapétus), au cours du Pennsylvanien, a engendré les déformations dites 'alléghaniennes' dans le sud des États-Unis d'Amérique (Arthaud et Matté, 1977; Piqué, 1981; Lefort et Van der Voo, 1981; Russel et Smythe, 1983; Haszeldine, 1984; Kent et Opdyke, 1985; Lefort *et al.*, 1988; Kent et Keppie, 1988; Rodgers, 1988). Durant cette période, le bassin des Maritimes subissait des déformations transpressives (Piqué 1981; Ruitenberg and McCutcheon 1982; Plint and Van de Poll 1983; Yeo and Gillis 1984; Nance 1987; Nance and Waner 1986; Gibling *et al.*,

[1] L'échelle stratigraphique de Harland *et al.* (1990) est utilisée ici et ailleurs dans la thèse.

1987; Yeo and Ruixiang 1987; Ryan *et al.,* 1988; Thomas and Schenk 1988; Waldron *et al.,* 1989; Pe-Piper *et al.,* 1991; St. Peters 1993; Reed *et al.,* 1993). Au cours du Pennsylvanien, et jusqu'au Permien inférieur, une partie des produits d'érosion de la chaîne Alléghanienne s'accumulent dans le bassin des Maritimes (Thomas et Schenk, 1988; Gibling *et al,* 1992).

Contexte géologique post-carbonifère

Selon Ryan et Zentilli (1993), 1 à 4 km de la couverture sédimentaire permo-carbonifère du bassin des Maritimes ont été décapés depuis leur mise en place, la plus grande partie au cours d'un épisode d'érosion majeur qui s'est déroulé pendant le Permien, le Trias et le début du Jurassique, et qui serait associé à un bombement causé par le développement embryonnaire du rift Atlantique. Aujourd'hui, la couverture résiduelle des roches du Pennsylvanien n'atteint plus la Gaspésie (Fig. 3), et les roches du Permien inférieur sont maintenant limitées au coeur du bassin des Maritimes, au niveau de l'Île-du-Prince-Édouard et des Îles-de-la-Madeleine (Fig. 2).

Jutras et Schroeder (1999) ont proposé que la pénéplaine principale des Appalaches, la 'surface principale' de Grant (1989), soit le fait de cet épisode d'érosion s'étant achevé au Jurassique. Le Jurassique sera aussi témoin de l'ouverture de l'Atlantique, laquelle provoquera une nouvelle phase d'érosion, plus modérée, liée au soulèvement 'en bloc' et graduel des marges passives de cet océan (Peulvast *et al.,* 1996).

PROBLÉMATIQUE

Étude géomorphologique préliminaire

Cette étude doctorale donne suite à des indices paléoenvironnementaux relevés à l'intérieur d'une étude géomorphologique de Maîtrise (Jutras 1995). À l'intérieur de cette étude préliminaire, plusieurs hypothèses tectoniques et paléoenvironnementales furent émises à partir de l'identification des différents éléments morphologiques de deux paléosurfaces exhumées d'âge Dévonien supérieur à Carbonifère. Ces dernières sont situées dans le sud de la Gaspésie, sous le niveau de la principale pénéplaine appalachienne, laquelle est localement nommée 'Plateau Gaspésien' par Gray et Hétu (1985). Dans cette région, une surface continentale interprétée comme ayant évolué sous un climat tropical aride est séparée par un escarpement de faille d'une surface interprétée comme étant le fait d'une érosion marine côtière (Jutras 1995; Jutras et Schroeder, 1999).

Pour expliquer la disposition des paléosurfaces et de leur couverture clastique résiduelle, Jutras (1995) a proposé un modèle suggérant que les deux surfaces n'aient pas été fossilisées par le même épisode clastique, malgré que l'ensemble des dépôts en question soit alors cartographié comme faisant partie d'une seule unité stratigraphique, la Formation de Bonaventure. Selon cette étude, deux épisodes clastiques d'âge Dévonien supérieur à

Carbonifère, dont un serait lié à d'importants mouvements de failles normales, auraient été séparés par une transgression marine.

Hypothèses et objectifs de travail

Le modèle proposé par Jutras (1995) se heurtait à la documentation géologique du Carbonifère de la Gaspésie, laquelle ne reconnaissait qu'un seul épisode de sédimentation, entièrement continental (Alcock 1935; Rust 1981, 1982; Zaitlin et Rust 1983; Rust *et al.*, 1989; van de Poll 1995). Le modèle est par-contre compatible avec la tectonostratigraphie du Carbonifère des Provinces Maritimes, où une série d'épisodes de sédimentation clastique continentale, à l'intérieur de nombreux grabens (Groupe de Horton; Dévonien supérieur et Tournaisien), a été suivie par une vaste transgression marine épicontinentale (sédimentation des groupes de Windsor et de Codroy; Viséen moyen à Namurien inférieur), puis par un retour a une sédimentation clastique continentale (les groupes de Mabou, Cumberland et Pictou; Namurien à Permien inférieur) (Howie and Barss, 1975; Durling et Marillier, 1993; St. Peter, 1993; van de Poll, 1995).

Cette compatibilité du modèle géomorphologique avec les données stratigraphiques des Provinces Maritimes a donc encouragé a développer le volet sédimentaire du présent projet de recherche. Il est en effet vraisemblable que la transgression viséenne ait pu s'étendre jusqu'au sud de la Gaspésie, puisqu'on retrouve des dépôts associés à celle-ci jusqu'au nord du Nouveau Brunswick (Howie and Barss, 1975). Une révision générale de la stratigraphie et de la sédimentologie du Carbonifère de la Gaspésie a donc été entreprise pour vérifier si cohérence il y a avec le modèle géomorphologique. Le projet avait comme second but de vérifier si les déformations transpressives alléghaniennes, qui sont également enregistrées jusque dans le nord du Nouveau Brunswick (Durling et Marillier , 1993), n'avaient pas aussi affecté la Gaspésie.

L'hypothèse de travail du présent projet de recherche était donc que l'histoire géologique du Carbonifère de la Gaspésie est possiblement plus complexe que ne le laissaient supposer les données géologiques publiées antérieurement. L'idée qu'une transgression marine et des coulissages post-acadiens aient pu affecter la Gaspésie est intéressante pour l'étude du potentiel pétrolier de la baie des Chaleurs, de par les possibilités de pièges stratigraphiques et structuraux qu'elle implique.

APERÇU SUR LES MÉTHODES DE TRAVAIL

Le projet qui a été entrepris cherche donc à retracer l'évolution paléoenvironnementale et tectonostratigraphique du Carbonifère de la Gaspésie en s'appuyant sur une révision générale des unités lithologiques qui reposent en discordance sur les structures acadiennes. La méthodologie employée est conforme aux études traditionnelles de terrain en sédimentologie des formations terrigènes clastiques et en tectonique cassante.

Les chapitres 1 à 3 sont basés sur (1) l'étude ponctuelle des affleurements, (2) l'établissement de colonnes stratigraphiques synthétiques, (3) la reconnaissance cartographique dans quelques secteurs clés, (4) l'analyse morphologique des surfaces sous-jacentes aux dépôts, (5) les mesures de paléocourants, (6) l'étude d'environ 200 lames minces, (7) des analyses minéralogiques au microscope à balayage électronique (MEB) et au diffractomètre à rayons-X, (8) des inventaires palynologiques et une identification paléontologique, et (9) des analyses géochimiques des isotopes stables et des terres rares.

Le Chapitre 4 est basé sur (1) la reconnaissance de déplacements de contacts stratigraphiques, (2) les mesures de plans de failles, de stries, de pendage des lits et d'axes de plis (présentées dans l'Appendice VI), et (3) l'analyse de projections stéréographiques. Les différentes méthodes de travail seront explicitées en plus grand détail à l'intérieur des différents chapitres de la thèse, en relation avec leur problématique spécifique.

APERÇU SUR LES CHAPITRES DE LA THÈSE

Au niveau des apports stratigraphiques, l'étude a permis d'identifier trois nouvelles unités post-acadiennes (les formations de Paspébiac, de La Coulée et du Chemin-des-Pêcheurs), et d'en redéfinir une, puisque les membres inférieur et moyen de la Formation de Cannes-de-Roches sont maintenant attribués à la Formation de Bonaventure, tandis que le membre supérieur est renommé Formation de Pointe Sawyer. Au point de vue tectonique, les recherches ont mené à l'identification de trois systèmes de failles transcourantes affectant l'ensemble de la succession stratigraphique nouvellement redéfinie, avec déformations compressives associées (Figure 4). Les résultats sont exposés à l'intérieur des quatre chapitres de thèse, lesquels correspondent à autant de manuscrits d'articles soumis à des revues avec comité de lecture, les deux premiers étant publiés et les deux suivant soumis.

Le premier chapitre introduit la Formation de La Coulée, une unité clastique continentale d'au moins 60 m d'épaisseur recouverte de façon discordante par la Formation de Bonaventure et affectée par une calcrétisation d'eau souterraine pénétrante. Ce type de calcrètes d'eau souterraine (*groundwater calcrete*), massives et épaisses de plusieurs mètres, est identifié pour la première fois à l'intérieur de sédiments pré-quaternaires. Ce chapitre présentera les caractéristiques sédimentologiques des faciès bréchiques et conglomératiques inclus à l'intérieur de la Formation de La Coulée et une étude pétrographique des calcrètes. Une définition du contexte tectonostratigraphique de cette nouvelle unité est proposée.

Le deuxième chapitre est une révision sur la relation stratigraphique entre les formations de Bonaventure et de Cannes-de-Roches. L'abandon de la Formation de Cannes-de-Roches y est proposé, ses membres inférieur et moyen étant corrélés à la Formation de Bonaventure, et son membre supérieur étant corrélé à une nouvelle unité, la Formation de Pointe Sawyer. Cette formation est définie comme une unité clastique contenant des fragments de plantes et reconnue comme recouvrant en discordance de ravinement la Formation de Bonaventure. Le chapitre introduit également une unité sus-jacente à la Formation de Pointe Sawyer, la Formation du Chemin-des-Pêcheurs. Cette dernière représente un retour à des conditions environnementales arides et oxiques et correspond au début d'une sédimentation plus distale que celle caractérisant les unités post-acadiennes sous-jacentes.

Des données de paléocourant prises à l'intérieur de la Formation de Bonaventure permettent de définir deux bassins incluant la même succession d'unités post-acadiennes dans la région gaspésienne, et ainsi d'introduire le Bassin de Cannes-de-Roches, adjacent au Bassin de Ristigouche de van de Poll (1995). Finalement, des corrélations palynostratigraphiques et tectonostratigraphiques avec les unités des Provinces Maritimes sont proposées à l'intérieur de ce chapitre pour les formations de La Coulée (Groupe de Windsor), de Bonaventure (Windsor ou Mabou), de Pointe Sawyer et du Chemin-des-Pêcheurs (Groupe de Mabou).

Le troisième chapitre introduit la Formation de Paspébiac, une unité clastique rouge dont les lits supérieurs karstifiés ont subséquemment été digérés par une calcrète d'eau souterraine typique de celle qui perturbe la base de la Formation de La Coulée. Dans l'état actuel des connaissances, la Formation de Paspébiac constitue la base de la stratigraphie du Carbonifère de la Gaspésie. L'étude sédimentologique d'une série de colonnes stratigraphiques de la Formation de Paspébiac est exposée à l'intérieur de ce chapitre. Des schémas paléogéographiques sur l'évolution tectonostratigraphique du Carbonifère de la Gaspésie sont également proposés.

Le quatrième chapitre décrit trois systèmes de failles transcourantes post-acadiennes, regroupées selon leur orientation et leur cinématique, et définies à l'intérieur de trois secteurs de la Gaspésie. Les failles principales n'étant que très rarement exposées, l'analyse cinématique est surtout basée sur l'étude de structures cisaillantes et compressives subordonnées. Ces déformations transpressives qui ont fragmenté le bassin de Ristigouche et qui l'ont juxtaposé au bassin de Cannes-de-Roches.

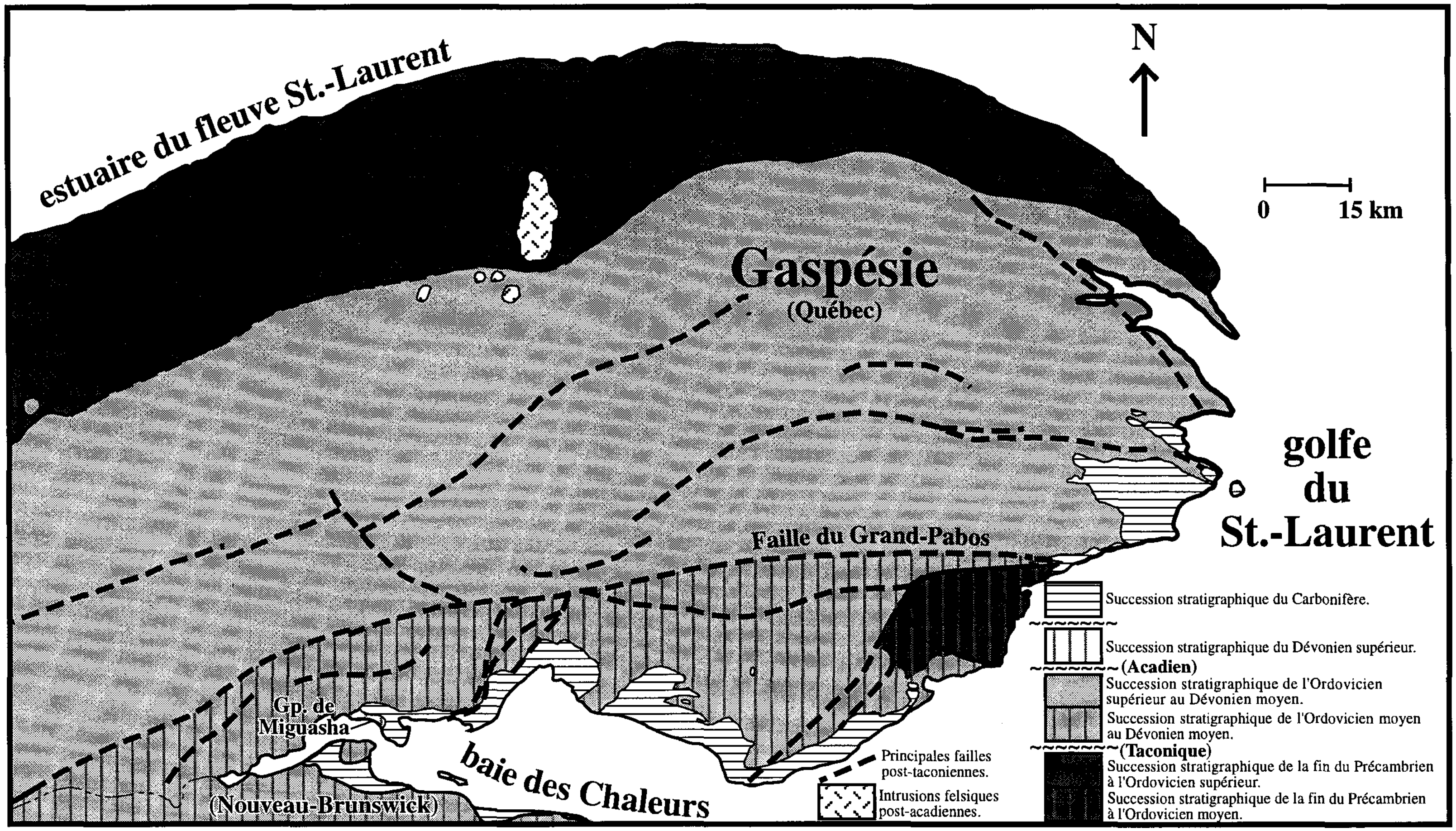

Fig. 1. Géologie simplifiée de la Gaspésie. Modifié de Brisebois *et al.* (1992), pour la partie québécoise, et de Potter *et al.* (1979), pour le Nouveau-Brunswick.

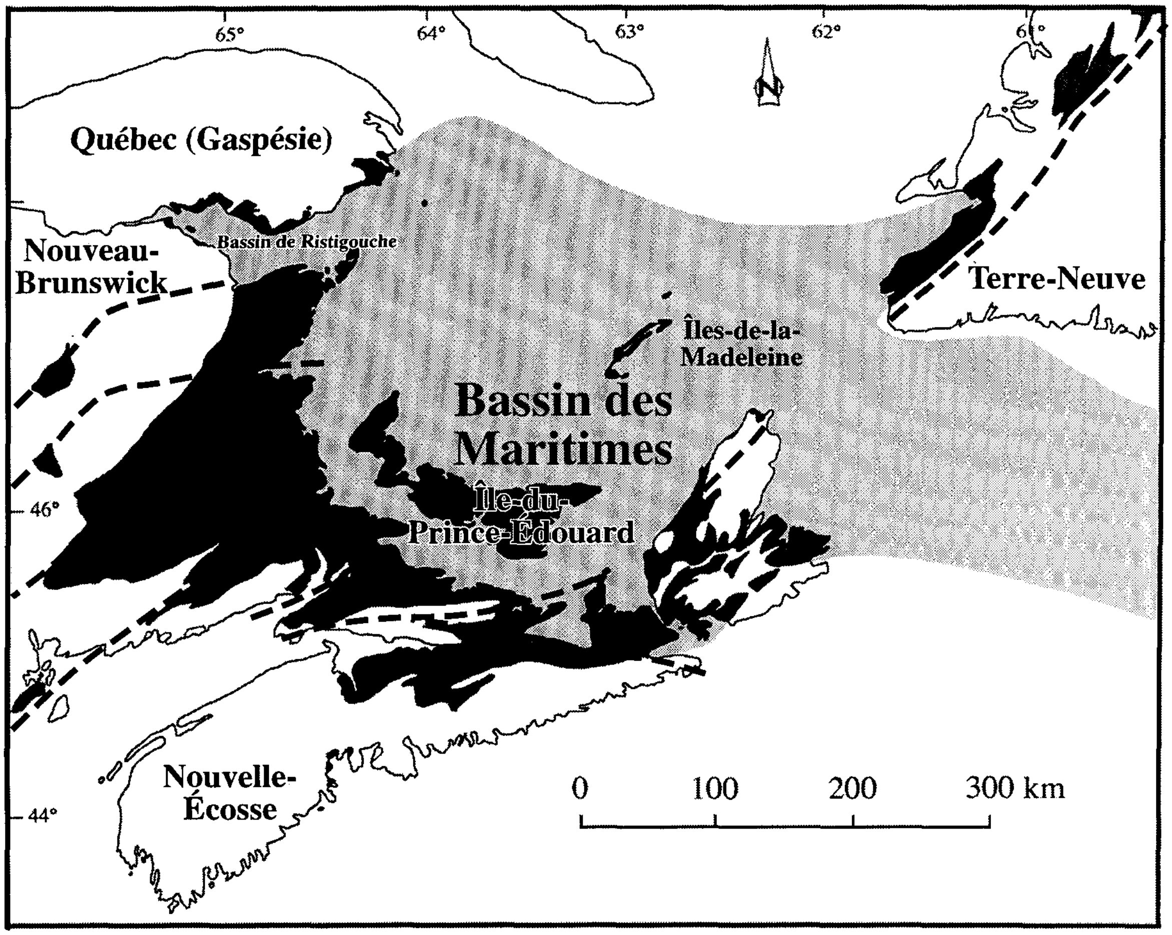

Fig. 2. Couverture continentale (gris-foncé) et sous-marine (gris pâle) du Bassin des Maritimes, d'âge Permo-Carbonifère. Les principales failles post-acadiennes reconnues avant la présente étude sont identifiées par un tireté. Modifié de Gibling *et al.* (1992).

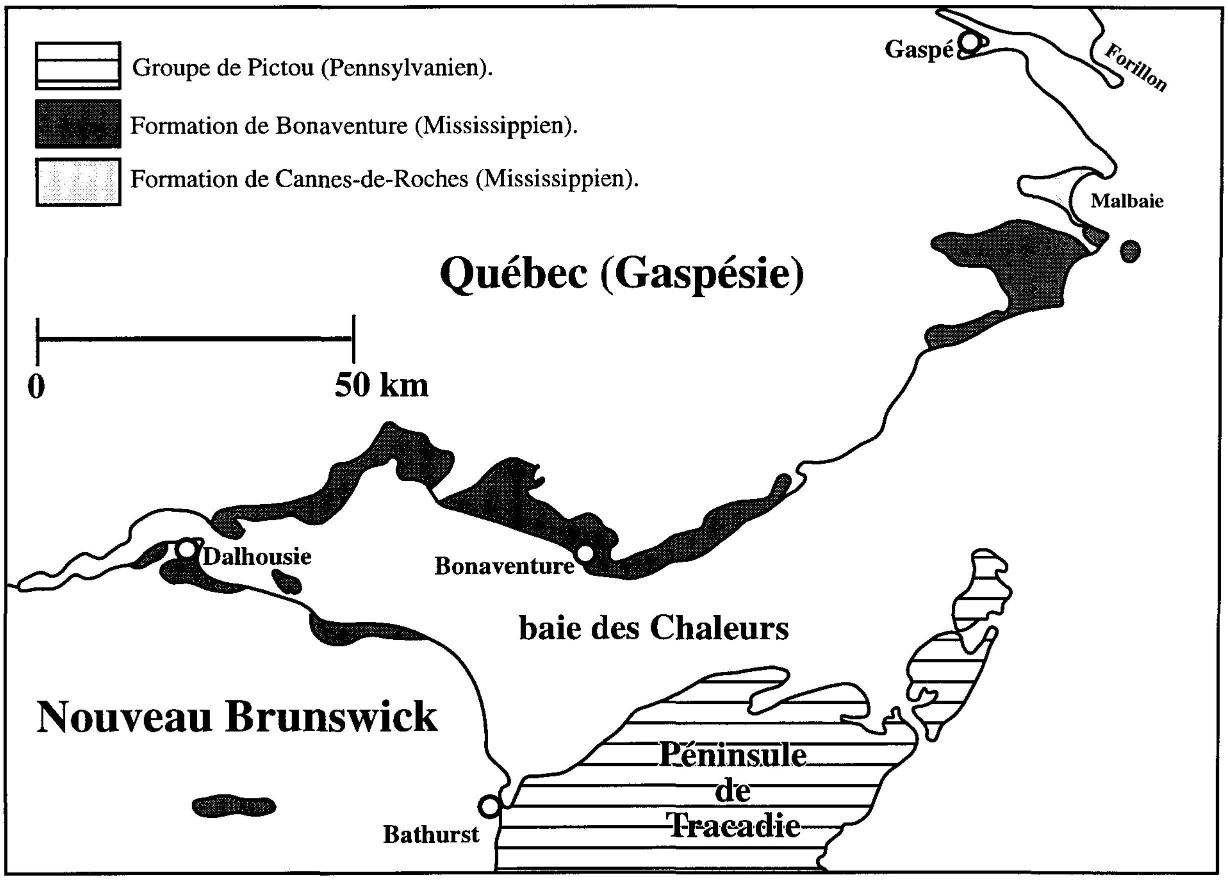

Fig. 3. Unités du Carbonifère en Gaspésie et dans le nord du Nouveau Brunswick selon Rust *et al.* (1989). Modifié de Rust *et al.* (1989) et de Potter *et al.* (1979).

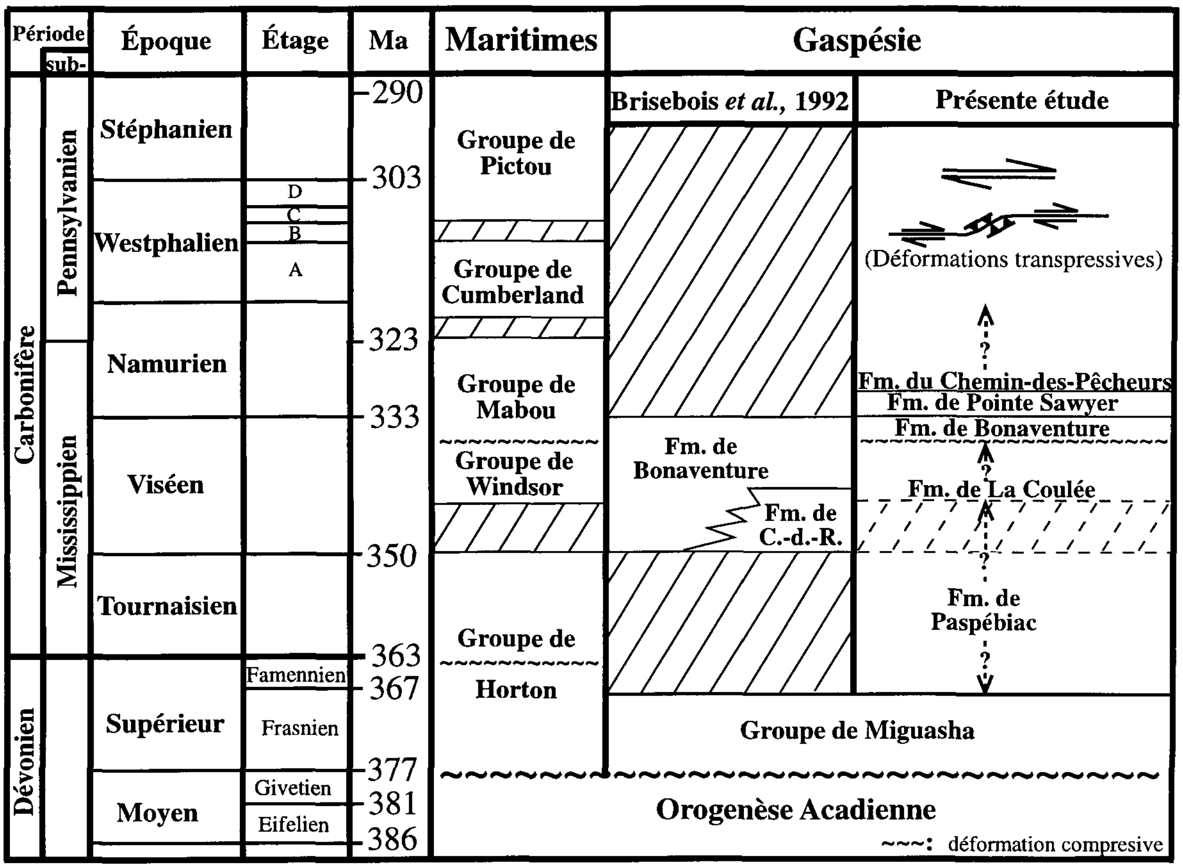

Fig. 4. Tableau stratigraphique du Paléozoïque supérieur dans le Provinces Maitimes et en Gaspésie. L'échelle chronologique, avec étages selectionnés, est tirée de Harland *et al.* (1990). Fm. de C.-d.-R.: Formation de Cannes-de-Roches.

CHAPITRE I

THE LA COULÉE FORMATION, A NEW POST-ACADIAN CONTINENTAL CLASTIC UNIT BEARING GROUNDWATER CALCRETES, GASPÉ PENINSULA, QUÉBEC

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1.1 ABSTRACT

A 1 km^2 erosional remnant of the La Coulée Formation, a previously unrecognized stratigraphic unit, has been studied in the Percé area of the Gaspé Peninsula. It unconformably overlies folded Cambrian to Devonian rocks and is unconformably overlain by the mid-Carboniferous Bonaventure Formation. The erosional remnant includes the lowest 60 m of this newly identified formation of unknown thickness. Original sedimentary facies are limited to 50 m of breccia debris flows passing stratigraphically upward into 10 m of conglomeratic debris flows. Groundwater calcrete formation has partially or completely transformed the lowest 30 m of the succession. The depositional environment is interpreted as being related to a proximal continental alluvial fan. The nearby presence of a saline body of water is inferred to account for thick and massive groundwater calcrete formation and water-saturated debris flows in a relatively arid climatic context. Most of the formation was eroded prior to deposition of the Bonaventure Formation. However, the basal groundwater calcretes were more widely preserved. They underlie the Bonaventure Formation in most of the Percé area and in the Saint-Elzéar area, close to a hundred kilometres to the southwest. Post-sedimentary faulting has affected both the La Coulée and Bonaventure formations.

1.2 RÉSUMÉ

La Formation de La Coulée, une unité stratigraphique nouvellement répertoriée, a été étudiée à l'intérieur d'une masse résiduelle de 1km^2 dans la région de Percé en Gaspésie. La séquence recouvre en discordance des roches plissées du Dévonien Inférieur et elle est recouverte en discordance par la Formation de Bonaventure qui est attribuée au Carbonifère moyen. La masse résiduelle inclue les 60 premiers mètres de cette formation nouvellement identifiée et d'une épaisseur inconnue. Les faciès sédimentaires originels sont limités à cinquante mètres de coulées de débris bréchiques, passant à une dizaine de mètres de coulées de débris conglomératiques. La formation d'une calcrete phréatique affecte les premiers 30 mètres de la séquence, lesquels sont en partie ou complètement transformés. L'environnement sédimentaire est interprété comme étant lié à un cône de déjection continental dans sa partie proximale, mais la présence non-lointaine d'un plan d'eau salée est suggérée pour expliquer la formation de calcretes phréatiques épaisses et massives, ainsi que la saturation en eau des coulées de débris dans un contexte climatique relativement aride. La formation a presqu'entièrement été érodée avant que ne survienne la sédimentation de la Formation de Bonaventure. Toutefois, la base de calcrete a été plus largement préservée, ce qui fait qu'on la retrouve sous la Formation de Bonaventure presque partout dans la région de Percé ainsi que dans la région de Saint-Elzéar, à presqu'une centaine de kilomètres au sud-ouest. Des failles post-sédimentaires ont affecté à la fois la Formation de La Coulée et la Formation de Bonaventure.

1.3 INTRODUCTION

The Gaspé Peninsula of eastern Québec is located at the northwestern periphery of the upper Paleozoic Maritimes Basin and its subbasins (Fig. 1.1a). Prior to this study, the Carboniferous record in the Gaspé Peninsula included only two formations, namely the Bonaventure and Cannes-de-Roches formations (Fig. 1.1b). The post-Acadian stratigraphy of the Gaspé Peninsula, in which major hiatuses are recorded, has received much less attention than that of the Maritime Provinces over the last century (Table 1.1).

A 1 km^2 erosional remnant of a new stratigraphic unit has been identified in the Percé area. Resting unconformably on folded Cambrian to Devonian rocks, it is related to a post-Acadian sedimentation event. The lowermost section of this unit is occupied by a calcrete of several metres in thickness. Two similar calcretes, underlying the Bonaventure Formation at other localities, were also identified. This paper provides a sedimentological and tectonostratigraphic analysis of the newly recognized unit, which we herein formally name the La Coulée Formation (Appendix I).

1.4 GEOLOGICAL SETTING

The oldest rocks in the Percé area are the Murphy Creek and Corner-of-the-Beach formations, both of Cambrian age (Kindle, 1942). They form a small inlier unconformably overlain by a succession of Siluro-Devonian rocks that occupies most of the southern half of the Gaspé Peninsula. Both sets of rocks were involved in the mid-Devonian Acadian orogeny, which is related to the final closure of the Iapetus Ocean (Kent and Opdyke, 1985; Briden *et al.,* 1988; Kent and Keppie, 1988).

The stratigraphic record of the Gaspé Peninsula (Table 1.1) currently does not account for the Late Devonian through early Viséan extensional tectonics and thick clastic sedimentation, which occurred intermittently in the rest of southeastern Canada, and to which the Horton Group and equivalent units are related. There is also no record of the mid-Viséan transgression that deposited the Windsor Group limestones and evaporites in New Brunswick, Nova Scotia and Québec (in the Magdalen Islands), and the Codroy Group limestones and evaporites in Newfoundland.

Prior to this study, the Bonaventure and Cannes-de-Roches formations (Fig. 1.1b and Table 1.1) were regarded as the first records of post-Acadian sedimentation after the synorogenic, Frasnian age Miguasha Group (Brideaux and Radforth, 1970). Although the stratigraphic relationship between the Bonaventure and Cannes-de-Roches formations is not clear, they are considered as probably synchronous (Rust, 1981; Rust *et al.,* 1989). Only the upper member of the Cannes-de-Roches Formation is unoxidized and has provided spores for dating. Hacquebard (1972) suggested an early Namurian age for the spores, whereas Barss (in Rust, 1981) suggested a mid- to late Viséan age. Both formations are interpreted as the product of fault-related continental clastic sedimentation in two distinct Carboniferous paleovalleys (Rust, 1981; Zaitlin and Rust, 1983).

Few attempts have been made to correlate the post-Acadian successions of eastern Québec with the well established stratigraphy of the Maritime provinces. Howie and Barss (1975) considered the Miguasha Group to be a Horton Group equivalent. They correlated the Bonaventure and Cannes-de-Roches formations with the Canso-Riversdale groups (Mabou-Cumberland, *sensu* Ryan et al., 1991) based on their age (early Namurian, Hacquebard, 1972) and their nonmarine nature. Van de Poll (1995) considered the Bonaventure as a Windsor-Canso (Winsor-Mabou) groups equivalent, and the Cannes-de-Roches as a Canso-Riversdale (Mabou-Cumberland) groups equivalent.

1.5 SEDIMENTOLOGY OF THE LA COULÉE FORMATION IN THE MONT SAINTE-ANNE SUCCESSION

A ~60 m-thick succession has been observed at numerous outcrops on the northern side of Mont Sainte-Anne, which overlooks the village of Percé. The best outcrops are located in a deep gully occupied by a creek with waterfalls. The creek is unnamed but its main waterfall is named La Coulée. It is therefore referred to as the La Coulée Creek, and the newly identified formation over which it flows is referred to as the La Coulée Formation. This unit has been divided into three main facies (Fig. 1.2a), as defined below. The only exposure of the unconformable contact between the Mont Sainte-Anne succession of the La Coulée Formation and the underlying basement is located at the 10 m-high La Coulée waterfall (Figs. 1.2c and 1.3), a vertical section located a few hundred metres west of Percé.

The basement consists of subvertical green mudstones (strike 275°, dip 80°) mapped as the Early Devonian Indian Point Formation by Kirkwood (1989). The overlying La Coulée Formation rests on this basement with a 60° angular unconformity. It is poorly stratified and the 'beds' dip gently towards the south-southwest (strike 295°, dip 20°).

1.5.1 Massive groundwater calcrete facies (0-11 metres)

The contact of the La Coulée Formation with the basement shows a sharp passage from brecciated green mudstone in the basement, with only minor calcite infiltrations (Fig. 1.3a), to mature calcrete with a few silicified, fossiliferous limestone clasts of ~1 cm maximum diameter (Fig. 1.3c). The lowermost 2 m of the section also include abundant intraclasts of calcrete (Fig. 1.3d).

Between 2.0 and 2.5 m, non-calcrete clasts are larger and more abundant but are still floating in a calcrete matrix. Sparse clasts of calcareous sandstones and calcareous mudstones of up to 10 cm maximum diameter are overlain by several large biocalcilutite blocks of up to 40 cm maximum diameter, all of the same lithology and parallel to the bedding.

The 2.5 - 5 m interval is mainly occupied by brecciated calcrete, analogous to that of the 0 - 2 m interval (Fig. 1.3d), with only a few sparse clasts of slightly fossiliferous microsparite.

The uppermost 1 m of the section is mainly pure calcrete, but two large tabular clasts of biosparudite (Fig. 1.3e) were observed, the largest being ~1 m in maximum diameter. They are dominated by bryozoans, brachiopods, crinoids, echinoderms and ostracodes. Correlation with regional basement rocks could not be determined but conodont genus *Icriodus* (Fig. 1.3e) loosely constrains the age of the biosparudite between Late Silurian (Pridolian) and Late Devonian (Famennian) (Clark *et al.,* 1981). Many discontinuous laminar structures and ooids are present in this upper part of the outcrop.

Numerous outcrops can be observed for 500 m upstream from the La Coulée waterfall. The slope of the creek bed is steeper than the dip of the La Coulée Formation for the first 250 m upstream and, thus, the outcrops represent progressively higher stratigraphic levels (Fig. 1.2b). The creek then becomes less steep and cuts back into lower stratigraphic levels. It is estimated that the base of the highest outcrop upstream represents approximately the same stratigraphic level as at the top of the waterfall, although the calcrete facies masks original stratification and only allows imprecise correlation.

The lowest stratigraphic levels exposed upstream from the waterfall (6-11 m) are occupied by a stratiform calcrete where all features of the host sediment have been destroyed (Fig. 1.4a, b). The calcrete is mainly characterized by structureless microsparite; however, numerous coated grains and discontinuous laminar structures can here again be observed.

According to Wright and Tucker (1991), the only calcretes known to exceed 3 metres in thickness are 'groundwater calcretes'. The calcrete developed in the La Coulée Formation is therefore regarded as the non-pedogenic product of groundwater circulation.

Local silicification is typical of groundwater calcretes (Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989; Wright and Tucker, 1991) and is most probably responsible for the preservation of the limestone clasts. Figure 1.3e indicates how siliceous calcrete clasts observed throughout the calcrete are formed directly from the host sediment by mineral replacement. A siliceous coating formed *in situ* protects the clast from further mineral replacement. This silica is probably issued from disseminated host sediment quartz grains that were dissolved by groundwaters, replaced by calcite, and subsequently precipitated in concentrated areas. The observation on thin sections of quartz grains half replaced by calcite supports this conclusion.

Abundant intraclasts of calcrete, related to karstic collapsing, are also typical of groundwater calcretes (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Arakel *et al.*, 1989; Wright and Tucker, 1991), although brecciation also appears in pedogenic forms but is then usually root-induced (Wright and Tucker, 1991).

The discontinuous laminar structures do not correspond to any of the three types of laminar calcretes defined by Wright *et al.* (1988), namely (1) the 'surficial laminar calcretes', formed at the bedrock-atmosphere interface, (2) the 'pedogenic laminar calcretes', usually formed over hardpans in soils, and (3) the 'capillary rise-zone laminar calcretes', forming a continuous horizon immediately over the water table. They correspond most closely to the 'ribbon-like geometries' described by Wright and Tucker (1991) for groundwater calcretes, which they interpret as the product of lateral shifts of groundwater flow in response to the profile becoming progressively plugged by cementation. Being associated with coated grains, they were probably formed in the vadose zone. Peryt (1983) referred to such coated grains as 'vadoids'.

1.5.2 Grey limestone breccia facies (11-50 m)

The 11 to 30 m stratigraphic levels are occupied by very poorly sorted, clast-supported grey limestone breccia with a calcretized matrix. It is only at about the 30 m stratigraphic level that the original sedimentary matrix is unaffected by calcrete replacement (Fig. 1.4c, d). This facies is rather uniform, with sporadic more rounded intervals within the next 20 m, up to the 50 m stratigraphic level, based on outcrops along various roads across Mont Sainte-Anne.

Only limestone clasts were recognized, most of them typical of the Ordovician to Silurian White Head Formation calcilutites, and some rare quartz granules and sands. The finest fraction of the non-calcretized matrix contains sparse goethite and marcasite, which gives the matrix a yellowish colour, but no hematite. Based on X-ray diffractometry, kaolinite forms 8-10% of the matrix, which suggests deep weathering under relatively warm and humid conditions.

For a given stratigraphic level, clasts become smaller south-southwest upsteam along La Coulée Creek. Close to the waterfall, abundant clasts of more than 50 cm maximum diameter can be found, whereas 500 m upstream, they rarely exceed 10 cm. Clasts exceeding 5 cm diameter are usually sub-angular to sub-rounded while smaller clasts range from very angular to sub-rounded (Fig. 1.4d).

We interpret the grey to yellowish-grey breccia forming the 30-50 m stratigraphic levels as a succession of several mud-poor debris flows. The wide lateral extent of the beds, the lack of erosional bases and the tendency for large clasts to be flat-lying, all suggest laminar rather than turbulent (" floating plug ") flow (Enos, 1977). The scarcity of fine mud and the tendency for a parallel-to-flow fabric imply that water was abundant when the flows were initiated (Wells, 1984; Nemec and Steel, 1984).

1.5.3 Grey limestone conglomerate facies (50-60 m)

A 5 m thick by 10 m wide outcrop of massive grey to greenish-grey limestone conglomerate is exposed on the eastern flank of Mont Sainte-Anne (Fig. 1.4e, f) and represent the 55-60 m stratigraphic levels of the La Coulée Formation. The unit therefore has a minimum thickness of approximately 60 m (see composite column, Fig. 1.2a);

extrapolation of the extra 5 m of conglomerate underlying the uppermost 5 m-thick section was made from small outcrops on the road that leads to Mont Sainte-Anne summit.

The conglomerate is neither well sorted nor well packed (matrix- to clast-supported) and is poorly imbricated. It ranges between the Gmg (matrix-supported gravel) and the Gci (clast-supported gravel) facies of Miall (1996). It does not show clear internal stratification (planar or cross-bedding) or interbeds of sandstone or gravelly sandstone, which would reveal flow variations and vertical aggradation. The sandy to granular matrix lacks fine silts and clays. The clasts, mainly limestone with occasional calcareous sandstone and calcareous mudstone, are sub-rounded but generally have low sphericity. They are mainly blade-shaped. Some of the larger casts are oriented vertically, although surrounded by smaller fractions (Fig. 1.4e). The above-mentioned traits pertain more to debris flow than channelized fluvial environments, but could also pertain to ephemeral, high-energy sheetfloods (Miall, 1977, 1996; Wasson, 1977; Ethridge and Wescott, 1984; Harvey, 1984; Kleinspehn *et al.*, 1984; Nemec and Steel, 1984).

The entire 5 m high section is massive. Two small lenses of laminated sandstone, at different levels, are the only indication that the section does not represent only one single depositional event. One of them has partially crumbled under the subsequent flow. We interpret these two lenses, which are 4 and 10 cm in maximum thickness, as surficial run-off subsequent to debris flows or flash floods. A high frequency of flows would prevent sufficient consolidation between two events and explain the lack of demarcation between flows.

1.6 PERCÉ-BEACH CALCRETE

The sea-cliff directly south of Percé, less than 2 km from the La Coulée waterfall, exposes the unconformable contact between the Carboniferous Bonaventure Formation and the underlying Matapedia limestone basement. A basal limestone unit up to 5 m thick, first reported by Kirkwood (1989), separates the Bonaventure Formation red clastics from the basement (Fig. 1.5a-c). This limestone unit has been interpreted as a massive pedogenic calcrete (P.A. Bourque, personal communication, 1998). However, based on its thickness, abundance of silica, absence of soil profile and plant-induced features, and on current classifications (Wright and Tucker, 1991), we interpret it as a non-pedogenic groundwater calcrete.

The Percé-Beach calcrete apparently differs from the basal calcrete of La Coulée Creek from the fact that it is not covered by the rest of the La Coulée Formation but by the seemingly conformable Bonaventure Formation red clastics. However, a probable continuation of the same basal calcrete, 4 km away, shows a stepped topography (i.e. the surface shows a succession of step-like levels) under the Bonaventure Formation on the northern tip of Bonaventure Island, revealing an erosional discontinuity. This suggests that the basal groundwater calcrete formed prior to the deposition of the Bonaventure Formation. The latter formation would therefore not be its host sediment.

From an apparent stratigraphic continuity with the La Coulée Creek calcrete, the calcrete underlying the Bonaventure Formation at Percé-Beach is most likely an erosional remnant of the La Coulée Formation. In more dissected regions, groundwater calcretes often cap mesas, thus revealing their high resistance to erosion (Mann and Horwitz, 1979). Being more resistant to erosion than the rest of the overlying La Coulée Formation, it was therefore more widely preserved during the pre-Bonaventure erosion.

Large calcrete clasts up to 70 cm maximum diameter are found in sandy to microconglomeratic matrix within the Bonaventure Formation (Fig. 1.6a, b) on the south side of Cap d'Espoir (Fig. 1.1b), approximately 15 km from Percé. The paleosurface underlying the Bonaventure Formation in this area is very irregular and these large pieces are most likely derived from local paleorelief. This supports the hypothesis that the erosional remnants of the calcrete base had a larger extent than the rest of the La Coulée Formation and that it is not necessary to hypothesize a second groundwater calcrete formation event to account for the sporadic presence of thick groundwater calcretes underneath the Bonaventure Formation (Fig. 1.7a).

1.7 TECTONOSTRATIGRAPHIC SETTING OF THE LA COULÉE FORMATION IN THE PERCÉ AREA

The La Coulée Formation is limited by faults along its northern and southern margins (Fig. 1.7b, c). The previously unidentified southern fault, here referred to as the Mont Sainte-Anne Fault, cuts across Mont Sainte-Anne, leading to the juxtaposition of the grey limestone breccia and conglomerates of the La Coulée Formation and the red sandstones and conglomerates of the Bonaventure Formation. The latter may be traced in nearly continuous outcrops along the creeks of the area and on the Mont Sainte-Anne cliffs, from Percé-Beach to the top of the hill, indicating a minimum thickness of 350 m (Fig. 1.7a).

The two formations differ not only in terms of colour, structure, stratigraphy and stratigraphic position, but also in terms of clast composition: as was mentioned earlier, all gravels in the La Coulée Formation conglomerates are composed of clasts of limestone, calcareous mudstone or calcareous sandstone, whereas these lithologies comprise between 65% and 80% of the Bonaventure Formation conglomerates at Percé (based on three petrographic counts). The Bonaventure Formation conglomerates are readily distinguished from those of the La Coulée Formation by the presence of 10-20% of rounded quartz pebbles. Most conglomeratic beds of the Bonaventure Formation, at all locations, also include sparse but highly visible red jasper pebbles.

At the coast, the Mont Sainte-Anne fault (Fig. 1.7b, c) separates the Cambrian Murphy Creek Formation from the Bonaventure Formation (Fig. 1.8, cross-section A-B).

Further west, just north of the La Grotte amphitheatre, the fault separates the calcrete base of the La Coulée Formation from its conglomeratic upper beds (Fig. 1.8, cross-section E-F). It then cuts through the Bonaventure Formation on the northern side of Mont Blanc (Fig. 1.7b, c). The Mont Saint-Anne Fault is well defined on air photos but outcrops are not preserved along the fault line.

At the base of the La Grotte amphitheatre, south of the Mont Saint-Anne Fault, a 15° degree angular unconformity between the Bonaventure Formation and the underlying La Coulée Formation conglomerates can be observed (Fig. 1.8, cross-section A-B). North of the fault, this unconformity has not been documented but is inferred to the west.

Finally, the grey limestone breccia of the La Coulée Formation is separated from the red breccia of the Bonaventure Formation by a splay of a northern fault system (Fig. 1.8, cross-section C-D), previously unidentified, which is most probably the eastern extension of the east-west trending Grande-Rivière Fault system attributed to the Acadian deformation (Malo and Béland, 1989; Malo *et al.*, 1992, 1995; Kirkwood and Malo, 1995; Kirkwood *et al.*, 1995).

1.8 THE SAINT-ELZÉAR CALCRETE

Close to a hundred kilometres southwest of Percé (Fig. 1.1b), the village of Saint-Elzéar is situated on an exhumed Carboniferous paleosurface interpreted as the product of marine erosion (Jutras, 1995; Jutras and Schroeder, 1999). It is a key area since a residual hill of Bonaventure Formation red clastics lies on the hypothetical wave-cut platform just 1 km away from an exhumed Carboniferous coastal-cliff that locally marks the maximum extent of the postulated Carboniferous paleomarine invasion (Fig. 1.9).

The base of the hill was investigated in detail in an attempt to find some sedimentological evidence for this proposed transgressive event. A 10-12 m-thick, flat-lying calcrete base was identified (Fig. 1.10a-c) overlying the steeply dipping green mudstones mapped as the Silurian Weir Formation (Bourque and Lachambre, 1980). This calcrete is also interpreted as non-pedogenic since it largely exceeds 3 m in thickness. Like the calcretes of La Coulée Creek and Percé-Beach, it is lying directly on relatively fresh basement (the direct contact is not exposed but has been confirmed by excavation), which also indicates that it was not formed within a soil profile.

The calcrete is stratiform and gives an impression of sedimentary bedding. The host sediment has, however, been thoroughly digested by the calcretization front. The result is a very mature calcrete, composed of more than 98% calcite, that has entirely obscured the nature of the host sediment.

Apparent conformity of the calcrete with the overlying Bonaventure Formation is denied by the fact that a small outcrop on the north side of Duval River (Fig. 1.10a), less than 500 m from the exposure of groundwater calcrete, shows red clastics lying directly on the mudstone basement. Such an abrupt discontinuity is best explained by pre-Bonaventure Formation erosion.

1.9 GEOCHEMISTRY OF THE LA COULÉE CREEK, PERCÉ-BEACH AND SAINT-ELZÉAR CALCRETES

1.9.1 Stable isotopes

Insufficient work has been done on the stable isotopes of groundwater calcretes to derive solid paleoenvironmental conclusions (Wright and Tucker, 1991). Stable isotope data for the brecciated calcrete facies of the La Coulée waterfall section clearly shows the difference between the remaining marine limestone clasts of the host sediment and the meteoric-water-precipitated, invading calcrete (Fig. 1.11a). Going up the calcrete profile, heavier values for both C and O are typical and related to a higher evaporation and CO_2 degassing rates in the upper part of the profile (Dever *et al.,* 1987).

Stable isotopes for the three calcretes (Fig. 1.11b) suggest a similar environment. The three calcretes tend to have lower delta ^{18}O values than those reported for the arid climate groundwater calcretes of Central Australia (Jacobson *et al.*, 1988), which could reflect a less arid climate.

1.9.2 General constitution and rare earth elements

The three calcretes are mineralogically similar. They consist of > 90% calcite except in areas were silica is concentrated. They have a similar REE distribution pattern (Fig. 1.12) that shows the typical negative anomaly of Ce in marine environments (Elderfield *et al.*, 1981). Since both the La Coulée and the Bonaventure clastics are dominated by marine limestone clasts, this does not preclude the possibility, in all three cases, that the host sediment is a continental clastic. For the Saint-Elzéar and Percé-Beach calcretes, where no clasts were found to indicate that the host sediment is clastic, the Ce anomaly does however exclude the possibility that a lacustrine or palustrine phase would have preceded the continental clastic sedimentation event (such limestones can develop a very similar calcrete facies; Wright and Tucker, 1991). What is not excluded is that the 10-12 m-thick Saint-Elzéar calcrete, which rests on a surface interpreted as a Carboniferous wave-cut platform (Jutras and Schroeder, in press), could be masking the sedimentological record of a change from coastal-marine to continental environments.

1.10 DISCUSSION

1.10.1 Sedimentology

The Saint-Elzéar, Percé-Beach and La Coulée Creek calcretes are similar in terms of composition, structure, stable isotopes, REE distribution and stratigraphic relationship, which suggests that they are lateral equivalents. We group them, along with the rest of the La Coulée Creek succession, within the La Coulée Formation ([2]).

It should be kept in mind, however, that only the La Coulée Creek calcrete is demonstrably pre-Bonaventure, being included in a succession unconformably overlain by the Bonaventure Formation. The existence of an apparent conformity between the Bonaventure Formation and the Percé-Beach calcrete is negated by the fact that the continuity of the same basal calcrete shows several metres of stepped topography underneath that formation on Bonaventure Island.

The calcrete outcrop at Saint-Elzéar is narrow and offers no direct evidence contrary to its apparent conformity apart from the fact that it is discontinuous. However, conformity would mean that it developed within the Bonaventure Formation. There are two major objections to this: (1) a very sharp contact is observed between the Bonaventure Formation

[2] Il est suggéré dans le Chapitre 3 d'utiliser le terme informel de 'calcrète de La Coulée' pour les calcrètes d'eau souterraine qui sont situées sous la Formation de Bonaventure mais dont le sédiment encaissant n'est pas démontré comme étant la formation clastique de La Coulée.

clastics and the underlying calcretes at both Percé-Beach and Saint-Elzéar. This is unlikely to occur within the sediment where the calcretes are formed since they are influenced by fluctuations of the water table. For instance, the La Coulée Formation at Mont Sainte-Anne shows almost 20 m of incomplete calcrete formation above the mature, clast-free calcrete; and (2) the three groundwater calcretes here ascribed to the La Coulée Formation, including the one at Saint-Elzéar, are grey and free of iron oxides, which is not the case for the pedogenic calcretes observed sporadically throughout the Bonaventure Formation. It is very unlikely that any thick calcrete that had developed in red clastics would remove or replace all iron oxides, whether in oxidized or reduced form.

Attempts to date the La Coulée Formation through spore analysis have been unsuccessful so far. South of the Mont-Sainte-Anne Fault, the formation is unconformably overlain by the Bonaventure Formation, which is attributed to the mid-Carboniferous and is either time-equivalent to the Windsor Group or the Mabou (ex-Canso) Group. Being also unconformable with the pre-Acadian basement, the La Coulée Formation is therefore time-equivalent to either the Horton Group (Late Devonian to early Viséan) or the Windsor Group (mid to late Viséan).

In the entire 60 m succession of the La Coulée Formation at Mont Sainte-Anne, prior to the post-sedimentary calcrete formation, the omnipresence of coarse debris flow and flash flood deposits, without interbedded decantation muds, suggests subaerial alluvial fan sedimentation. The size of the clasts, especially a 1 m-long biosparudite clast, suggests the close proximity of a fault, most likely the Grande-Rivière Fault system. The La Coulée waterfall, where the largest clasts are found, is the closest outcrop to the fault and is the only locality where an original sedimentary dip, although partly obscured by calcrete formation, can be observed. This sedimentary dip suggests that the source is to the north-northeast, thus crossing the Grande-Rivière Fault system.

For a given stratigraphic level, clasts fine away from the Grande-Rivière Fault system, toward the south- southwest. The sedimentary dip is also towards the south-southwest and decreases gradually in that direction till it becomes difficult to determine. The north-northeastward 20° dip, which is very consistent throughout the La Coulée Formation at Mont Sainte-Anne, is structural. It is probably slightly underestimated since its direction is opposite to that of the sedimentary dip.

The alluvial fan that formed the La Coulée Formation is not very steep: the sedimentary dip quickly becomes negligible away from the fault, although the sediments remain quite coarse. It is also non-channellized and the beds are more sheet-like than lenticular. The poverty in muds, the lack of lateral variation, the absence of a strong sedimentary dip, as well as the internal structure of the debris flows, all suggest an abundance of water in the sedimentation process. Some green reduction in the conglomerates, some alteration to kaolinite in the breccia and the absence of red coloration also suggest a water-rich environment.

Paradoxically, the absence of organic remains and the development of groundwater calcretes suggest that the climate was relatively arid. Locally, more abundant water supply can be found internally by passive saturation from an adjacent water reservoir (Nemec and Steel, 1984). The La Coulée Formation can therefore be regarded as having evolved under a somewhat arid climate, with perhaps a higher water table than the typical Carboniferous red clastic successions of southeastern Canada.

A high water table would bring about rapid saturation during rainfalls and would favour debris flows; however, the effective drainage that occurs within coarse clastics would not allow much water retention and would have thus prevented vegetation from developing if the climate was sufficiently arid. A high water table would also narrow the vertical zone in which oxidation can occur and, with a high sedimentation rate, could possibly prevent red hematite from developing, even under a relatively arid climate. According to Miall (1996), the level of the water table is more important than climate in controlling colour differences amid continental clastics.

The Mont Sainte-Anne erosional remnant of the La Coulée Formation includes only the proximal reaches of the fan and does not enable us to reach any conclusions regarding the outer reaches. It is therefore not possible to determine whether the fan was connected to a lake, a sea or an alluvial plain. However, a fan-delta model would partly explain some of the non-arid features of the La Coulée Formation and perhaps even the extensive calcretization that has affected it: since groundwater calcretes tend to develop in drainage systems where the water table is very close to the surface, their formation usually occurs in proximity to a body of water, very often close to salt lakes and playas, in the groundwater discharge zone where fresh and saline waters mix (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989).

The Percé region is just outside the zero isopach of the Windsor Group according to Howie and Barss (1975) (Fig. 1.13). Since both the stratigraphic and the geographic positions of the La Coulée Formation make it a Windsor Group candidate, and since it is underlain by a surface interpreted as being related to marine erosion processes in the Saint-Elzéar region, the proximity of a contemporaneous or abandoned arm of the Windsor Sea is possible.

We propose that small water bodies, resembling playa-lake extensions, were the most likely proximal environment when groundwater calcrete formation occurred. Such environments are commonly present in the peripheral environments of the Windsor Group (P. Giles, personal communication, 1998). However, the La Coulée Formation does not resemble the facies either of the Windsor Group or of any other upper Paleozoic formation of Atlantic Canada described in the literature. Solid correlation remains to be made.

Quaternary groundwater calcretes are abundantly recorded in Australia where they are laterally associated with gypsum-rich playa-successions (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989). If evaporite patches remain, they would most probably be under Chaleur Bay or under the thick Bonaventure Formation succession that extends south-southwest of the Cap Blanc Fault (Fig. 1.7b and c). However, groundwater calcretes have not been sufficiently studied outside Australia to discriminate regional versus general features and, thus, the presence of a groundwater calcrete does not automatically imply the proximity of gypsum deposits.

Some pre-Quaternary continental clastics cemented by calcite of groundwater origin have been reported (Kalliokosky, 1986; Thériault and Desrochers, 1993; Kalliokosky and Welch, 1996; Tandon and Gibling, 1997; Chandler, 1998). However, to our knowledge, this is the first pre-Quaternary record of thick and mature groundwater calcretes, where not only cementation but also thorough replacement of the host sediment has occurred.

In modern records, such massive groundwater calcretization appears to be systematically associated with the presence of salt (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989). Is mixing with saline water required for the development of such thick non-pedogenic 'hardpans'? The determination of such a relationship would be greatly facilitated by the establishment of a tighter nomenclature regarding the different types of groundwater calcretes.

1.10.2 Tectonics

The Grande-Rivière Fault system was probably active as a strike-slip during the Acadian orogenic phase (Malo and Béland, 1989; Malo *et al.*, 1992, 1995; Malo and Kirkwood, 1995; Kirkwood *et al.*, 1995), which would also explain why no green mudstone clasts of the underlying basement rocks have been found in the La Coulée Formation at Mont Sainte-Anne; they had already been displaced and were locally absent as source rocks when the fault system was reactivated during deposition of the La Coulée Formation.

The apparent layering of the different lithologies in the calcrete at La Coulée waterfall can also be explained by proximal, strike-slip fault-related sedimentation. The local Acadian folded strata generally have a very high dip, which would bring about rapid change of source rocks in a strike-slip context, unless the fault responsible for sedimentation of the La Coulée Formation was perfectly parallel to the tectonic grain, which was unlikely to have been the case.

Dextral strike-slips have occurred in the Maritime provinces from mid-Viséan through Westphalian B time (Ruitenberg and McCutcheon, 1982; Bradley, 1982; McCutcheon and Robinson, 1987; Thomas and Schenk, 1988). They are related to regional shear at the level of the Iapetan suture while the Theic Ocean, southern extension of the then-already-closed Iapetus (Kent and Opdyke, 1985; Keppie, 1985, 1992; Briden *et al.*, 1988; Kent and Keppie, 1988; Reed *et al.*, 1993), was still in the process of closing

(Arthaud and Matté, 1977; Piqué, 1981; Lefort and Van der Voo, 1981; Russel and Smythe, 1983; Haszeldine, 1984; Kent and Opdyke, 1985; Lefort et al, 1988). Hence, arguments for strike-slip movement being responsible for sedimentation of the La Coulée Formation are weak but contextual.

The 20° structural dip of the La Coulée Creek succession, which is not shared with the Bonaventure Formation, tilts away from the Cap Blanc Fault (Fig. 1.7b, c). This fault separates the Bonaventure Formation from limestones of the Matapedia Group (Fig. 1.8, cross-sections C-D and E-F). It demonstrably affects the Bonaventure Formation but it may also have acted as a normal fault during the pre-Bonaventure uplift and erosion of the La Coulée Formation.

Extensional magmatic events of approximate Viséan age have been reported for the Hog's Back (338±10 Ma; de Römer, 1974) and Vallières-de-Saint-Réal (338±6 Ma; Larocque, 1986) plutons of the north-central highlands of the Gaspé Peninsula. Many other similar highlands occupied by Devonian to Permian plutonic complexes are found throughout the Maritime provinces (Fyffe *et al.*, 1981; Barr, 1984; Fyffe and Barr, 1986; Waldron *et al.*, 1989; Pe-Piper, 1991; Pe-Piper *et al.*, 1991; MacDonald *et al.*, 1992; Piper *et al.*, 1993; Kontak, 1994). They are interpreted as horst structures induced by plutonic activity and would have served as intermittent sources for clastic sedimentation during Late Devonian and Mississipian times (St. Peter, 1993). The uplift of the La Coulée

Formation, prior to deposition of the Bonaventure Formation, could have been related to such extensional magmatic events.

Reactivation of the Grande-Rivière Fault system was probably responsible for deposition of the Bonaventure Formation, an event that buried the erosional remnants of the La Coulée Formation. Based on the presence of inversely graded conglomerate-filled channels which, they argued, suggests dip-slip rejuvenation, Rust *et al.* (1989) proposed that the Bonaventure Formation was the product of dip-slip related sedimentation. Reactivation of the fault system also occurred after deposition of the Bonaventure Formation and caused block displacements affecting both formations.

1.11 CONCLUSIONS

The grey clastic succession on the northern side of Mont Sainte-Anne is the erosional remnant of an undated post-Acadian unit, the La Coulée Formation, which stratigraphically underlies the Bonaventure Formation, also undated but estimated as Viséan in age (Rust *et al.*, 1989; Brisebois *et al.*, 1992). A fault-controlled, continental alluvial fan environment is suggested by the sedimentological features of the La Coulée Formation.

The presence and nature of a thick groundwater calcrete at the base of the succession, combined with structure, fabric and matrix composition in alluvial fan deposits, suggest that the La Coulée Formation was connected to a passive body of probably saline water under a relatively arid climate. In opposition, the alluvial fans of the Bonaventure Formation were connected to a deeply oxidized alluvial plain (Zaitlin and Rust, 1983), suggesting an environment that was further from base level. It is unlikely that thick groundwater calcretes could have developed in such an environmnent, especially at the level of the alluvial fans.

The calcrete at Percé-Beach seems to be the continuity of the nearby La Coulée Creek calcrete and it is considered a thin erosional remnant of the La Coulée Formation. Since massive groundwater calcretes are very rare in the stratigraphic record, and since they only seem to develop in very specific environmental settings, it is postulated that the calcrete at Saint-Elzéar, ~100 km away, is more or less synchronous with the similar groundwater calcretes of the Percé area. It notably holds the same stratigraphic position, underneath the Bonaventure Formation. The Quaternary groundwater calcretes of Central Australia (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989) are an example of such setting where massive groundwater calcretes develop almost simultaneously in various areas of the same region.

The Saint-Elzéar calcrete rests on a surface interpreted as having been carved by the Windsor Sea (Jutras and Schroeder, 1999). This suggests that the calcrete postdated maximum Windsor transgression. In this interpretation, the lower age limit of the La Coulée Formation would be mid-Viséan since no Windsor Group limestones older than that are known (Howie and Barss, 1975).

The La Coulée Formation is most easily pictured in the general subsidence context of the Windsor Group. It belongs to one of the numerous events of post-Acadian fault activity in southeastern Canada during the upper Paleozoic.

Period	sub-	Epoch	Selected Stages	Ma	Maritimes	Gaspé Peninsula
Carboniferous	Penn.	Westphalian			Cumberland Group (or Riversdale Group)	?
				323		?
Carboniferous	Mississippian	Namurian	Pendleian		Mabou Group (or Canso Group)	(Cannes-de-Roches Fm. ?) Bonaventure Fm.
				333		(wavy line)
Carboniferous	Mississippian	Viséan	Brigantian		Windsor Group	?
			Asbian			
			Holkerian			?
				350		La Coulée Fm.
Carboniferous	Mississippian	Tournaisian			Horton Group	?
				363		
Devonian		Late	Famennian		Horton Group	
				367		Miguasha Group
			Frasnian			
				377	Acadian orogeny (wavy line)	Acadian orogeny (wavy line)
Devonian		Middle	Givetian			
				381		
			Eifelian			
				386		

Table 1. Comparative post-Acadian stratigraphy of the Maritime provinces and the Gaspé Peninsula. The generalized environment (from several authors) is indicated for each group. Each major group has equivalent units (not shown) elsewhere within the Maritime provinces and in Newfoundland (time scale after Harland *et al.*, 1990). Dashed areas represent deformation events with hiatuses; wavy lines represent deformation events without a recorded hiatus.

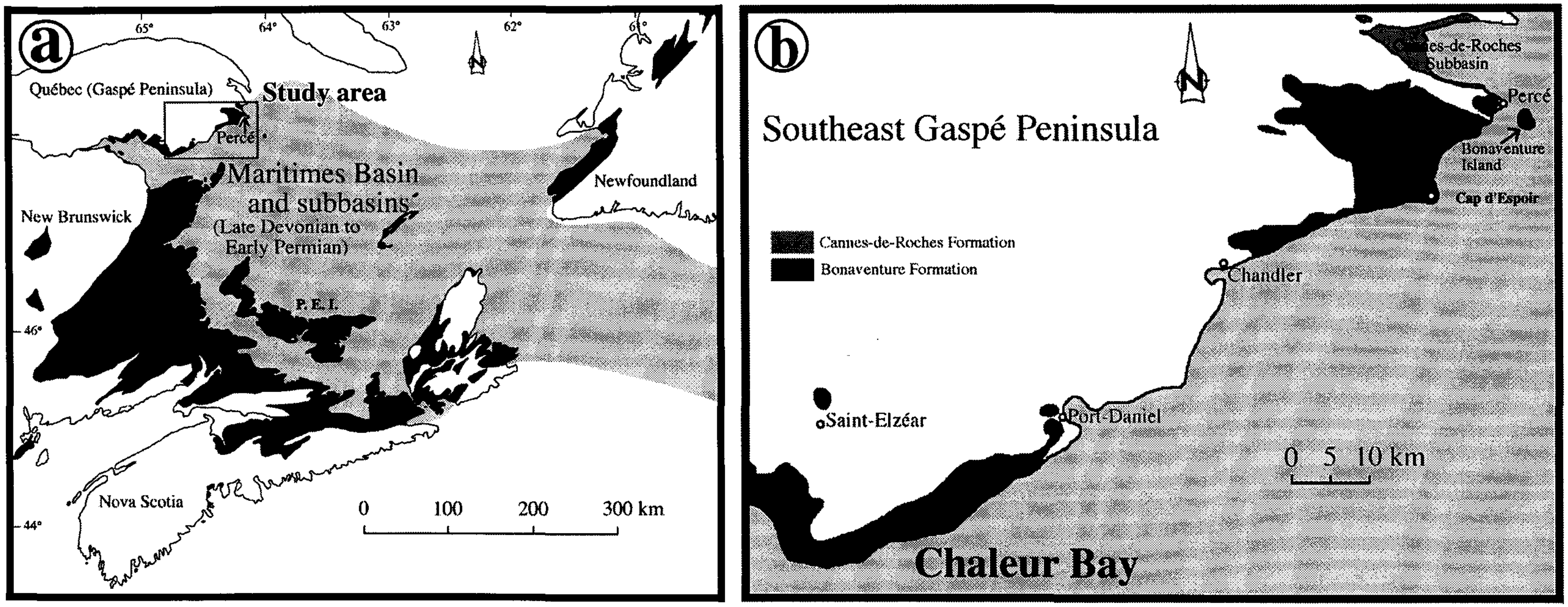

Fig. 1.1. The study area. (a) Position within the upper Paleozoic Maritimes Basin of southeastern Canada (modified from Gibling *et al.*, 1992). (b) Carboniferous formations of southeast Gaspé Peninsula (modified from Brisebois *et al.*, 1992).

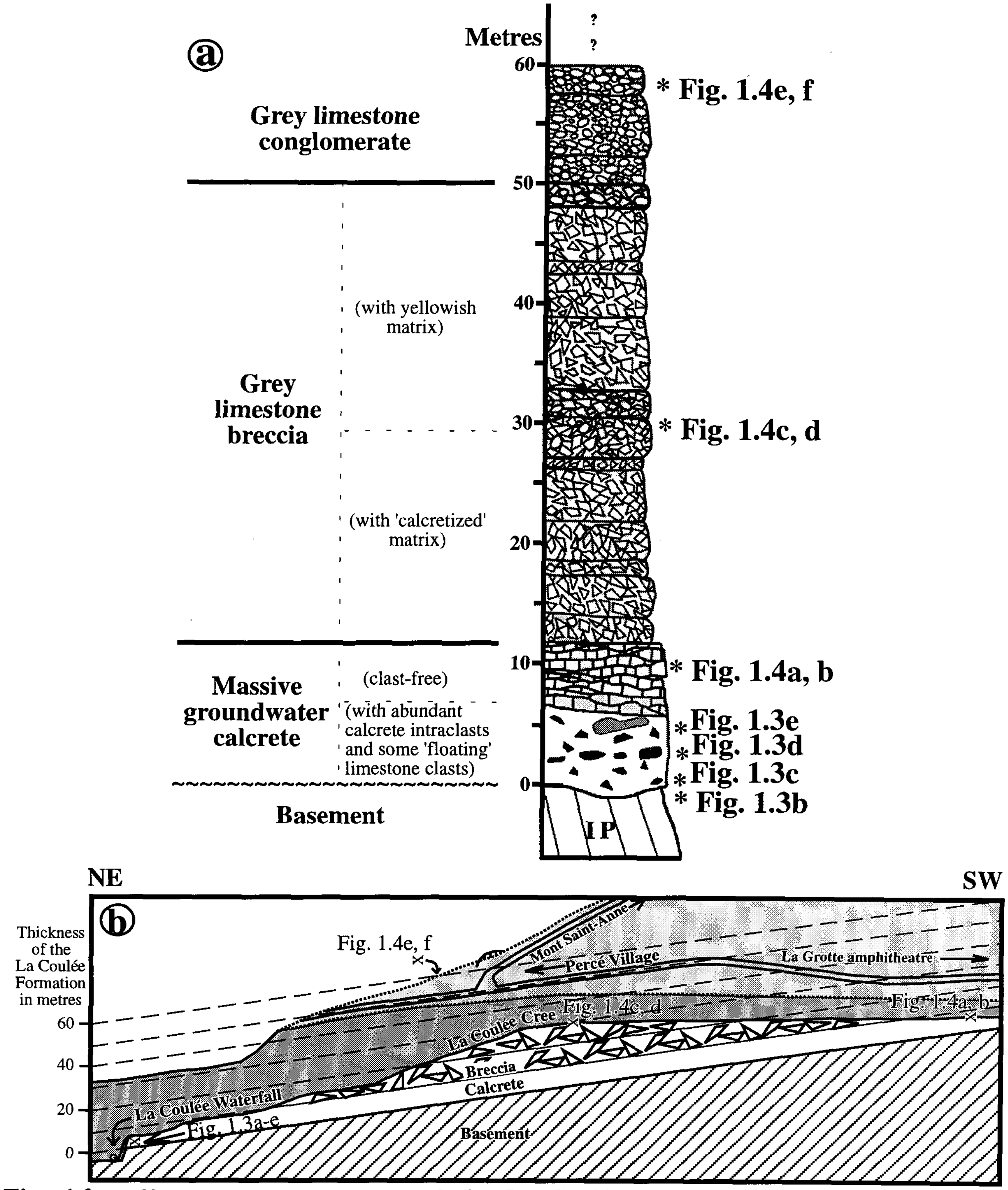

Fig. 1.2. 60 m remnant sequence of the La Coulée Formation at Mont Sainte-Anne. (a) Composite stratigraphic column of the La Coulée Formation in the Mont Sainte-Anne sequence showing the three main facies. The basement is the Indian Point Formation (IP) of Early Devonian age. The stratigraphic levels (asterisks) of Figures 1.3b-e and 1.4b-f are shown. (b) Schematic cross-section along La Coulée Creek (with locations of Figures 1.3a-e and 1.4a-f).

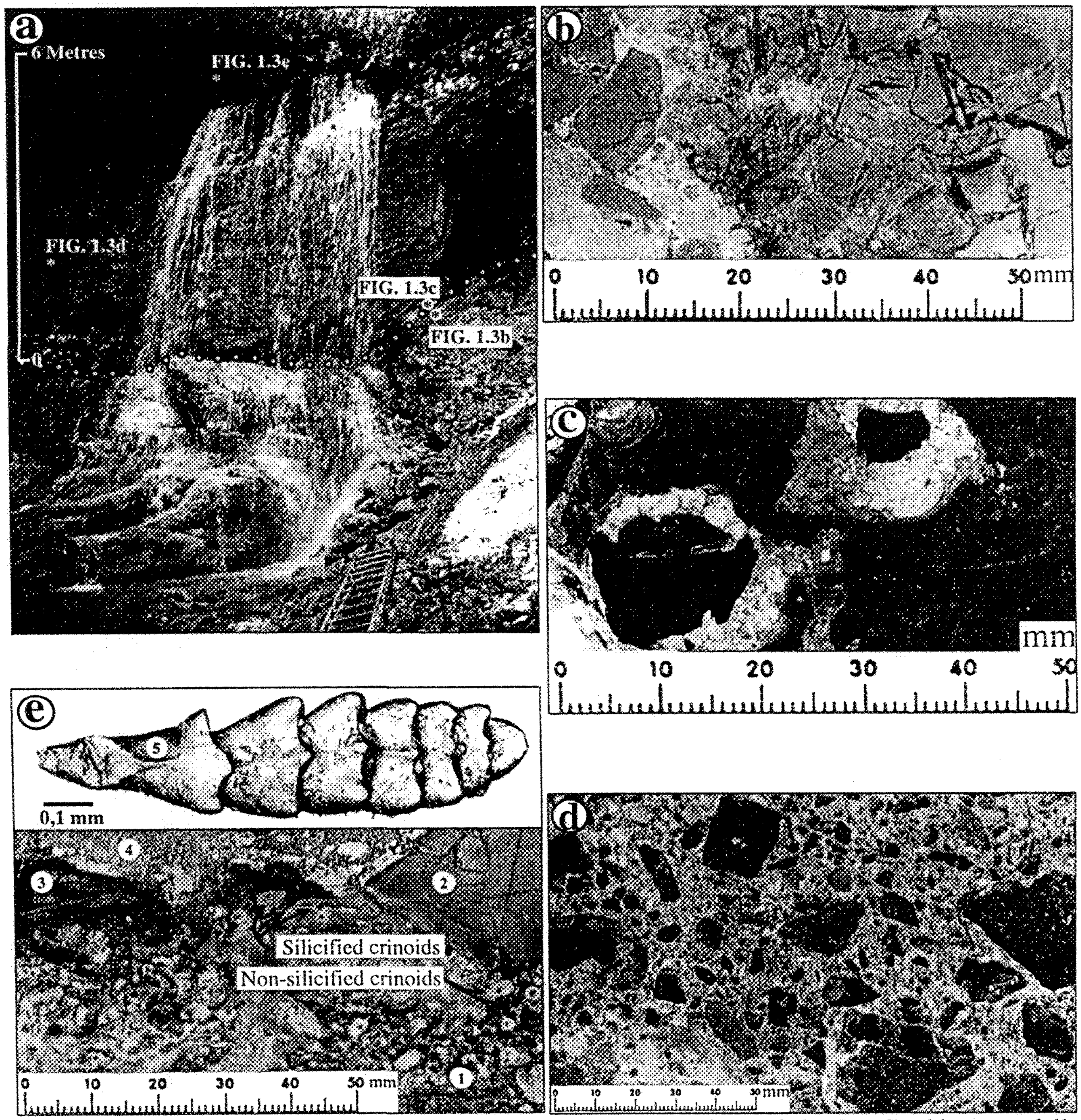

Fig. 1.3. The La Coulée waterfall section. (a) General view of the La Coulée waterfall. Dotted line indicates the irregular contact between the La Coulée Formation and the underlying basement. The locations of Figures 3b-e are shown. (b) Basement green mudstone, brecciated at the contact with the La Coulée Formation. (c) Calcrete with silicified (dark) fossiliferous limestone clasts. (d) Brecciated calcrete, the most common facies throughout the 6 m-thick section. The smaller, darker clasts are silicified. (e) Biocalcirudite (1) with silicified zones (2) and (3) that seem to represent concentrations of silica-rich elements from (1). (4) is the surrounding calcrete matrix. (5): conodont genus *Icriodus* (Royal Ontario Museum [Palaeobiology], #53514).
Mineralogical concentrations according to X-ray diffraction:
1: 98% Calcite; 1.45% Silica; 0.13% K-feldspar. 2: 57.21% Calcite; 36.57% Silica; 6.22% K-feldspar. 3: 13.33% Calcite; 75.45% Silica; 10.61% K-feldspar. 4: 84.83% Calcite; 13.34% Silica; 1.83% K-feldspar.

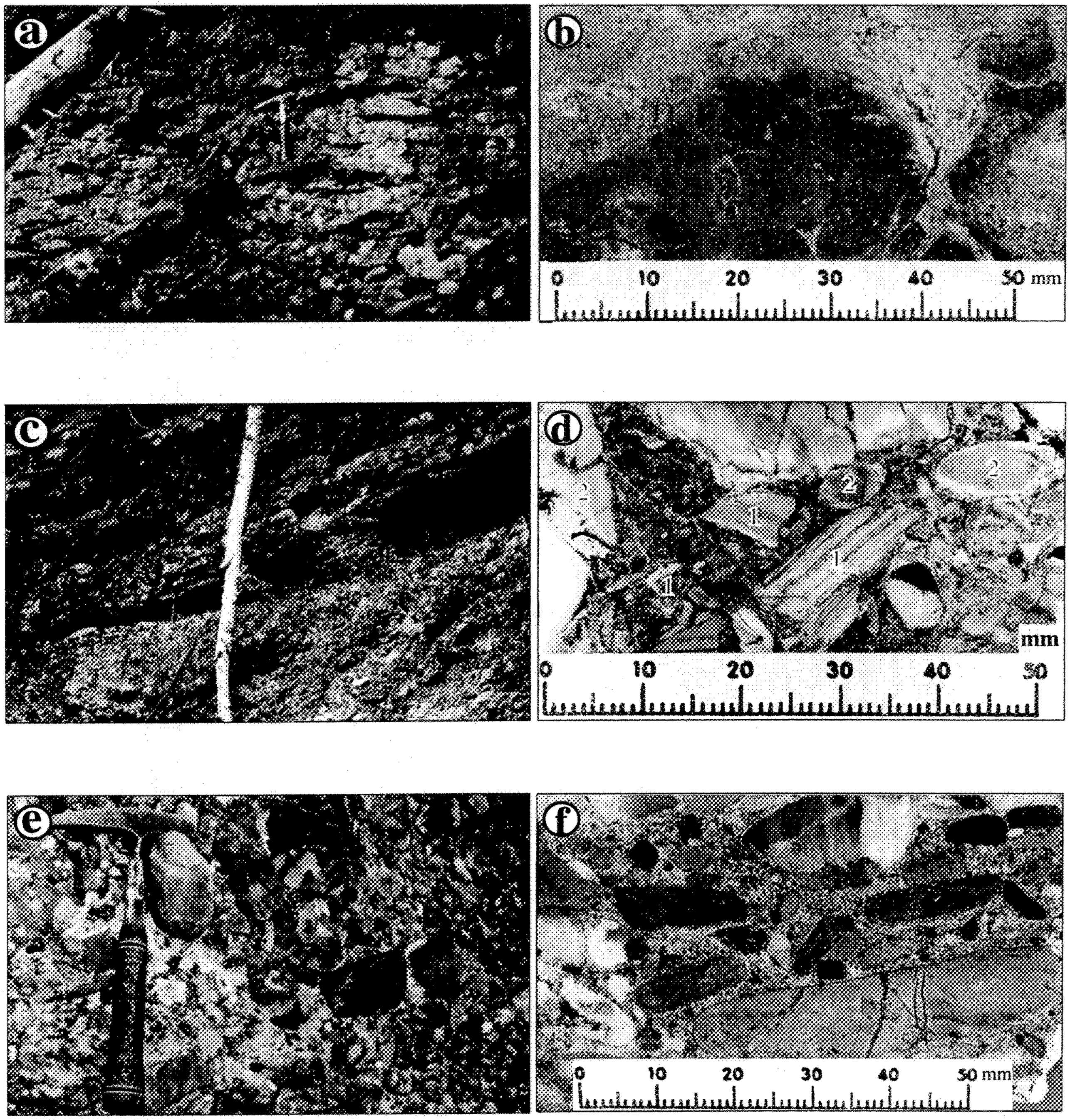

Fig. 1.4. Main facies of the La Coulée Formation from stratigraphic level 6 to 60 m. (a) Clast-free calcrete. It has a lenticular to stratiform structure but, (b) the host sediment is thoroughly calcretized. (c) Sheet-like beds of limestone breccia. (d) Examples of angular to very angular clasts (1) associated with sub-rounded clasts (2); the fine fraction of the matrix is mainly composed of kaolinite with small amounts of goethite, marcasite (which gives it a yellowish colour) and some titanium oxides.
(e) Limestone conglomerate with an overall chaotic debris flow structure. The conglomerates are polymodal and matrix- to clast-supported. (f) The clasts have high roundness but low sphericity. As the photo illustrates, numerous clasts are aligned parallel-to-flow, revealing a certain degree of organization during emplacement.

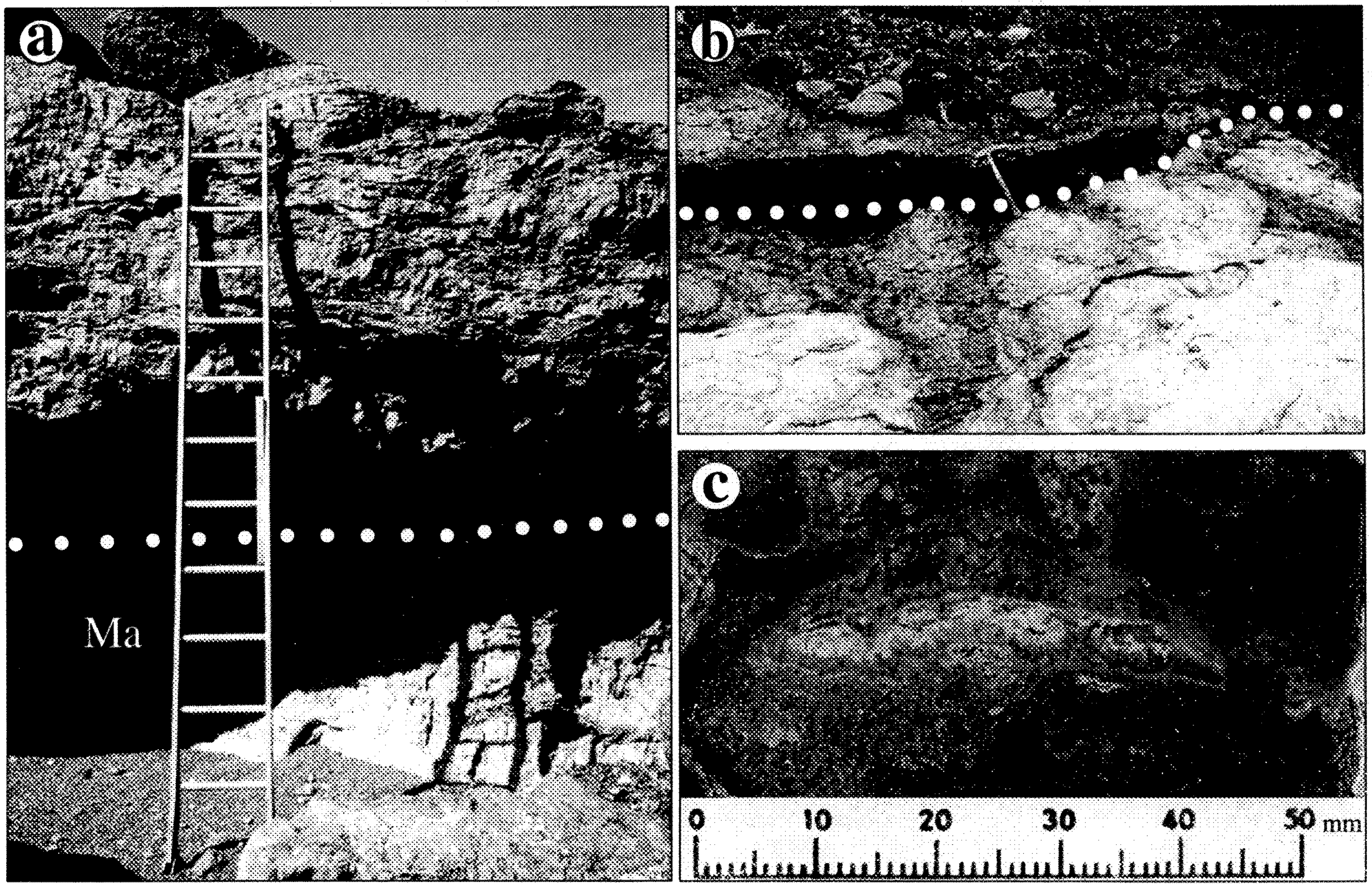

Fig. 1.5. The Percé-Beach calcrete. (a) Underlain by the Matapedia Limestone (Ma). Dotted line marks contact between the calcrete and the basement. (b) Sharp but seemingly conformable contact between the calcrete and the overlying red clastics of the Bonaventure Formation. (c) Clast-free calcrete with vadoids and laminated structures.

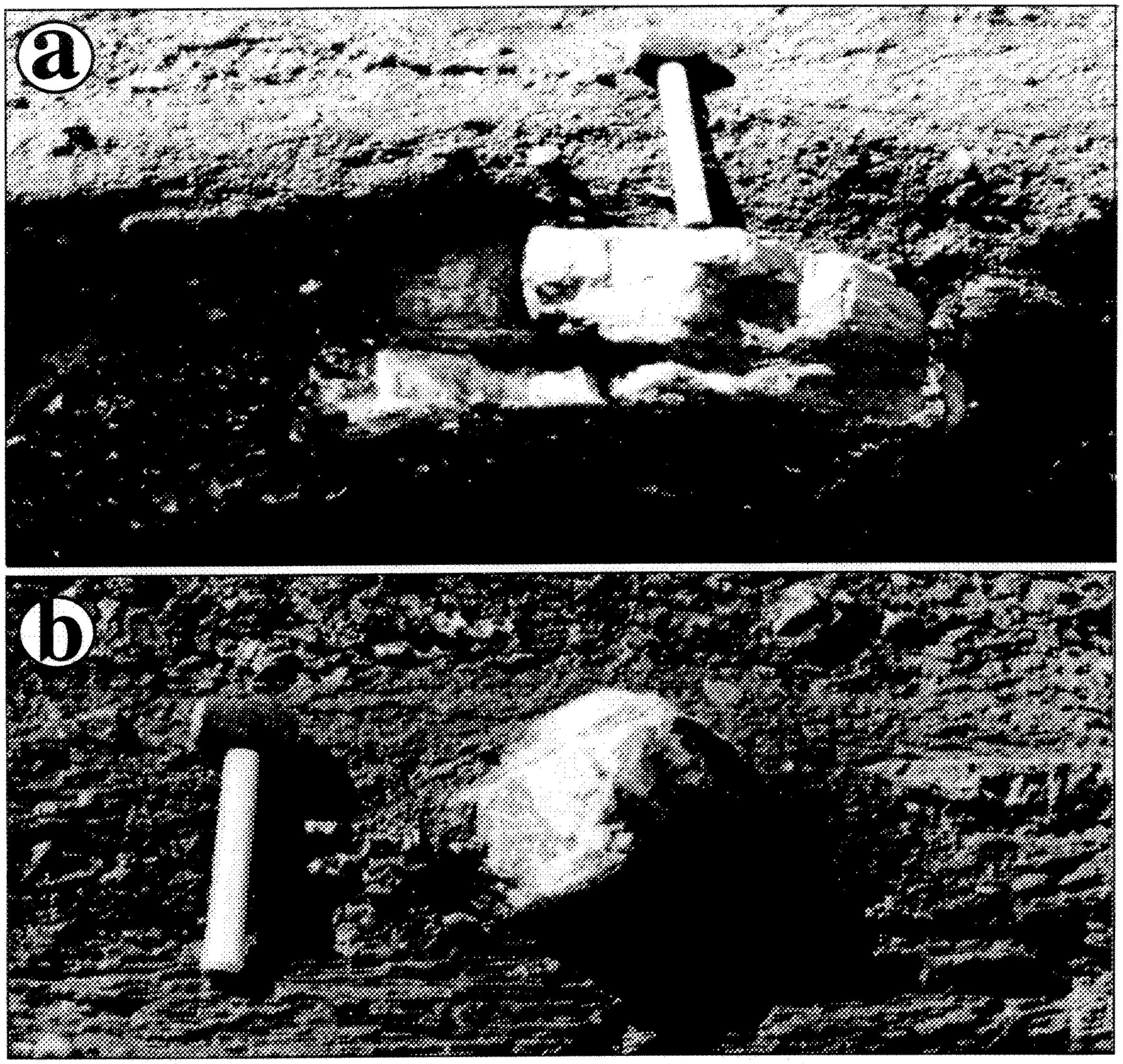

Fig. 1.6. Large calcrete clasts lodged in micro-conglomeratic (a) and sandy (b) matrix of the Bonaventure Formation on the south side of Cap d'Espoir.

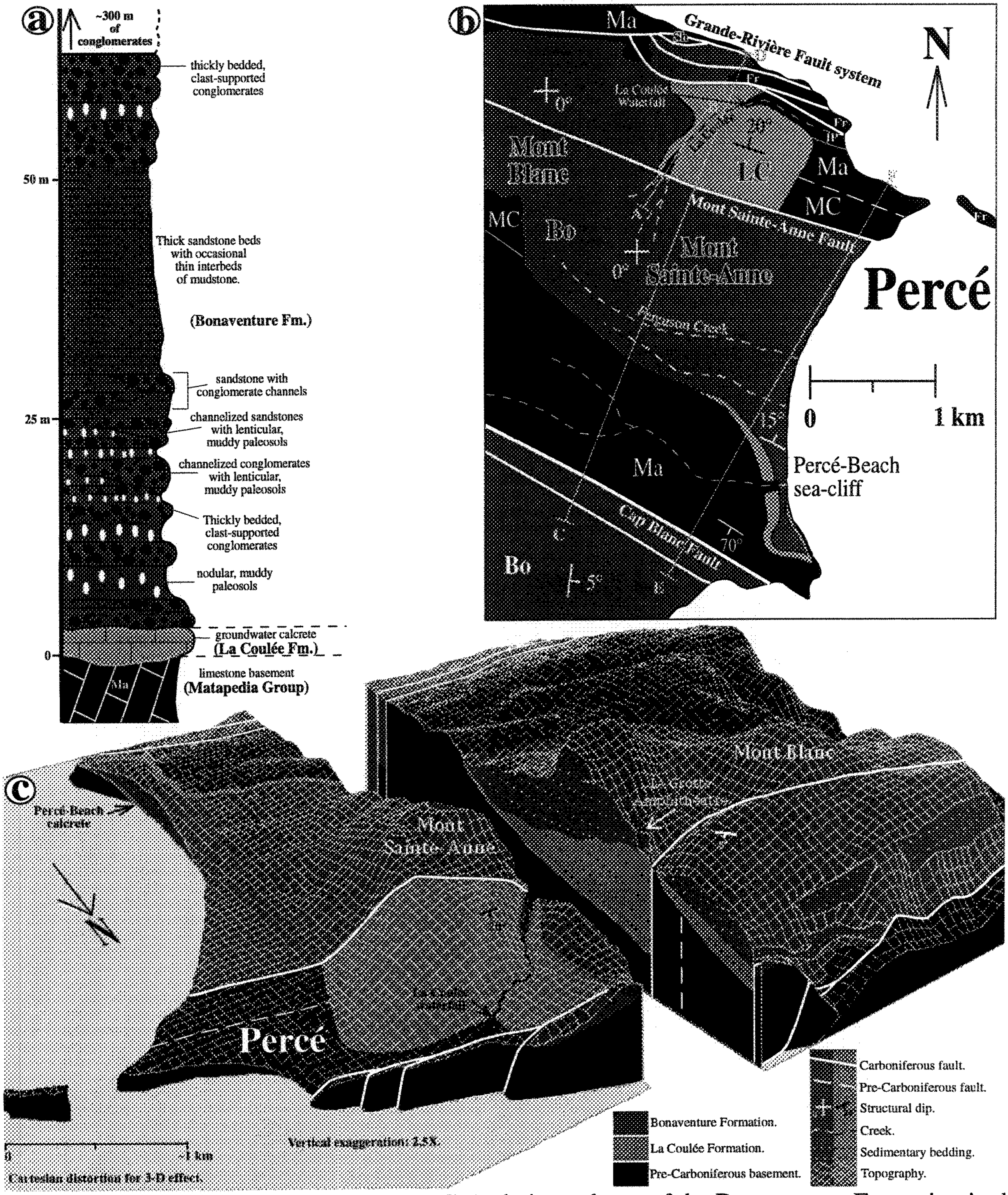

Fig. 1.7. Geology of the Percé area. (a) Cumulative column of the Bonaventure Formation in the Percé region. The detailed section was measured on the Percé-Beach sea-cliff and extrapolations of the remaining upper conglomeratic beds are from the Ferguson Creek outcrops (see figure 1.7b) and the Mont Sainte-Anne cliffs. (b) Outline geological map (Modified from Kirkwood, 1989). Cross-sections for transects A-B, C-D and E-F are shown on figure 8. MC=Murphy Creek Fm. (Cambrian); Ma=Matapedia Gp. (Ordovician to Silurian); IP=Indian Point Fm. (Early Devonian); Fr=Forillon Fm. (Early Devonian); Sh=Shiphead Fm. (Early Devonian); LC=La Coulée Fm. (Late Devonian or Mississippian); Bo=Bonaventure Fm. (Mississippian). (c) Block Diagram.

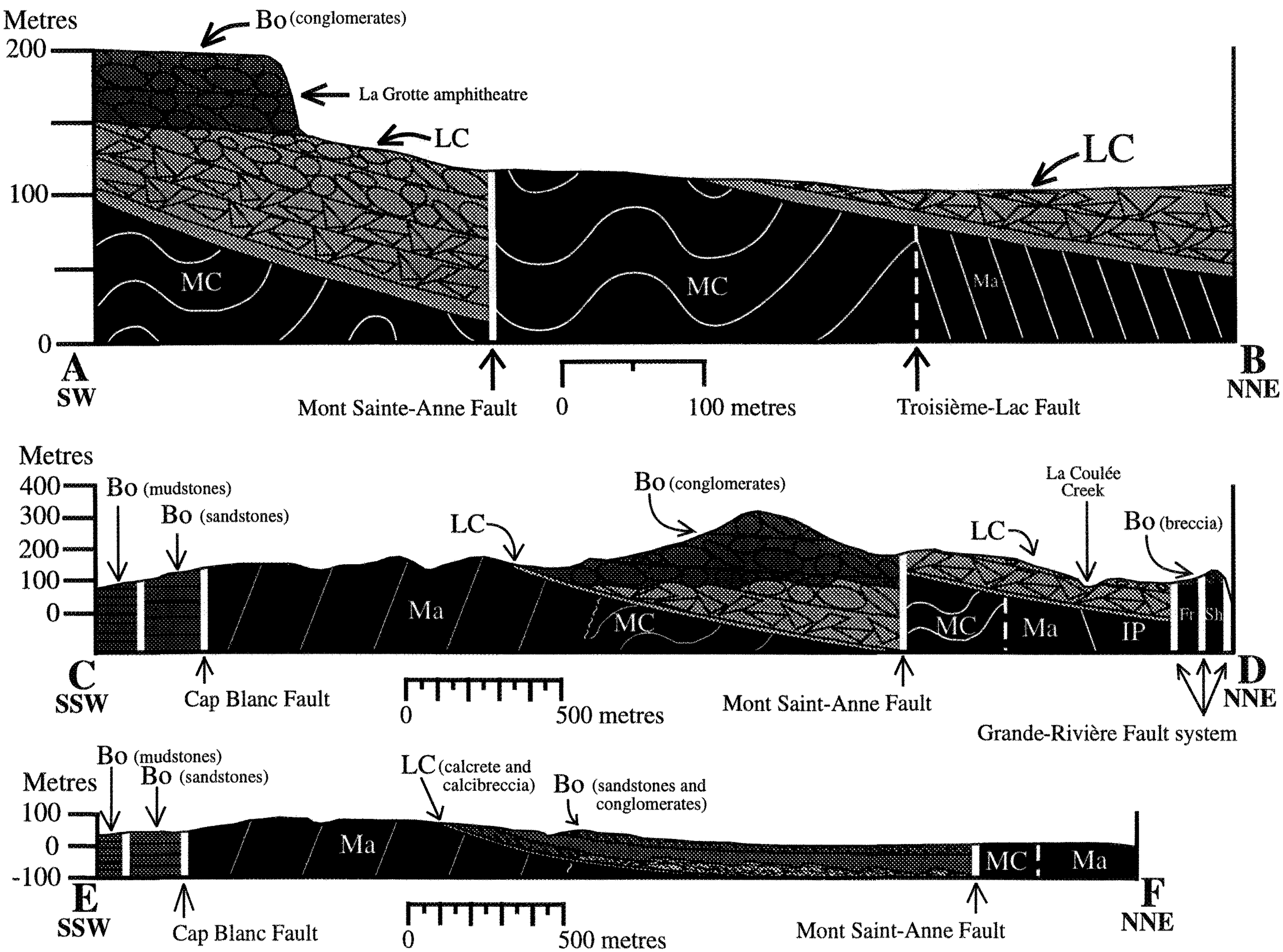

Fig. 1.8. Cross-sections A-B, C-D and E-F. MC=Murphy Creek Fm. (Cambrian); Ma=Matapedia Gp. (Ordovician to Silurian); IP=Indian Point Fm. (Early Devonian); Fr=Forillon Fm. (Early Devonian); Sh=Shiphead Fm. (Early Devonian); LC=La Coulée Fm. (Late Devonian or Mississippian); Bo=Bonaventure Fm. (Mississippian).

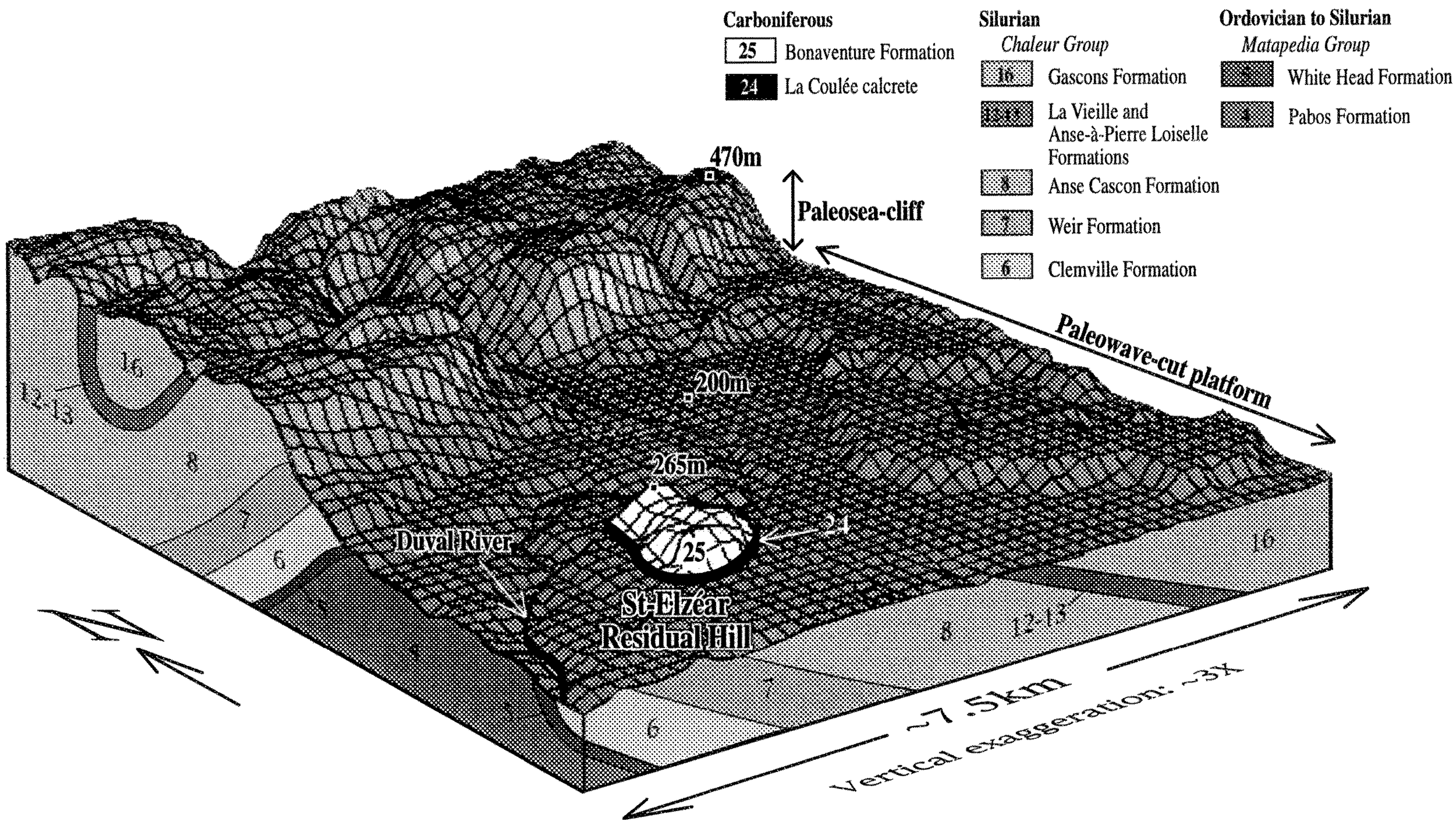

Fig. 1.9. 3-D geology and topography of the Saint-Elzéar area (modified from Jutras and Schroeder, 1999), based on geological mapping by Bourque and Lachambre (1981) and Brisebois *et al.* (1992).

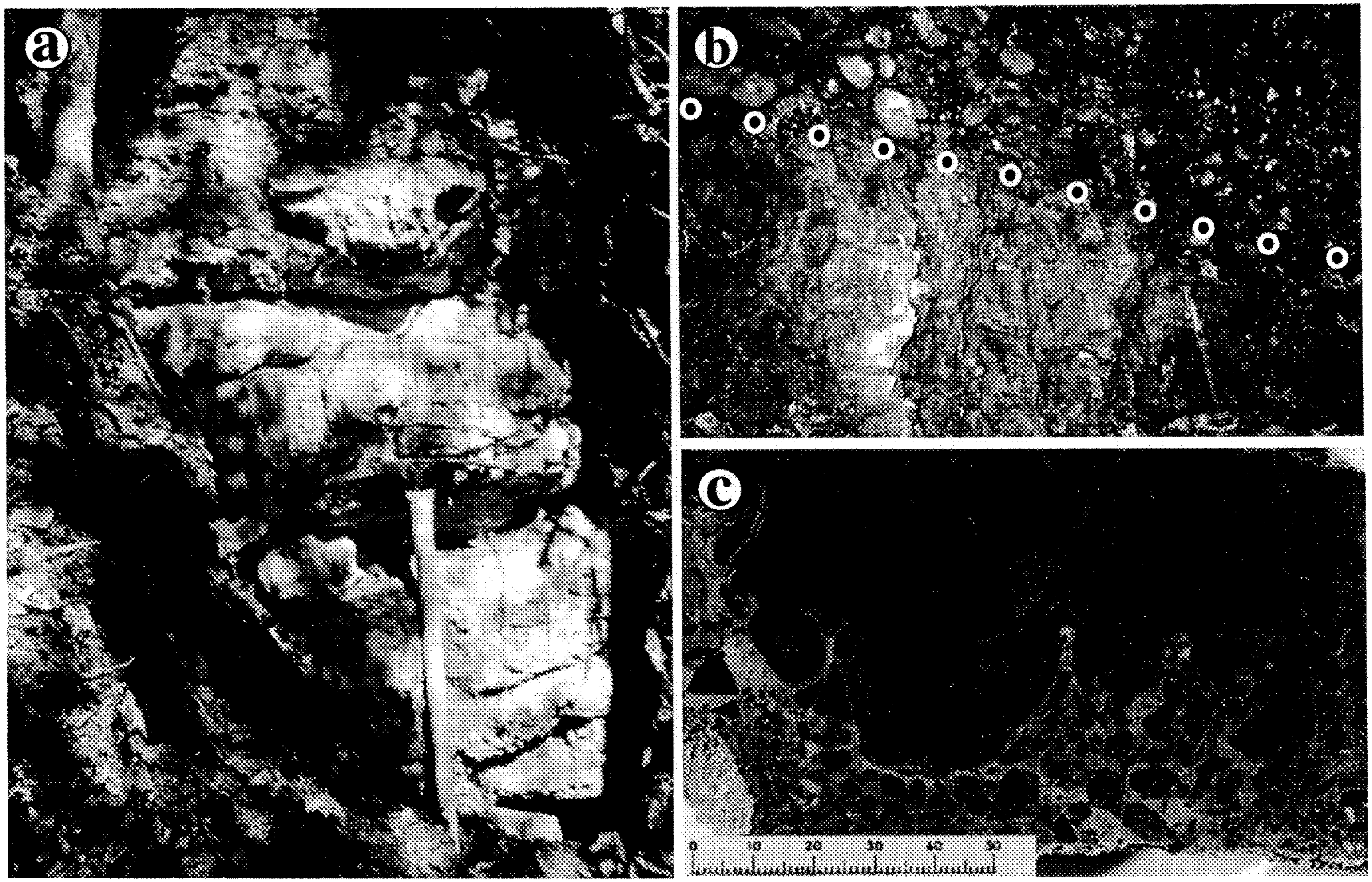

Fig. 1.10. The Saint-Elzéar calcrete. (a) Stratiform structure. (b) Sharp but seemingly conformable contact between the calcrete and the overlying red clastics of the Bonaventure Formation. (c) Mature calcrete with brecciated horizons.

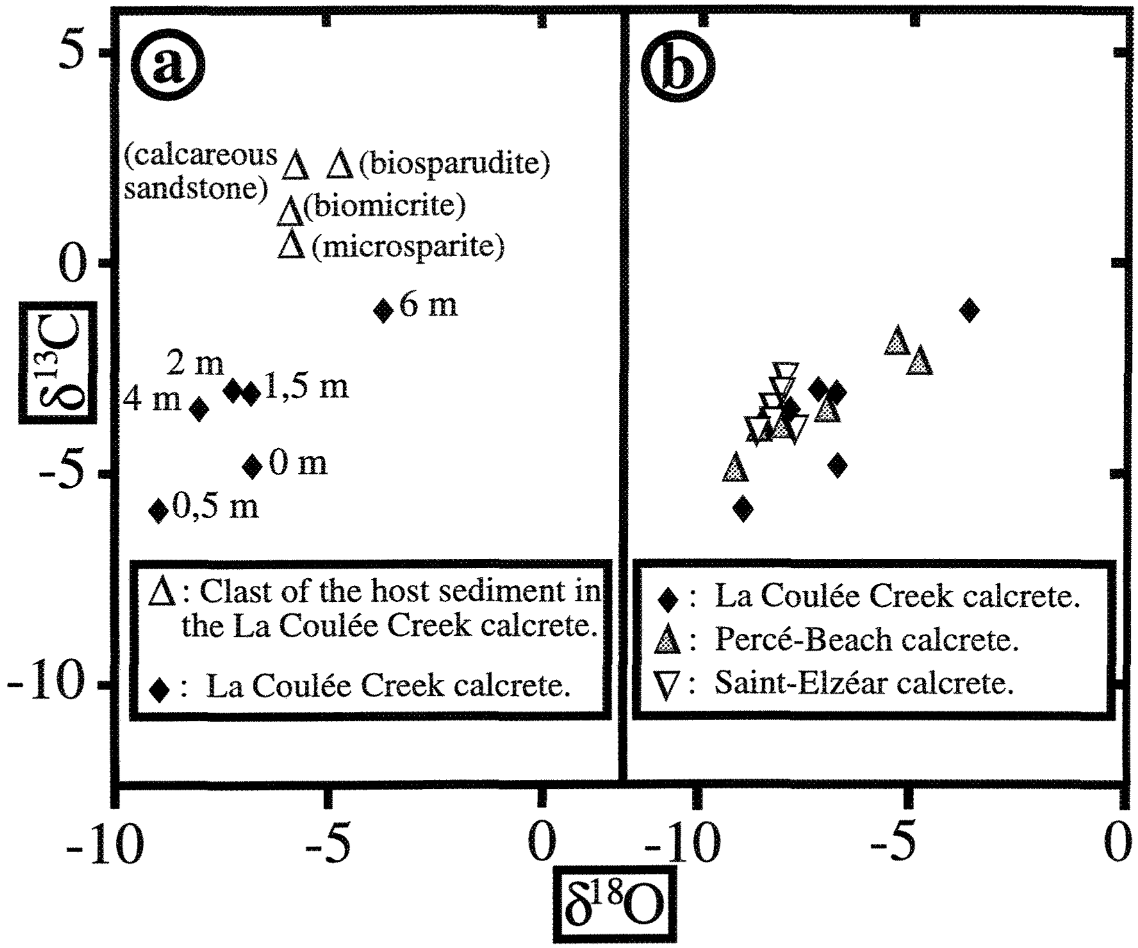

Fig. 1.11. Stable isotopes of carbon and oxygen. (a) The La Coulée Creek calcrete versus some remaining limestone clasts of the host sediment at the level of the waterfall. b) Stable isotopic range of the three studied calcretes.

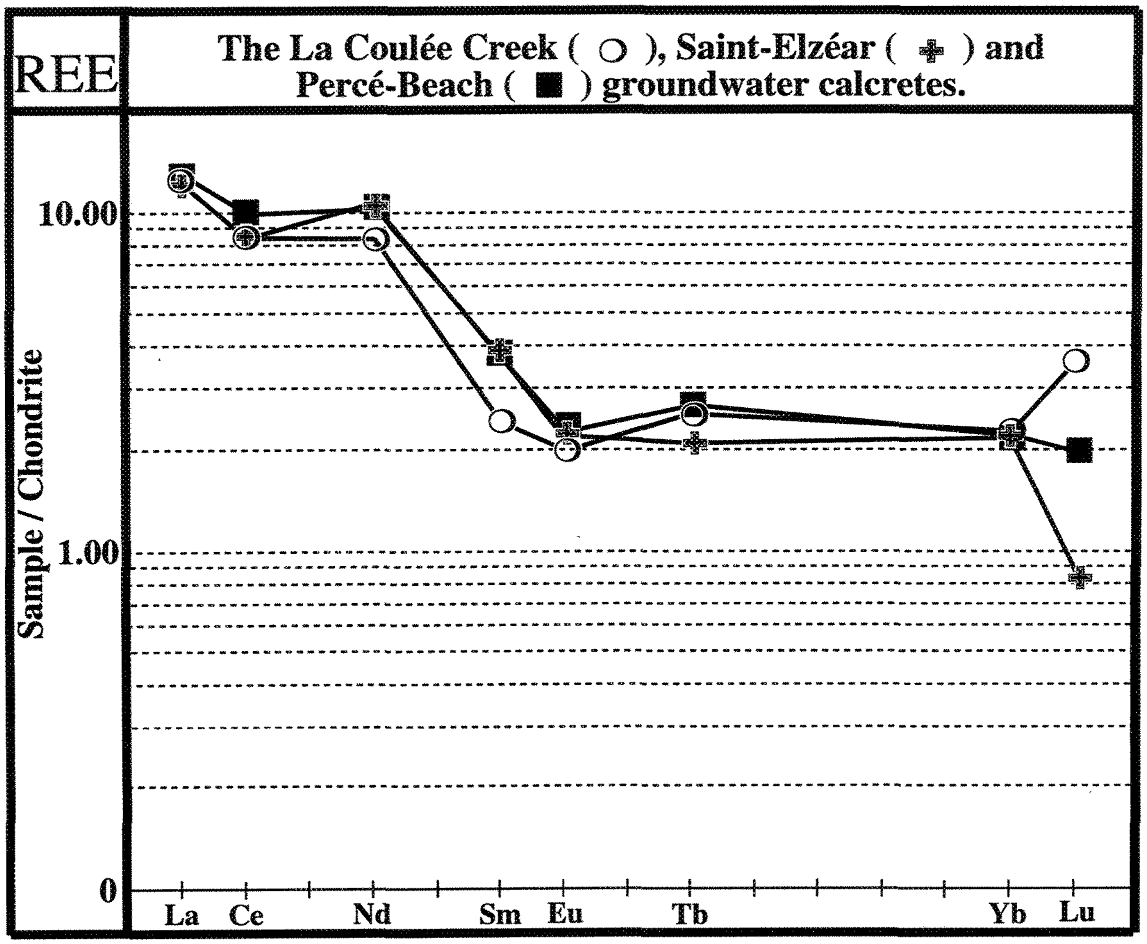

Fig. 1.12. Rare earth elements distribution pattern in the three studied groundwater calcretes.

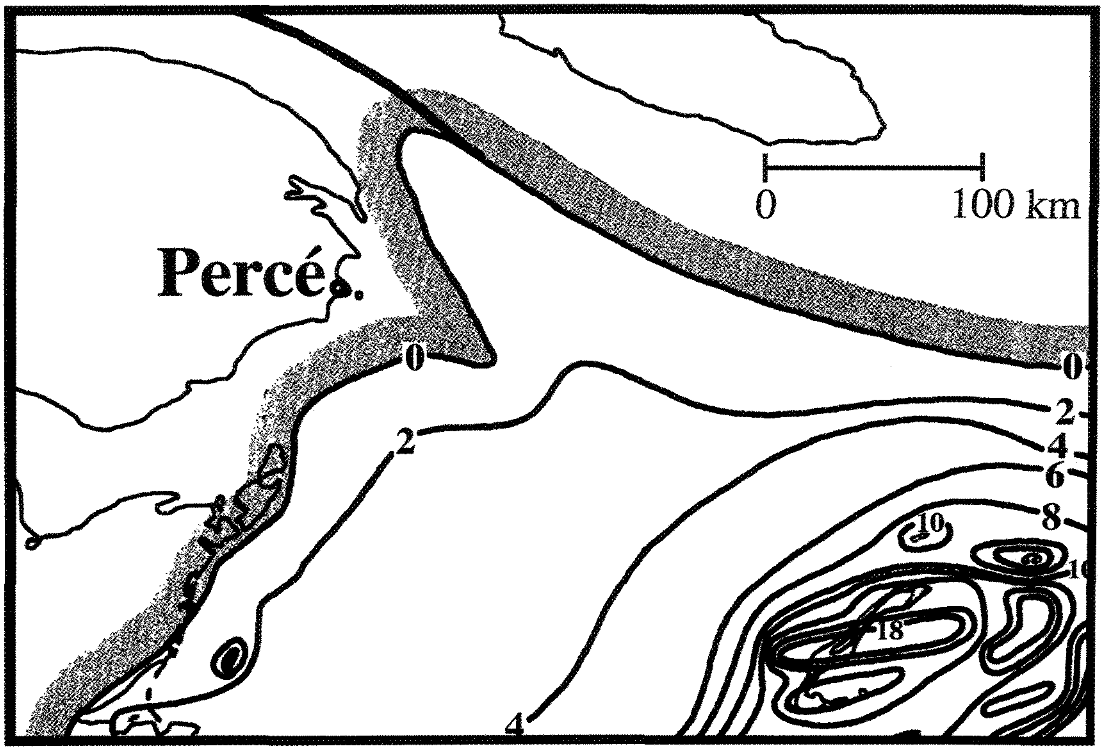

Fig. 1.13. Isopach map of the Windsor Group in thousands of feet (modified from Howie and Barss, 1975).

CHAPITRE II

NEWLY IDENTIFIED CARBONIFEROUS UNITS (THE POINTE SAWYER AND CHEMIN-DES-PECHEURS FORMATIONS) IN THE GASPÉ PENINSULA, QUÉBEC; IMPLICATIONS REGARDING THE EVOLUTION OF THE NORTHWESTERN SECTOR OF THE MARITIMES BASIN

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2.1 ABSTRACT

The Upper Member of the Cannes-de-Roches Formation was recently recognized overlying the Bonaventure Formation in the New-Carlisle area, over 100 km southwest of the previously documented exposures of this unit. Moreover, remnants of the La Coulée Formation, which are unconformably overlain by the Bonaventure Formation, have also been recognized underlying with a similar type of contact the Lower Member of the Cannes-de-Roches Formation. From this and from facies similarities, the Lower and Middle members of the Cannes-de-Roches Formation are now considered to be equivalent to the Bonaventure Formation. It is proposed to abandon these two member designations and to only keep the Bonaventure Formation. The remaining Upper Member of the Cannes-de-Roches Formation is renamed the Pointe Sawyer Formation. A late Viséan to early Namurian age is attributed to this grey clastic formation from spore analysis. Dark reddish-brown sandstones conformably overlie the Pointe Sawyer Formation in the Mal Bay area. They correspond to the beginning of sedimentation from more distant sources within the regional Carboniferous stratigraphic succession, which was until then characterized by sedimentation from proximal sources. This previously unidentified unit is here referred to as the Chemin-des-Pêcheurs Formation.

2.2 RÉSUMÉ

Le Membre Supérieur de la Formation de Cannes-de-Roches a récemment été identifié recouvrant la Formation de Bonaventure dans la région de New-Carlisle, plus de 100 km au sud-

ouest des affleurements qui furent antérieurement documentés pour cette unité. De plus, la couverture résiduelle discontinue de la Formation de La Coulée, recouverte en discordance par la Formation de Bonaventure, a aussi été identifiée sous le Membre Inférieur de la Formation de Cannes-de-Roches, montrant avec celui-ci le même type de contact. L'ensemble de ces faits mis de pair avec la similitude des faciès font que les membres Inférieur et Moyen de la Formation de Cannes-de-Roches sont maintenant considérés comme les équivalents de la Formation de Bonaventure. Il est proposé d'abandonner ces deux membres et de ne conserver que la Formation de Bonaventure. Le Membre Supérieur restant est renommé Formation de Pointe Sawyer. Un âge Viséen tardif à Namurien précoce est attribué à cette formation clastique grise de par l'analyse de spores. Des grès bruns rougeâtres foncés recouvrent de façon concordante la Formation de Pointe Sawyer dans la région de La Malbaie. Ils correspondent au début d'une sédimentation provenant de sources plus distales à l'intérieur de la succession stratigraphique carbonifère régionale, laquelle était jusqu'alors caractérisée par une sédimentation provenant de sources proximales. Cette unité stratigraphique est nouvellement identifiée et est ici définie en tant que Formation du Chemin-des-Pêcheurs.

2.3 INTRODUCTION

The Carboniferous stratigraphy in the northwesternmost sector of the upper Paleozoic Maritimes Basin (southeastern Canada), in the area of the Gaspé Peninsula, was included within the Bonaventure Formation by Logan (1846). It was later subdivided into the Cannes-de-Roches and Bonaventure formations (Figs. 2.1 and 2.2) by Alcock (1935), who also excluded the red clastics of the Malbaie Formation (Devonian) from the Bonaventure Formation.

Alcock (1935) subdivided the Cannes-de-Roches Formation into three members: a Lower Member dominated by red conglomeratic breccia, a Middle Member mainly composed of red mudstones, and an Upper Member mainly composed of grey sandstones and conglomerates with carbonized plant remains (see also Rust, 1981). The more extensive Bonaventure Formation is mainly composed of red conglomerates, sandstones and mudstones. Paleosol overprints are common in both formations.

Of all these units, only the Upper Member of the Cannes-de-Roches Formation has yielded spores for dating, although no details concerning the composition of the assemblages have been previously published. Hacquebard (1972) and Barss in Hacquebard (1972) suggested an Early Namurian age (c/b zone) for the spores, whereas Barss (personal communication in Rust, 1981) proposed a Viséan age. The entire succession is interpreted as the product of fault-related continental sedimentation (Rust *et al.*, 1989).

The stratigraphic relationship between the two formations has never been clear. Since Alcock (1935), the hypothesis that they are penecontemporaneous, but deposited in two distinct Carboniferous basins separated by a thin ridge of pre-Acadian rocks, has prevailed. Kirkwood (1989) mentioned an interdigitation between the Bonaventure and

Cannes-de-Roches formations in the Percé area and considered the Cannes-de-Roches as contemporaneous with the basal beds of the Bonaventure Formation. This idea was subsequently adopted by Brisebois *et al.* (1992) (Fig. 2.1).

Van de Poll (1995) considered the Bonaventure Formation as a Windsor-Canso (Windsor-Mabou, sensu Ryan *et al.*, 1991) equivalent, and the Cannes-de-Roches as a Canso-Riversdale (Mabou-Cumberland, sensu Ryan *et al.*, 1991) equivalent. The correlations of van de Poll (1995) thus place the Cannes-de-Roches Formation higher in the stratigraphy than the Bonaventure Formation, which contradicts Kirkwood (1989) and Brisebois *et al.* (1992).

A third Carboniferous unit, the La Coulée Formation, has been recently identified in the Gaspé Peninsula (Jutras *et al.*, 1999). The erosional remnants of this formation are unconformably overlain by the Bonaventure Formation at different localities in the southern Gaspé Peninsula (Fig. 2.2).

New field data collected during a thorough review of the Carboniferous series in the Gaspé Peninsula have cast doubt regarding the current interpretation of the stratigraphic record. A thick, discontinuous groundwater calcrete, typical of the erosional remnants of the La Coulée Formation, is not only found underneath the Bonaventure Formation but has also been identified below the lithologically similar Cannes-de-Roches Formation at various localities (Fig. 2.2). Moreover, a plant bearing facies identical to that of the Cannes-de-

Roches Upper Member has been identified overlying the Bonaventure Formation in two outcrops along the coast between the towns of New-Carlisle and Bonaventure.

These new data have demonstrated the need to re-evaluate the stratigraphic relationship between the Cannes-de-Roches and Bonaventure formations. The two formations are examined in this paper using facies analysis from outcrops and thin sections, stratigraphic correlation, paleocurrent measurements, calcimetry, X-ray diffraction and palynology. Full description is provided for three composite sections from two specific study areas (Fig. 2.3, 2.4). A new stratigraphic framework and more detailed paleoenvironmental reconstructions are proposed. Also, an attempt is made to correlate the northern Chaleur Bay units with those of the rest of the Maritimes Basin.

2.4 SEDIMENTARY FACIES DESCRIPTION

2.4.1 The Cannes-de-Roches Cove succession (Fig. 2.3A and Fig. 2.4A)

This section is located on the south shore of Mal Bay. The direct contact between this subvertically tilted post-Acadian succession and its basement is obscured by brittle sliding of the basal Carboniferous strata on the underlying basement rocks, which probably occurred during the deformation episode that led to nearly vertical tilting of the strata. A massive calcrete up to 12 m thick overlies the Ordovician to Silurian limestone basement of the Matapedia Group (Fig. 2.2, locality 5). Rust (1976) identified a thinner section of this basal calcrete near Belle-Anse, on the north shore of Mal Bay (Fig. 2.2, locality 4), but the thick south shore outcrops, which are relatively inaccessible, have not previously been reported.

As shown in Table 2.1 (samples 9 and 10) and Fig. 2.5A, the calcrete cement is composed of over 80% calcite. It is also rich in silica. Scarce floating clasts are disseminated throughout the calcrete and become progressively more rounded and abundant going up the section. Limestone and volcanic clasts are most abundant and are often silicified.

Red clastics overlie the calcrete with a sharp contact (Fig. 2.6). The lower 15 to 20 m are conglomeratic breccia, with clasts mainly composed of siliceous limestone from local sources (the Early Devonian Forillon and Indian Cove formations). The beds bearing more rounded clasts include abundant quartz pebbles and occasional red jasper. Large sub-angular red jasper clasts have also been found in coarse breccia. These coarse red beds correspond to what has been referred to as the Lower Member of the Cannes-de-Roches Formation (Alcock, 1935). They are followed by the 30 to 35 m thick Middle Member, composed of gradually fining upward alternations of coarse and fine red beds with abundant nodular paleosol overprints and green copper mineralization haloes (Fig. 2.7). Similar mineralization haloes are also found in the Bonaventure Formation at various localities along the Chaleur Bay shore cliffs, notably at Caplan (Fig. 2.2). Calcrete hardpans in mudstones are found within the topmost metres of the Middle Member.

The red clastic beds are overlain by ~20 m of grey clastics with carbonized plant remains (Fig. 2.8), which were assigned to the Upper Member of the Cannes-de-Roches Formation by Alcock (1935). The difference in competence between the first grey beds and the underlying red beds has brought the former to slide on the latter during posterior gravity-induced collapsing within the subvertical sections of the Cannes-de-Roches Cove, a coastal erosion process that is still currently active. The uppermost mudstone beds are crumbled, which greatly limits interpretation of their contact with the overlying grey clastics.

Such brittle sliding of large slabs, which can be more than 100 m-wide, has extensively affected the subvertical sections at Cannes-de-Roches Cove. As these slabs are lying flat on each other, they can easily be confused for continuous strata and attempts to trace back the stratigraphy have to be made with caution, otherwise erroneous thicknesses may be obtained. For example, Rust (1981) recorded an inflated thickness of almost 40 m for the Upper Member of the Cannes-de-Roches Formation, whereas we obtained a thickness of only 20 m for the same strata.

Braided conglomerate channel fills are dominant in the Upper Member. In 1997, a 1-2 m layer of buff sandstone separating two fining-upward conglomeratic units could be observed in a 20 m thick outcrop. Unfortunately, since then, the upper conglomeratic unit has collapsed into the sea, along with the underlying buff sandstone, and no continuous section of the Upper Member remains, although slabs of both fining-upward units can still be observed in their entire thickness.

Clast composition in the Upper Member is slightly more polygenetic than in the underlying red beds, but locally derived limestone clasts are still largely dominant in the conglomerates as are limestone grains in the lithic graywackes (sensu Pettijohn 1975), which are the dominant type of sandstones in both units. This suggests that the source was very local, even for the sandstones. The unabraded and unsorted nature of the coaly fragments also suggest relatively short transportation by water prior to deposition.

The grey clastics with plant remains of the Upper Member pass upward into 4 to 5 m of pinkish-grey cross-bedded sandstones, which gradually become dark reddish-brown along with a progressively reduced content in calcite and plant remains (Fig. 2.5 and samples 25-27 in Table 1). Several large pieces of carbonized wood can be observed parallel to bedding between the grey clastics and the pinkish-grey beds (Fig. 2.8).

The remaining 5 to 6 m of the succession are dark reddish-brown laminated sandstones (Fig. 2.9) with no more than 0.2% calcite and 97.6% quartz (Table 2.1, samples 28-30). There is 15-25% porosity in this poorly cemented sandstone which was partly caused by recent sub-soil weathering and which may lead to an underestimation of the original calcite content. However, based on the observation of small non-porous areas on thin-sections, the matrix and cement that have been removed by weathering were apparently clay-rich and nearly calcite-free. Although some clasts may also have been removed, it is inferred that limestone grains were absent prior to weathering because they were already absent from the well-preserved rocks of the underlying pinkish-grey transitional beds.

Although X-ray diffraction indicates 97.6% quartz, these sandstones include 10-15% lithic fragments, many of which are strongly silicified. The sandstones are therefore still relatively immature and classify as sublitharenites (Pettitjohn, 1975). The original thickness of this previously unidentified dark reddish-brown sandstone unit is unknown and only 10 m, including the transitional pinkish-grey beds, have been recognized.

2.4.2 The Percé-Beach - Mont Sainte-Anne succession (Fig. 2.3A and Fig. 2.4B)

The basement, consisting of limestone of the Matapedia Group, is separated from the red clastic beds of the Bonaventure Formation by a 4 to 5 m-thick groundwater calcrete which has been interpreted as an erosional remnant of the La Coulée Formation by Jutras *et al.* (1999). The contact between the basement and the calcrete is clear but not sharp, the topmost metre of the basement being affected by calcretization.

The contact with the overlying red clastics is sharper. Red conglomerates and muddy, nodular paleosols, with a very high lateral variability, occupy most of the lowest 25 m. They are followed by ~25 m of laminated sandstones with thin interbeds of mudstone.

The remaining 300 m of the succession, which forms the Mont Sainte-Anne outlier, is composed of massive conglomeratic beds, several metres thick.

Clast composition in the conglomerates includes 65-80% limestone, 5-15% clastic rocks, 10-20% quartz pebbles, and disseminated red jasper (according to three petrographic counts; N=112). The conglomerates lack internal structures such as clearly defined clast imbrication and intrabed stratification. As there is no overlying formation, total thickness of the Bonaventure Formation in the Percé area is unknown.

2.4.3 The New-Carlisle succession (Figs. 2.3B and 2.4C)

The mudstone basement on the west side of New-Carlisle belongs to the Late Silurian Indian Point Formation of the Chaleurs Group (Bourque and Lachambre, 1980). A 2 m erosional remnant of an unidentified clastic formation ([3]) separates the pre-Acadian basement from the red clastics of the Bonaventure Formation. There is no remnant of the La Coulée Formation calcretes underlying the Bonaventure Formation in this area, but a 3 m thick calcrete underlies that formation at Caplan (Fig. 2.2, locality 9), 36 km to the west-northwest, and a 12 m calcrete underlies that formation at Saint-Elzéar (Fig. 2.2, locality 8), 22 km to the north-northwest (Jutras *et al.*, 1999).

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[3] Cette unité est associée à la Formation de Paspébiac dans le Chapitre 3.

Planar beds of sandstone occupy the first few metres of the succession, passing into ~7 m of trough cross-stratified sandstones and conglomerates. Locally derived volcanic and sedimentary rocks of the Chaleurs Group (Silurian) and of the unidentified basal post-Acadian clastic unit form the bulk of the clasts in the conglomerates. Quartz pebbles form ~15% of the 1-5 cm clast fraction (n=30) and disseminated red jasper clasts are common. The overlying 15 m are monotonous planar beds of sandstone, locally incised by a large ~3 m thick conglomerate bed.

Close to the 25 m level, a series of large and laterally persistent planar cross-sets, up to 3 m thick, appear and remain abundant throughout the upper half of the Bonaventure Formation in this area (Fig. 2.10). The first occurrences are intercalated with nodular, muddy paleosols. They are followed by ~9 m of thickly bedded sandstones and a second series of thick planar cross-sets. In one of these beds, several 10-15 cm-thick hardpans, composed of up to 100% calcite, have formed parallel to the cross-sets and oblique to the general bedding (Fig. 2.11).

A channel fill of grey clastics with plant remains, identical to the Upper Member of the Cannes-de-Roches Formation but over 100 km southwest of Cannes-de-Roches Cove, cuts through the uppermost laminar sandstones of the Bonaventure Formation at Pointe Sawyer (Figs. 2.12A, B). A lag of coarse and rounded Bonaventure Formation sandstone clasts occupies the bottom of the channel (Fig. 2.12C). This is followed by ~ 1 m of grey conglomerate and sandstone showing numerous vertical changes in the granulometry, which indicate flow intensity variations and which are typical of fluvial environments. The upper 3 m are grey mudstones intercalated with thin beds of grey sandstone. The contact between the red clastics of the Bonaventure Formation and the first metre of overlying grey clastics has also been observed at one more site, at the mouth of Cullens Brook, 4 km to the west (Fig. 2.3B). This outcrop can only be observed at low tide.

Numerous large boulders up to several metres in maximum diameter of the grey clastic facies with plant remains have been washed out of till material by coastal erosion and are abundant on the beach between the two sites, especially near the Cullens Brook outcrop. From the size of these blocks, it can be concluded that more extensive remnants of the same facies likely exist in the gentle synclinal structure where the Bonaventure River delta is located to the north, upstream from the general glacial flow established by Veillette and Cloutier (1993). This depression, however, is occupied by thick Quaternary material and recent alluvium. Mapping of the grey clastics with plant remains (PS) in the Bonaventure River delta (Fig. 2.3B) is therefore a cartographic extrapolation from only one bedrock exposure at the periphery of this well buried area.

2.5 PALYNOSTRATIGRAPHY

Seven mudstone samples were collected for palynological analysis from the Pointe Sawyer locality and eight from the Cannes-de-Roches Cove locality; all but one sample from each contained well preserved palynomorphs (Fig. 2.13). The assemblages are similar (Appendix II), and in terms of the zonal scheme proposed by Utting (1987), the presence of *Schopfipollenites acadiensis, Knoxisporites triradiatus, Rugospora corporata* var. *verrucosa* indicates an age no older than the *Schopfipollenites acadiensis - Knoxisporites triradiatus* (AT) Zone. However, in some samples, rare specimens of *Ibrahimispores magnificus* indicate a correlation with the younger *Grandispora spinosa - Ibrahimispores magnificus* (SM) Zone, although other taxa diagnostic of that zone, such as *Grandispora spinosa, Raistrickia nigra, Schulzospora bilunata* and *Tricidarisporites arcuatus,* were not seen.

Based partly on comparison with the spore zones of western Europe (e.g. Clayton *et al.*, 1977), the SM Zone was assigned a Brigantian (late Viséan) age by Utting (1987). However, even in western Europe the Viséan/Namurian boundary is difficult to place from palynological criteria, and thus here, where only limited data are available, a Brigantian to Pendleian (early Namurian) age range is suggested. In terms of lithostratigraphic units of Nova Scotia, this places the intervals studied at the Windsor/Mabou (Canso) boundary (Fig. 2.1), a conclusion similar to that reached by earlier workers (Hacquebard, 1972 and Barss, in Hacquebard, 1972).

The good spore preservation suggests a neutral environment at the sediment water interface that was neither oxic nor anoxic. One specimen of a spinose acritarch (*Veryhachium* sp.) was found in sample C-412602. If in situ this would suggest a marine environment of deposition, but it is more probably reworked from older rocks. The color of the spores is orange to dark reddish-yellow, indicating a Thermal Alteration Index of TAI 2 (Utting *et al.*, 1989*a*), which is within the "oil window".

2.6 PALEOCURRENT DATA IN THE BONAVENTURE FORMATION

Numerous paleocurrent measurements were taken in the Bonaventure Formation from 5-15 cm wide and 10-15 cm thick grooves at the base of breccia beds in the Percé area, and from orientated 0.5-10 m wide conglomeratic troughs in braided systems at various localities (Fig. 2.14). Only the most reliable features, where paleocurrent directions could not be mistaken, were taken into account. According to these measurements, the paleoflow direction is steadily to the south between Chandler and Percé, in the east part of the basin, and to the southeast between Chandler and Caplan.

Other measurements were taken from the laminae of thick (1 to 3 m) and laterally persistent tabular cross-bedded units such as the ones shown on Fig. 2.10. (1) The lateral persistence of these beds, over hundreds of metres, (2) the vertical succession of several sets in some cases, and (3) the lack of trend reversals, imply that they were probably not deposited by lateral accretion on longitudinal bars, but were rather deposited by avalanche on prograding transverse bars. The laminae therefore most likely dip in the current-flow direction. In the three areas in which such structures were identified, paleocurrent measurements suggest a drainage to the west or the southwest.

The exact stratigraphic level in which measurements were taken could not always be determined due to insufficient exposure. The change in paleocurrent orientation with time can best be observed within the continuous New-Carlisle succession (Fig. 2.4C). There, current directions change from a southeast orientation, in the coarse deposits of the lower half, to a northwest-to-southwest orientation, in the finer deposits of the upper half. Reliable paleocurrent measurements could not be made in the Bonaventure Formation facies of the two other successions (Fig. 2.4A, B).

2.7 PALEOENVIRONMENTAL INTERPRETATIONS AND STRATIGRAPHIC SUBDIVISIONS

2.7.1 The La Coulée Formation (calcretized clastics)

Rust (1982) considered that the calcrete separating the Cannes-de-Roches Formation from the Malbaie Formation conglomerates (Devonian) (Fig. 2.2, locality 4) is the product of intense weathering of the exposed basement surface, which would have occured prior to deposition of the Cannes-de-Roches Formation. This interpretation is supported by the fact that the basal calcretes, below both the Bonaventure and Cannes-de-Roches formations, show a sharp contact with the overlying clastics but a gradational one with the underlying basement. However, gravel-size volcanic clasts are found in the groundwater calcrete of the Cannes-de-Roches Cove succession, on the south shore of Mal Bay (Fig. 2.2, locality 5), although similar clasts are not found in the underlying Matapedia Group limestone basement. Hence, the calcrete there has developed within a coarse sediment overlying the basement and bearing volcanic rocks.

Furthermore, the interpretation of Rust (1982) does not correspond to any known case of calcrete formation. The thorough synthesis on calcrete genesis by Wright and Tucker (1991) does not mention any process in which an exposed surface is directly affected by the deep mineral replacement and displacement that is implied in the interpretation of Rust (1982). Laminar calcretes, which are the only ones developing directly on bedrock, are much thinner, do not penetrate the bedrock surface, and have a clearly different structure that can sometimes be confused with stromatolites (Wright, 1989). The only calcretes known to develop to a thickness exceeding 3 m are groundwater calcretes, occurring under the water table in thick unconsolidated sediments.

The discovery of the La Coulée Formation (Jutras *et al.,* 1999) offers new insights into the genesis of the thick calcretes that are commonly found between basement rocks and both the Bonaventure and Cannes-de-Roches formations. The coarse clastics of the La Coulée Formation were deeply affected by groundwater calcretization and were later uplifted and almost entirely eroded prior to sedimentation of the Bonaventure Formation, which has buried the few erosional remnants of the former unit. The basal calcretes, one of which clearly shows a stepped topography below the Bonaventure Formation at the northern tip of Bonaventure Island (Fig. 2.2, locality 7), are interpreted as being more widespread remnants of the La Coulée Formation due to their higher resistance to erosion than the formerly overlying clastic material of that formation. The basal groundwater calcrete that underlies the Cannes-de-Roches Formation is also interpreted as the erosional remnant of a calcretized clastic formation. It is similar in all respects to those underlying the Bonaventure Formation and also shows the same sharp contact with similar overlying red clastics (Fig. 2.6). However, the presence of volcanic clasts in the Cannes-de-Roches calcrete indicates that its host sediment was not fed by exactly the same source rocks as the clastic succession of the La Coulée Formation at Mont-Sainte Anne, which is exclusively composed of calcareous clasts.

The proposition of Jutras *et al.* (1999) to map the groundwater calcrete hardpans underlying the Bonaventure Formation as erosional remnants of the La Coulée Formation, even though the nature of the host sediment cannot always be determined ([4]), is extended to those found underneath the Cannes-de-Roches Formation. Although groundwater calcretes should be regarded as post-sedimentary diagenetic overprints, rather than stratigraphic units, they are rare enough in the geological record to be used as reliable stratigraphic markers. The thick and massive groundwater calcrete hardpans of the La Coulée Formation are the first reported occurrences of such calcrete facies in pre-Quaternary deposits (Jutras *et al.*, 1999). The environmental needs for massive groundwater calcrete formation are so specific

[4] Il est suggéré dans le Chapitre 3 de plutôt utiliser le terme informel de 'calcrètes de La Coulée' pour ces calcrètes.

that it is very unlikely that the few occurences within the Carboniferous rocks of Gaspé would represent more than one event. To date, no exposure has challenged the hypothesis that the various groundwater calcretes of Gaspé occupy the same stratigraphic position.

The La Coulée Formation is interpreted, from the absence of plant debris and from its extensive groundwater calcretization, as having evolved under a relatively arid climate (Jutras *et al.*, 1999). Based on modern settings (e.g., Arakel and McConchie, 1982; Arakel *et al.*, 1989; Jacobson *et al.*, 1988; Mann and Horwitz, 1979), proximal drainage connections to salt lakes, playas or an abandoned sea-arm is inferred (Jutras *et al.*, 1999). Such massive groundwater calcrete formation occurs in the zone where fresh groundwaters mix with the saline groundwaters of an evaporitic basin (Arakel *et al.*, 1989; Jacobson *et al.*, 1988).

2.7.2 The Bonaventure Formation (red clastics)

In the Percé - Mont Sainte-Anne succession, the first 25 m of the Bonaventure Formation are interpreted, from the high lateral variability and the chaotic nature of the conglomerates, to be distal alluvial fan material deposited during sudden and ephemeral events such as debris flows and flash floods. We agree with the conclusions of Rust (1984) and Rust *et al.* (1989) that such deposits must be the product of fault-controlled sedimentation. The overlying 25 m, containing finer fractions, are interpreted to represent the rapid passage from gravelly to sandy braidplain deposits, probably resulting from a slowing down of fault activity. The persistency of coarse conglomerates for over 300 m in the rest of the succession probably resulted from massive debris flows and flash floods in a rejuvenated alluvial fan environment generated by renewed fault activity.

The first half of the Bonaventure Formation in the New-Carlisle succession (i.e., the lowermost ~25 m) is interpreted as fluctuations from gravelly braidplain deposits to sandy braidplain and proximal alluvial plain deposits. As was mentioned earlier, the thick planar cross-strata that are abundant in the upper half of the succession are interpreted, from their lateral persistency over hundreds of metres, as prograding transverse hydraulic bar deposits. As the paleocurrent directions are perpendicular to those of the underlying alluvial fan and gravelly braidplain deposits (Fig. 2.14), the deposits are interpreted as belonging to trunk river systems. Such rivers are interpreted as having flowed parallel to the fault scarp from which clastic material issued, whereas flows from alluvial fans radiated perpendicular to the fault scarp. As for the oblique hardpans that are found near the top of the succession (Fig. 2.11), from the way they follow internal structures, it is clear that they are not pedogenic but were rather precipitated from groundwater circulation.

The Lower Member of the Cannes-de-Roches Formation is also interpreted as belonging to a fault-related alluvial fan complex (Rust, 1981). The environment of the Middle Member is interpreted as the distal equivalent of the Lower Member, a muddy braidplain intermittently receiving distal flood deposits (Rust, 1981; Rust *et al.,* 1989).

These two members have the same overall appearance, structure and composition as the Bonaventure Formation. The same succession of fault-related alluvial fan, gravelly braidplain and alluvial plain sediments, which would have evolved under an arid climate, is found in both successions (Rust, 1981; Zaitlin and Rust, 1983). They notably have the same characteristic deep orange-red color. Also, both show a predominance of limestone clasts and other locally-derived lithologies in their conglomeratic beds, along with abundant quartz pebbles and occasional red jasper (refer to samples 13-20 of Table 1 for sandstone composition). They also show the same characteristic green mineralization haloes and numerous nodular pedogenic calcretes (Figs. 2.4A-C).

The red clastics of the Cannes-de-Roches Formation are not only very similar in terms of facies to the Bonaventure Formation but are also in stratigraphic contact with the same units, namely the underlying groundwater calcrete hardpans and the overlying grey clastics with plant remains. The Bonaventure Formation at Percé (Fig. 2.4B) is much thicker than the red clastics of the Cannes-de-Roches Cove (Fig. 2.4A), but it is much thicker than those of the New-Carlisle area as well (Fig. 2.4C), which are also within the former limits of that unit.

As for the interdigitation between the Bonaventure and Cannes-de-Roches formations that was reported by Kirkwood (1989) for the Percé region, we believe that confusion may have occurred as this is one of the rare places where breccia beds, intercalated with conglomeratic beds, are found within the former limits of the Bonaventure

Formation (Fig. 2.15), whereas the coarse fractions of the red clastics in the Cannes-de-Roches Cove are typically more brecciated. The breccia beds only represent more proximal deposits and cannot be used to differentiate two formations.

We suggest abandoning the terms "Lower and Middle members" of the Cannes-de-Roches Formation as stratigraphic names since there is no apparent reason to differentiate these units from the Bonaventure Formation, which is more widely distributed and was identified first by Logan (1846).

Rust (1981) demonstrated that the red clastic beds of the Cannes-de-Roches Cove succession have southwest-trending paleocurrents on the north shore of Mal Bay, opposing northeast-trending paleocurrents on the south shore. From this and from facies distribution, he defined approximate limits to the paleovalley in which they were deposited (Fig. 2.16).

Zaitlin and Rust (1983) defined, from numerous paleocurrent data, the approximate limits of the much larger paleovalley in which the classic Bonaventure succession was deposited and which corresponds to the limits of the Chaleur Bay depression. Van de Poll (1995) refers to this paleovalley as the Ristigouche Basin (Fig. 2.16). The measurements taken by Zaitlin and Rust (1983) were concentrated in the western part of the basin and some conclusions regarding the drainage system of the entire basin were drawn from there.

Complementary paleocurrent data from the eastern part of the Ristigouche Basin have been collected in the Bonaventure Formation for this study. Figure 2.14 shows that paleocurrents in coarse alluvial fan and gravelly braidplain deposits of the Bonaventure Formation are steadily to the south on the north shore of Chaleur Bay, from Chandler to Percé. From the above-mentioned paleocurrent patterns, we conclude that the much thinner Cannes-de-Roches Cove succession, which has a distinct paleocurrent trend, was not deposited in the Ristigouche Basin but in an adjacent one, as was first proposed by Alcock (1935), that we herein refer to as the Cannes-de-Roches Basin (Fig. 2.16).

Laterally and vertically persistent systems of transverse bars, such as the ones illustrated on Figs. 2.10 and 2.11, have been identified in three areas of the Ristigouche Basin and indicate that trunk rivers, perpendicular to alluvial fans, were flowing steadily to the west or to the southwest. This contradicts the model of Zaitlin and Rust (1983), which suggested that ultimate drainage of the Ristigouche Basin was to the east (Fig. 2.16).

Deposits from large west-flowing trunk river systems are only found quite high in the stratigraphy of the Bonaventure Formation and it is possible that they represent a general flow reversal during the evolution of the basin. However, the pre-Carboniferous basement rocks extending to the west of Chaleur Bay are topographically higher than the above-mentioned Carboniferous trunk river deposits and, as there are no faults in between that could have been the locus of posterior block displacement between the two sectors, this probable paleorelief makes it unlikely for Carboniferous drainage to have maintained its westward trend much further. Carboniferous paleorelief is even steeper to the north (Gaspé Highlands) and to the south (Miramichi Highlands) (Peulvast *et al.,* 1996; Jutras and Schroeder 1999), and it thus seems probable that general drainage would have been trapped within the western part of the Ristigouche Basin. If this was the case, the rivers that built the thick transverse bars were then probably large enough to feed a big lake at approximately the same locality as present day western Chaleur Bay (Fig. 2.16).

As was mentioned earlier, the Bonaventure Formation, including what was formerly called the Lower and Middle members of the Cannes-de-Roches Formation, has been attributed to fault-related sedimentation from the high lateral variability of its continental deposits (Rust, 1981, 1984; Rust *et al.,* 1989; Zaitlin and Rust, 1983). Rust *et al.* (1989) proposed that the Bonaventure Formation was the product of dip-slip related sedimentation from the presence of inversely graded conglomerate channels which, they argued, suggest dip-slip rejuvenation. However, such rejuvenation could also be pictured in the context of oblique strike-slips.

From facies distribution and paleocurrent directions, it can be estimated that the main faults responsible for sedimentation of the Bonaventure Formation are, most realistically, (1) the Grand-Pabos and possibly the Rivière-Garin faults in the northwestern part of the Ristigouche Basin, (2) the Grande-Rivière Fault in the northeastern part, (3) the Millstream

Fault in the southern part ([5]), and (4) the Shickshock-Sud fault in the northeastern part of the Cannes-de-Roches Basin (Fig. 2.16). These correlations are proposed from the geographic relationship between the deposits and the main structures of the region.

2.7.3 The Pointe Sawyer Formation (grey clastics with plant remains)

From their equivalent facies and similar spore assemblage, it is clear that the grey clastics at Pointe Sawyer are lateral equivalents of the Upper Member of the Cannes-de-Roches Formation. This unit was thought to be synchronous with the red clastics of the Bonaventure Formation but characteristic of the Cannes-de-Roches Formation, which would have evolved in a slightly different environment where vegetation was able to proliferate (Alcock, 1935; Rust, 1981).

Noticing a 90° difference in paleocurrent directions between the red and the grey clastics of the former Cannes-de-Roches Formation, Rust (1981) proposed a model where the grey clastics were lateral equivalents of the red clastics but associated with a trunk river system flowing perpendicular to the alluvial fans (Fig. 2.17). According to this model, oxidization would not have occurred at the level of the trunk river system, the water table being closer to surface there than at the level of the nearby alluvial fans. This model is also supported by the fact that the grey clastics of the Cannes-de-Roches Formation have more

[5] Cette faille est retirée du modèle paléogéographique à l'intérieur du Chapitre 3, suite à l'obtention de nouvelles données dans le nord du Nouveau Brunswick.

rounded clasts and were subject to longer transportation than the underlying red clastics (Rust, 1981).

There is, however, nothing in the stratigraphic arrangement of the Cannes-de-Roches Cove succession that suggests a gradually prograding system of grey clastics over red clastics: the change from red to grey strata in Cannes-de-Roches Cove is quite sharp and shows coarse grey conglomerates overlying red mudstones. However, as was noted above, the collapse of subvertical strata obscures the contact between the two units in Cannes-de-Roches Cove, which leaves some uncertainties on its original sedimentologic nature.

A channel contact between the red and grey clastics with plant remains is well preserved at Pointe Sawyer, revealing a small erosional disconformity between the two units (Fig. 2.12). There, the drastic change in facies is clearly related to an overall environmental change because trunk river systems, red throughout, are identified in the underlying Bonaventure Formation from the presence of numerous and laterally persistent transverse bar systems (Figs. 2.10 and 2.11).

Following procedures from the International Subcommission on Stratigraphic Classification (Hedberg *et al.*, 1976), abandonment of the name Cannes-de-Roches is suggested for the remaining Upper Member to avoid confusion regarding the limits of that formation. Since the discovery of the Pointe Sawyer outcrop was fundamental in assessing this grey succession as a post-Bonaventure unit, we propose that it be referred to as the Pointe Sawyer Formation (Appendix III).

The common occurence of the trilete spores *Schopfites claviger* and *Colatisporites decorus* in the assemblages from the Pointe Sawyer Formation (Appendix II) would, according to van der Zwan *et al.* (1985), suggest that the climate was still arid, although it may have been relatively more humid than the underlying Bonaventure Formation, which lacks spores and has more arid characteristics such as oxidization, pedogenic calcretes and minor groundwater calcrete lenses.

muddy strata. As limestones are so well represented in the pre-Carboniferous basement geology of both the Gaspé Peninsula and northern New Brunswick, this must reflect a much more distant sediment source for the dark reddish-brown sandstones than for the underlying clastic successions. This passage from proximal to more distal sedimentation sources is observed diachronously in all of Atlantic Canada at approximately mid-Carboniferous time. The Maritimes Basin was dominated by fault-related sedimentation in Late Devonian and Mississippian times, while it mainly acted as a passive basin in Pennsylvanian and Early Permian times, collecting sediments from drainage systems whose sources were within the Alleghanian Orogen, which was being uplifted to the south (Gibling *et al.*, 1992; Thomas and Schenk, 1988).

Being in conformable and gradational contact with the underlying Pointe Sawyer Formation, of late Viséan (Brigantian) to early Namurian (Pendleian) age, deposition of the dark reddish-brown unit probably began during the Namurian, which may correspond to the approximate time when the northwest periphery of the Maritimes Basin would have started to receive sediments from the Alleghanian Orogen. This corresponds relatively well with the model of Gibling *et al.* (1992), in which drainage from the Alleghanian Orogen is suggested for the whole Pennsylvanian sub-period, starting in the middle of the Namurian. According to Slingerland and Furlong (1989), however, the Alleghanian chain first developed at the level of the southern United States, in early Pennsylvanian time, and peak deformation at the New England level only occurred in early Permian time. Consequently, the probable

Namurian age of the dark reddish-brown sandstones makes an Alleghanian provenance less likely.

Alternatively, cases of river antecedence with a north-south axis are reported in the north-central highlands of the Gaspé Peninsula (Mattinson, 1964). Jutras and Schroeder (1999) proposed, from geologic and geomorphic constraints, that these rivers must have maintained their trajectory during a late Paleozoic to early Mesozoic epeirogenic uplift in that region. As the south of the Peninsula acted mainly as a graben or half-graben structure, the source of these rivers, starting sometime in the late Paleozoic, must have been to the north, from the nearby Canadian Shield.

No paleocurrent data are available from the rare outcrops of these perfectly laminar sandstones to test the hypothesis that the source was either from the Alleghanian Chain, to the south, or from the Precambrian craton, to the north. However, the absence of feldspar grains, the small amount of metamorphic quartz and gneissic fragments (1-2%) and the presence of sedimentary rock fragments (~10%) do not support the hypothesis of a Precambrian source but rather suggest an Appalachian source.

These dark reddish-brown sandstones, which are the topmost unit of what remains of the Cannes-de-Roches Cove succession, have not been mentioned in earlier work on the former Cannes-de-Roches Formation. We propose to give this unit formation status in the light of the major environmental and petrographic changes that differentiate it from the underlying formations. We name it the Chemin-des-Pêcheurs Formation (Appendix IV) after the small dirt road that leads to the best outcrops.

2.8 CORRELATIONS WITH THE REST OF THE MARITIMES BASIN

As was mentioned earlier, thick groundwater calcretes such as the ones associated with the La Coulée Formation most typically develop at the periphery of evaporitic basins. In the upper Paleozoic stratigraphy of the Maritimes, such an environment is commonly represented in the strata of the Windsor Group. Moreover, the calcrete at Saint-Elzéar (Fig. 2.2, locality 8) overlies a surface that is interpreted as having been carved by coastal marine erosion (Jutras and Schroeder, 1999). Carboniferous marine erosion extending so far to the northwest can be best correlated with the base of the middle Viséan Lower Windsor, which consists of limestones of the Macumber Formation originating from a most extensive transgressive episode quickly followed by regression and thick deposition of evaporitic material (Geldsetzer, 1977; Lynch and Giles, 1995). The groundwater calcretes of the La Coulée Formation may have developed during the regressive lowstand that followed maximum transgression and left numerous evaporitic basins. A direct relationship between groundwater calcretization and regressive lowstands has been proposed in other studies (Sanborn, 1991; Tandon and Gibling, 1997).

The La Coulée Formation is known to be post-Middle Devonian as it lies unconformably on Acadian structures. Biostratigraphic data are unavailable to further constrain the age of this unit. However, based on geomorphic, lithostratigraphic and paleoenvironmental criteria, deposition of the La Coulée Formation most likely followed the Macumber Formation event (middle Viséan), and thus the former may be correlated with the evaporites of the upper part of the Lower Windsor.

The spore assemblage of the Pointe Sawyer Formation, which belongs to the SM Zone (late Viséan to early Namurian), is younger than the *Schopfipollenites acadiensis - Knoxisporites triradiatus* (AT) Zone (late Viséan), which is characteristic of the Upper Windsor, whereas the SM Zone is characteristic of the Mabou (or Canso) Group (Utting, 1987). The underlying red beds of the Bonaventure Formation, which lack biostratigraphic data, are possibly also equivalent to the Mabou Group ([6]); an hypothesis supported by the fact that this unit is separated from the underlying La Coulée Formation by a significant unconformity, which could possibly correlate with the one that separates the Windsor and Mabou (or Canso) groups in some sectors of the Maritimes (Howie and Barss, 1975).

It should be pointed out that the age ranges assigned to the AT and SM palynological zones do not correspond to the age attributed to the marine fauna that is found at the same stratigraphic level. Mamet (1970), based on foraminifers, assigned the uppermost carbonate of the Upper Windsor Group to the Namurian. However, this unit

[6] Une corrélation temporelle avec le Groupe de Windsor est considérée comme plus probable dans le Chapitre 3.

contains the AT spore assemblage, which lacks any spore taxa diagnostic of the Namurian. If the age determinations of the marine fauna are correct, the SM Zone is Namurian. The biostratigraphic uncertainty at the Viséan-Namurian boundary is currently being investigated ([7]).

As was mentioned earlier, the Chemin-des-Pêcheurs Formation is probably Namurian and therefore also correlates with the Mabou Group. It must have blanketed the whole Chaleur Bay region prior to post-Carboniferous erosion, as must the Pennsylvanian to Permian beds of the Pictou Group, which occupy the south shore of the Bay and most of the Gulf of St.-Lawrence (Legun and Rust, 1982; van de Poll, 1973). According to Ryan and Zentilli (1993), 1 to 4 km of the original late Paleozoic cover of the Maritimes has been eroded since Permian time, most of it prior to Jurassic time (also see Howie and Barss, 1975 and van de Poll *et al.,* 1995, for a synthesis of the upper Paleozoic stratigraphy of the Maritimes).

2.9 CONCLUSION

The thin Cannes-de-Roches Cove succession, which occupies the south shore of Mal Bay and which was previously included within the Cannes-de-Roches Formation by Alcock (1935), is a condensed version of the Carboniferous stratigraphy in the larger Ristigouche

[7] La Zone SM est maintenant considérée comme correspondante à un âge Namurien inférieur (J. Utting, comm. pers., 2001).

Basin, occupying most of the Chaleur Bay depression. It was synchronously deposited in a different basin that we propose to refer to as the Cannes-de-Roches Basin.

Four Carboniferous formations are recognized in the Cannes-de-Roches Basin, three of which are also found in the Ristigouche Basin:

1) Calcretized remnants of the La Coulée Formation (Jutras *et al.*, 1999) are sporadically found at the base of the succession in both basins. From geomorphic, lithostratigraphic and paleoenvironmental constraints, this non-dated unit is tentatively correlated with the Lower Windsor Group (middle Viséan).
2) The former Lower and Middle members of the Cannes-de-Roches Formation are correlated with the Bonaventure Formation, which unconformably overlies the La Coulée Formation. This unconformity is tentatively correlated with the one that separates the Windsor and Mabou groups of Nova Scotia and New Brunswick. In this view, the Bonaventure Formation would represent the basal Mabou (late Viséan or early Namurian). Faults responsible for sedimentation of the Bonaventure Formation in the southern Gaspé Peninsula were to the north, and drainage of trunk river systems, perpendicular to the alluvial fans, was mainly to the west or southwest, except for the western extremity of the basin where eastward paleodrainage has been previously interpreted (Zaitlin and Rust, 1983). Eastward and westward drainage probably merged into a lake.

3) The Upper Member of the former Cannes-de-Roches Formation, which records the passage from arid to slightly less arid conditions in late Viséan or early Namurian time, is now referred to as the Pointe Sawyer Formation, which can also be observed outside of the Cannes-de-Roches Basin, southeast of the town of Bonaventure. The spore assemblage of this formation correlates with Mabou units in the rest of the Maritimes Basin.

4) A fourth formation, which only crops out at the top of the Cannes-de-Roches Cove succession and which corresponds to a return to more oxic conditions, has also been recognized and named Chemin-des-Pêcheurs Formation. This non-calcareous formation (Namurian?) is also tentatively correlated with the Mabou Group and is notably the first record of sedimentation from distant sources in the post-Acadian succession of the Gaspé Peninsula which, till then, was characterized by proximal, fault-related

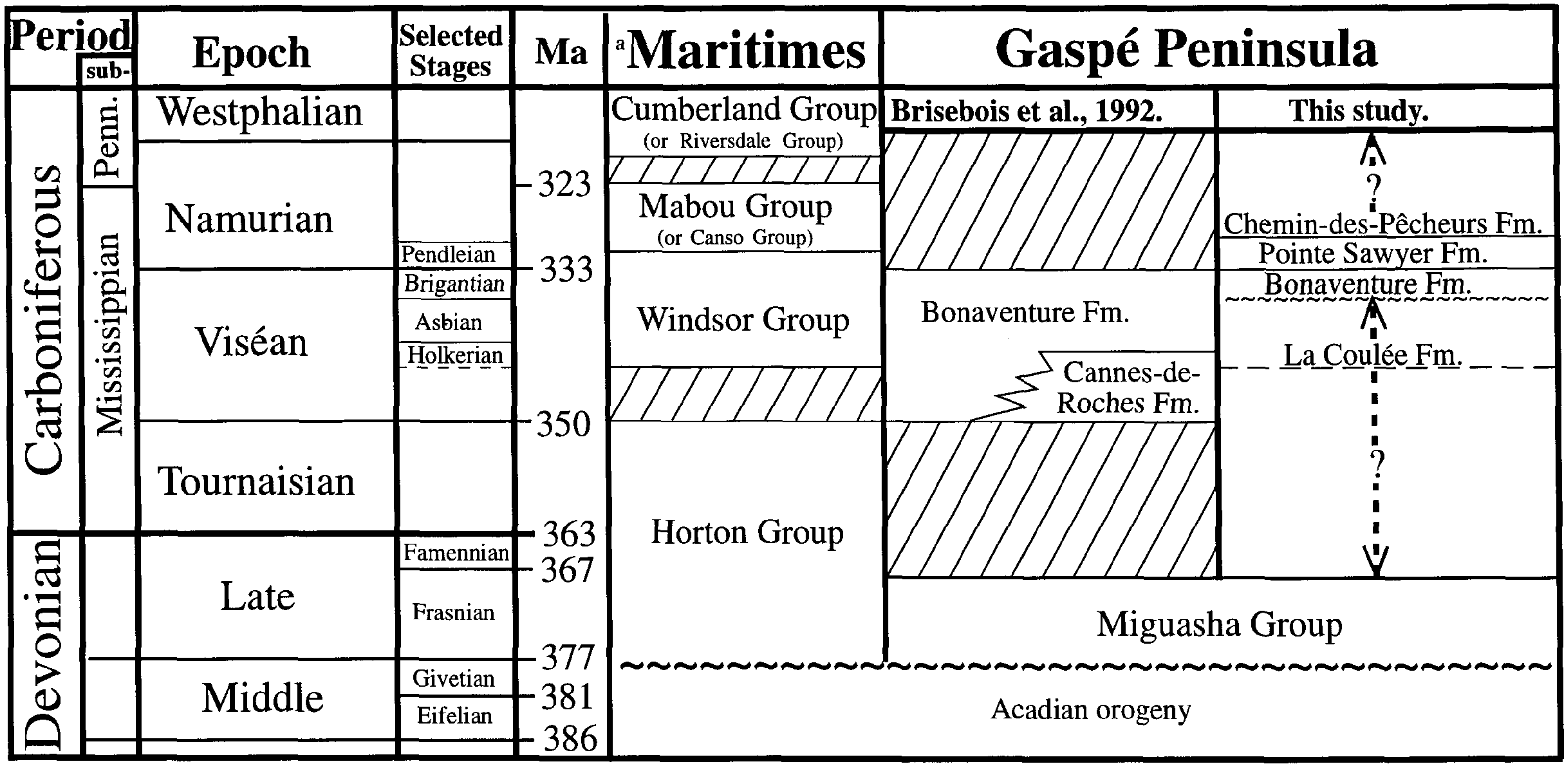

Fig. 2.1. Late Paleozoic stratigraphic record in the Maritimes and in the Gaspé Peninsula. Time-scale after Harland *et al.,* (1990). Cross-hatching represent hiatuses; wavy lines represent deformation events. (a) Modified from Bell (1944), Mamet (1970), Howie and Barss (1975), Utting (1987), Utting *et al.,* (1989b), and Ryan *et al.,* (1991).

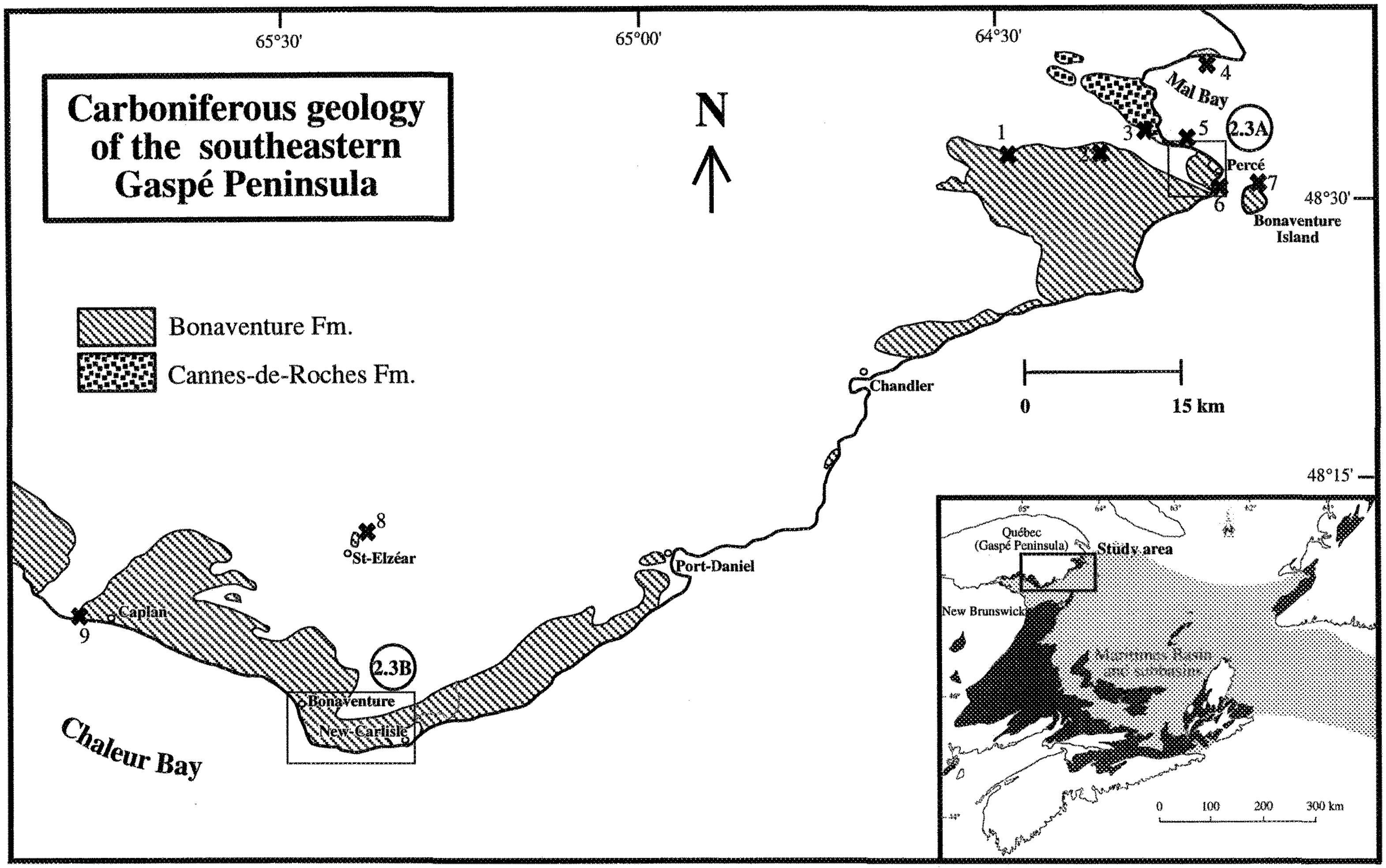

Fig. 2.2. Location of the study area. Rectangular blocks 2.3A and2.3B indicate the two specific study areas mapped on Figure 2.3. Also shown are the nine localities (1 to 9) where thick groundwater calcretes, typical of that found within the La Coulée Formation, have been identified underneath the Cannes-de-Roches and Bonaventure formations. The geology is from Brisebois *et al.*, (1992). The inset is modified from Gibling *et al.*, (1992), with dark and pale shadings representing, respectively, the inland and offshore rocks of the Maritimes Basin.

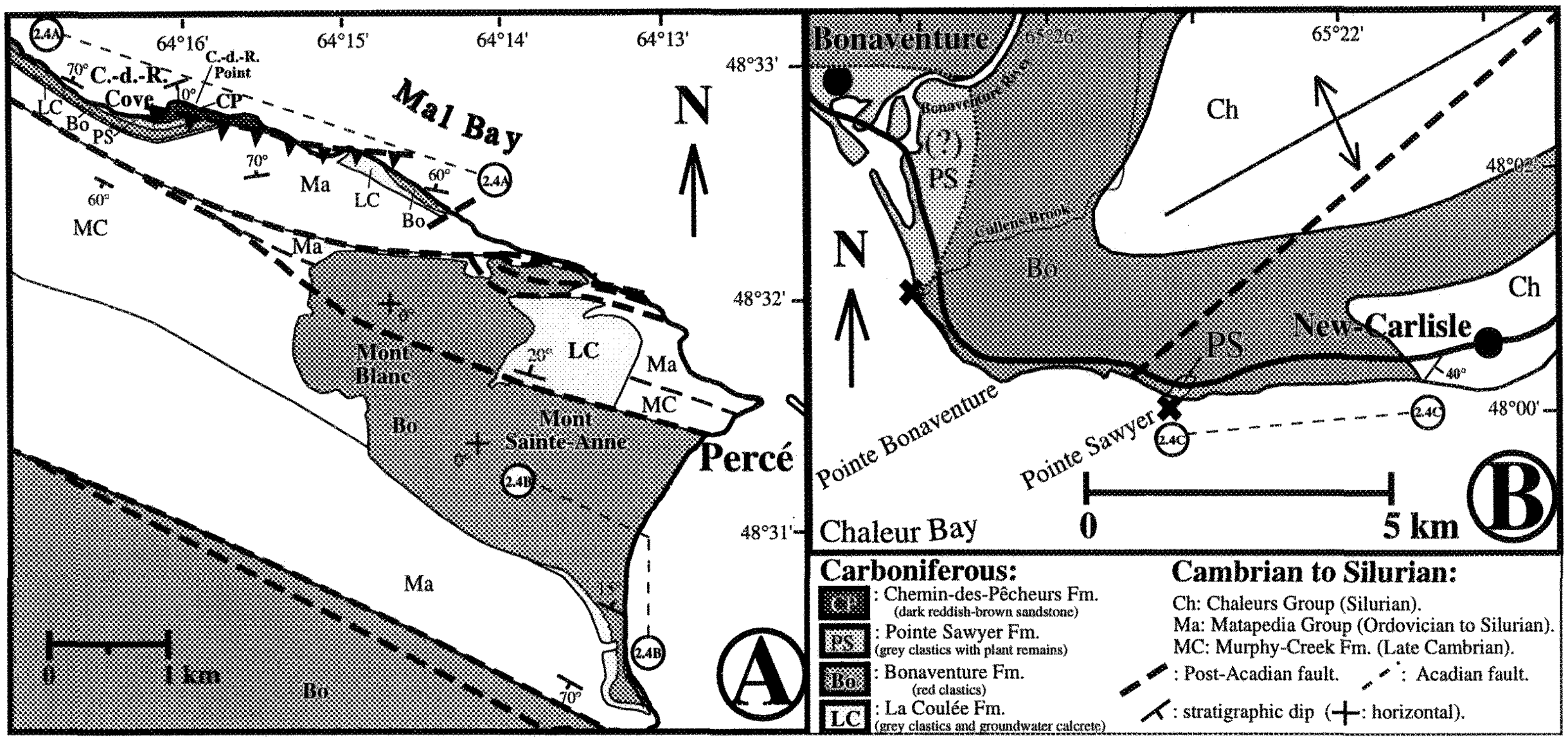

Fig. 2.3. The two specific study areas (A, B) showing the location of the three composite columns on Figure 2.4. (A) Geology of the Percé area, modified from Kirkwood (1989), with the location of columns 2.4A (Cannes-de-Roches sequence) and 2.4B (Percé-Beach - Mont Sainte-Anne sequence. C.-d.-R.: Cannes-de-Roches. (B) Geology of the New-Carlisle area, modified from Brisebois *et al.* (1992), with the location of column 2.4C (New-Carlisle sequence).

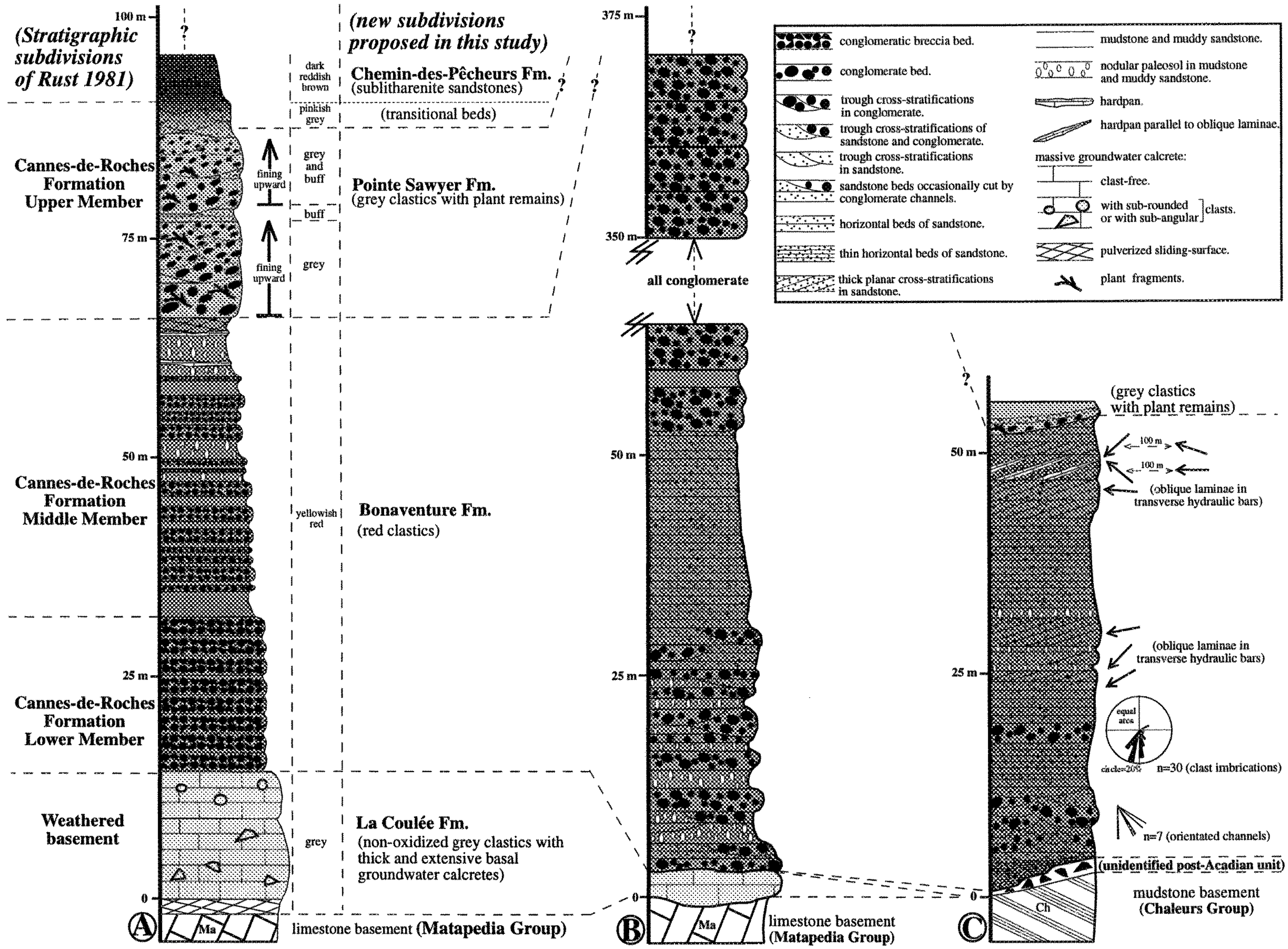

Fig. 2.4. Post-Acadian stratigraphy of the southeastern Gaspé Peninsula (A) Composite column of the Cannes-de-Roches Cove sequence. (B) Composite column of the Percé-Beach - Mont Sainte-Anne sequence. (C) Composite column of the New-Carlisle sequence (l'unité post-Acadienne non-identifiée est associée à la Formation de Paspébiac à l'intérieur du Chapitre 3).

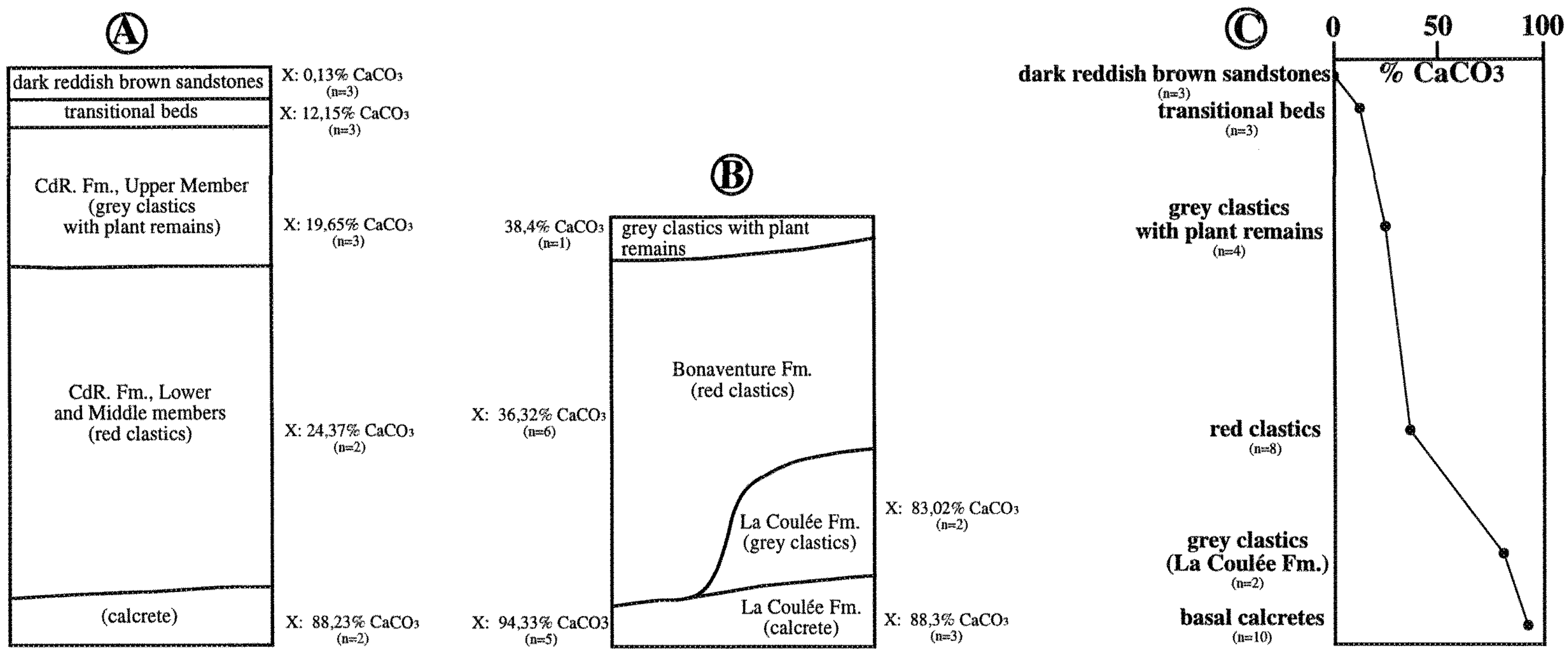

Fig.2.5. Average calcite content in the Carboniferous series of the southern Gaspé Peninsula according to numbers from Table 2.1. (A) Mal Bay exposures (Cannes-de-Roches Fm.). (B) Chaleur Bay exposures. (C) Cumulative average for each general facies.

Fig. 2.6. Contact between the basal groundwater calcrete and the overlying red clastics of the formerly called Lower Member of the Cannes-de-Roches Formation.

Fig.2.7. Alternations of (a) red conglomeratic microbreccia and (b) sandy mudstone beds with pedogenic features in the formerly called Middle Member of the Cannes-de-Roches Formation.

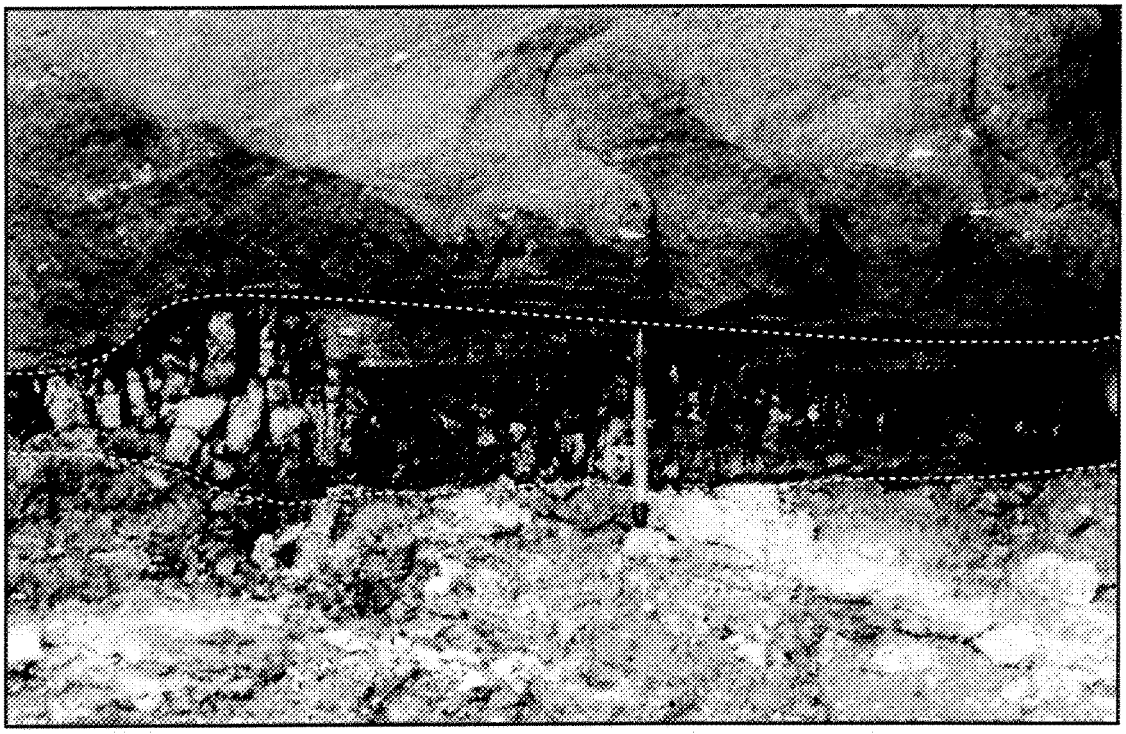

Fig. 2.8. Carbonized piece of wood at the contact between the grey clastics of the Cannes-de-Roches Cove (formerly called Upper Member of the Cannes-de-Roches Formation) and the overlying pinkish grey transitional beds.

Fig. 2.9. Laminar beds of the dark reddish brown sandstones at the Cannes-de-Roches Point.

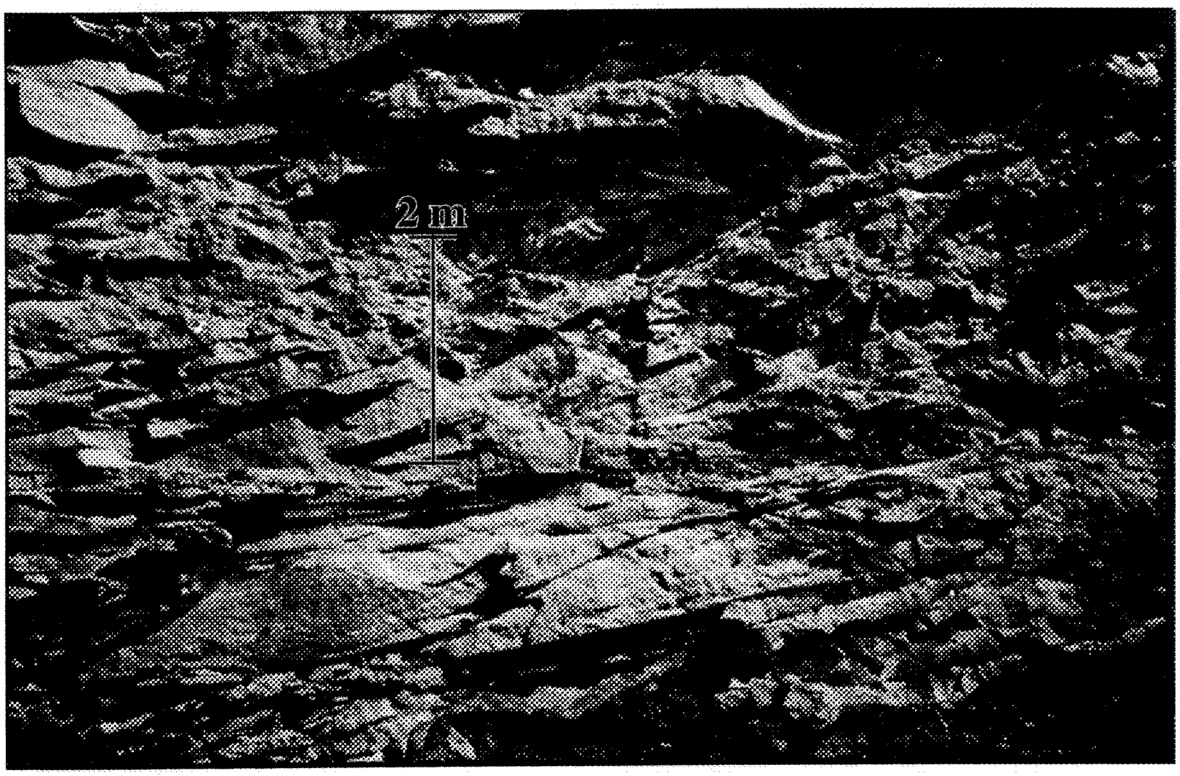

Fig. 2.10. Thick and laterally persistent cross-strata in the Bonaventure Formation near Pointe Sawyer.

Fig. 2.11. Hardpan parallel to cross-laminae in a thick tabular cross-bedded unit.

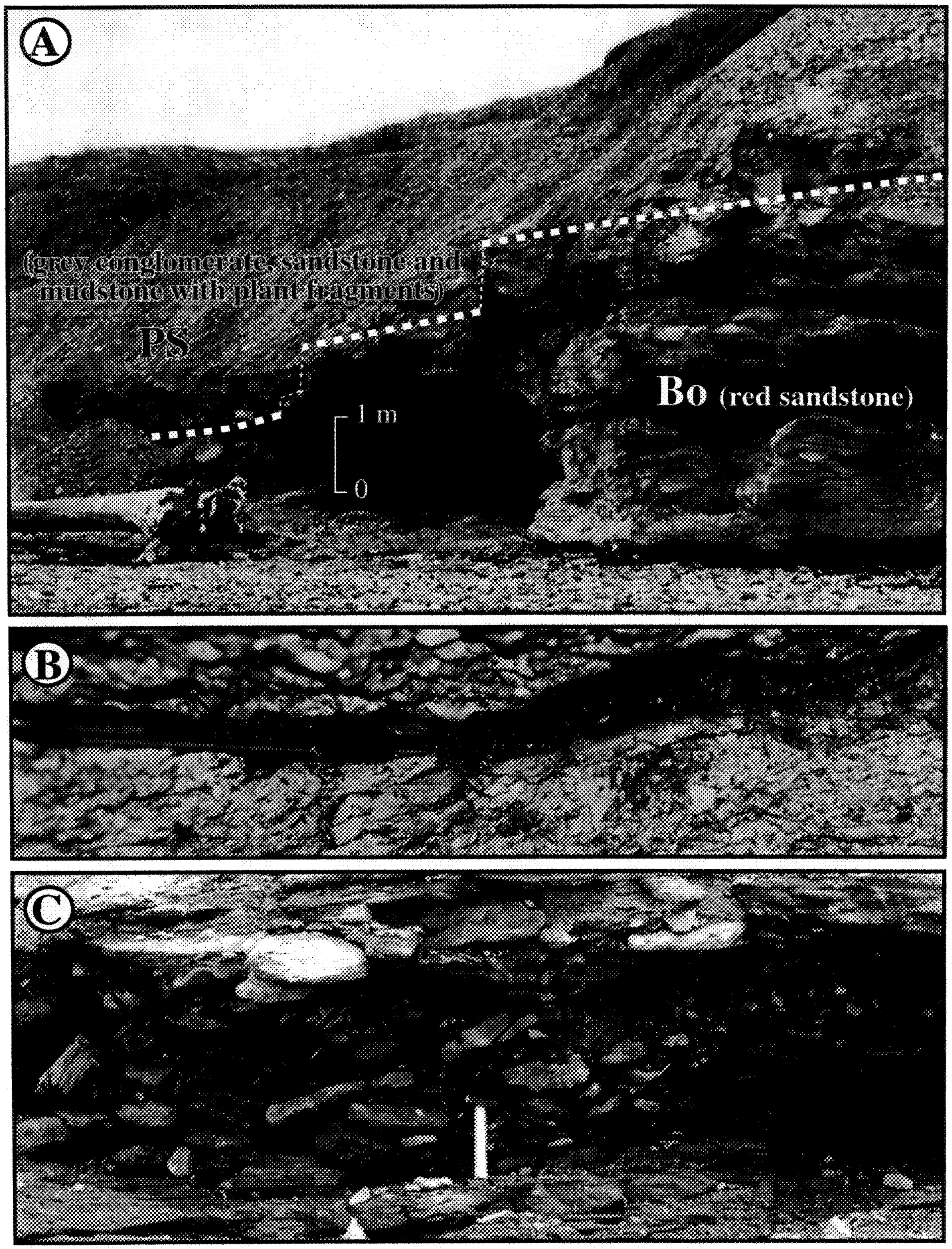

Fig. 2.12. Grey clastics with plant remains (PS) at Pointe Sawyer. (A) Channelized contact with the underlying Bonaventure Formation (Bo). (B) Carbonized piece of wood. (C) Lag of Bonaventure material at the bottom of the channel fill.

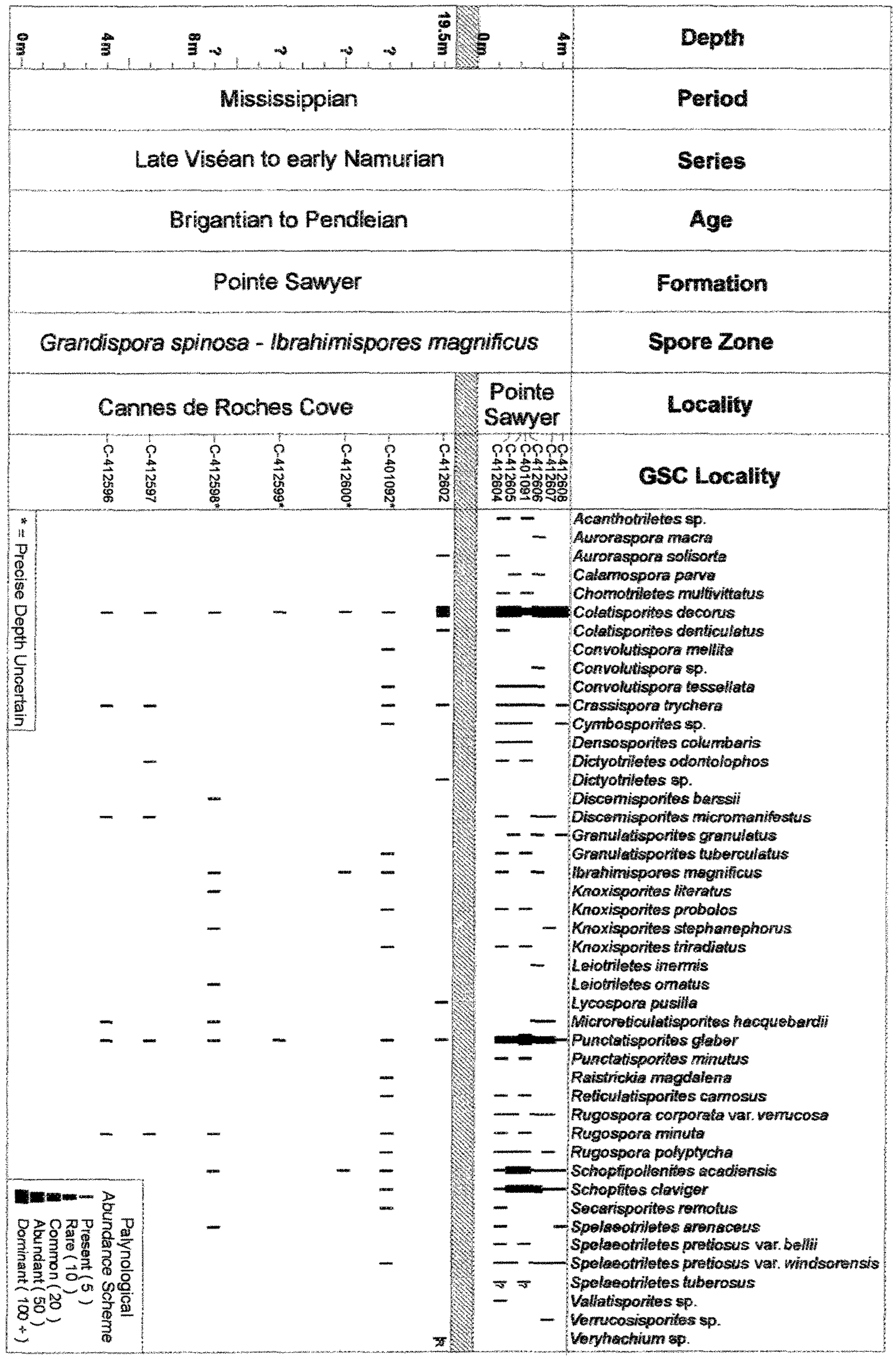

Fig. 2.13. Depth above base of section, age, spore zone, and vertical distribution of palynomorphs in the Pointe Sawyer Formation at the Cannes de Roches Cove and Pointe Sawyer localities (the GSC locality corresponds to the file number of each sample at the Geological Survey of Canada).

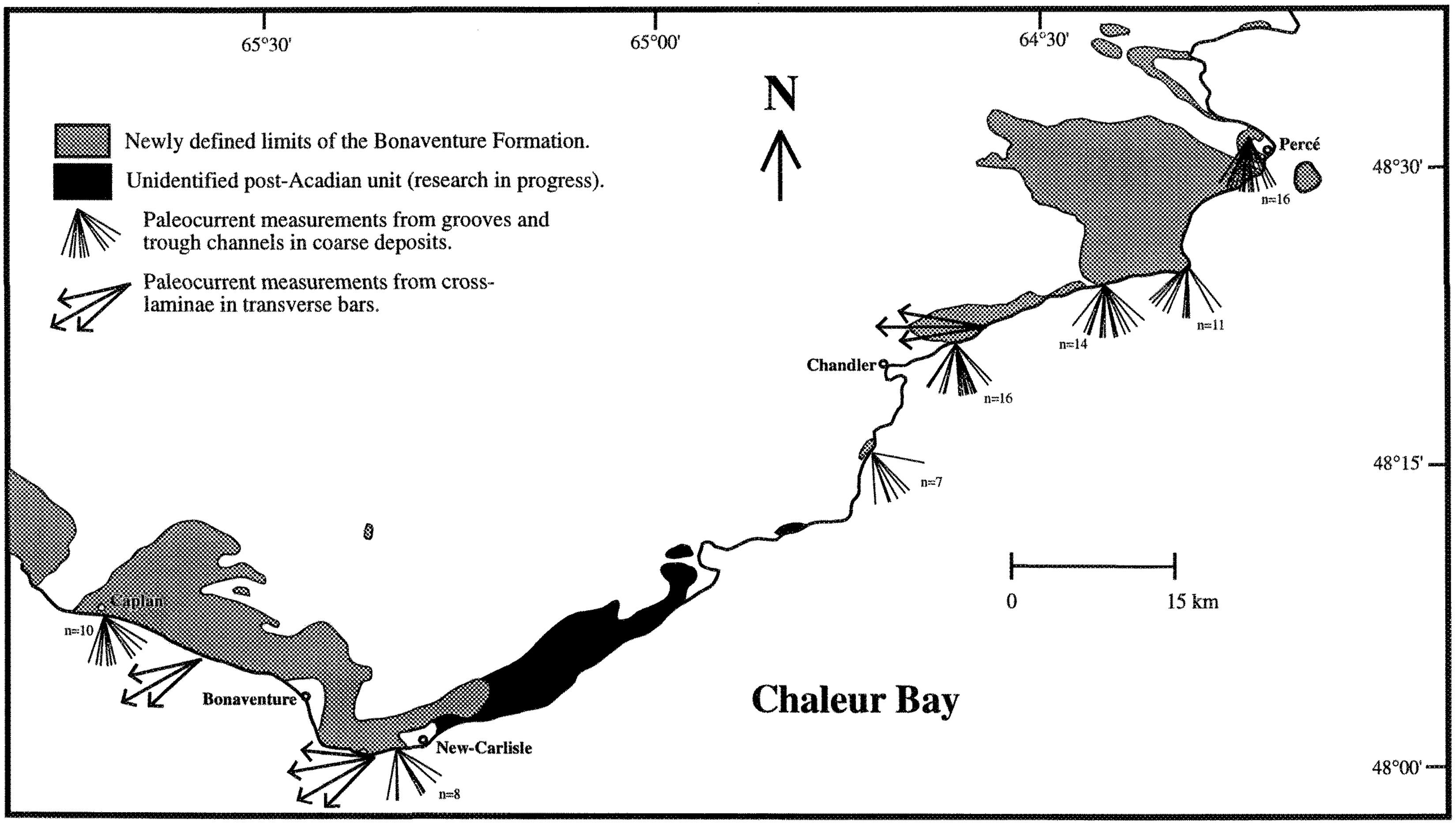

Fig. 2.14. Paleocurrent measurements taken from the Bonaventure Formation in the southeastern part of the Gaspé Peninsula. (l'unité post-acadienne non-identifiée sur cette figure est associée à la Formation de Paspébiac à l'intérieur du Chapitre 3)

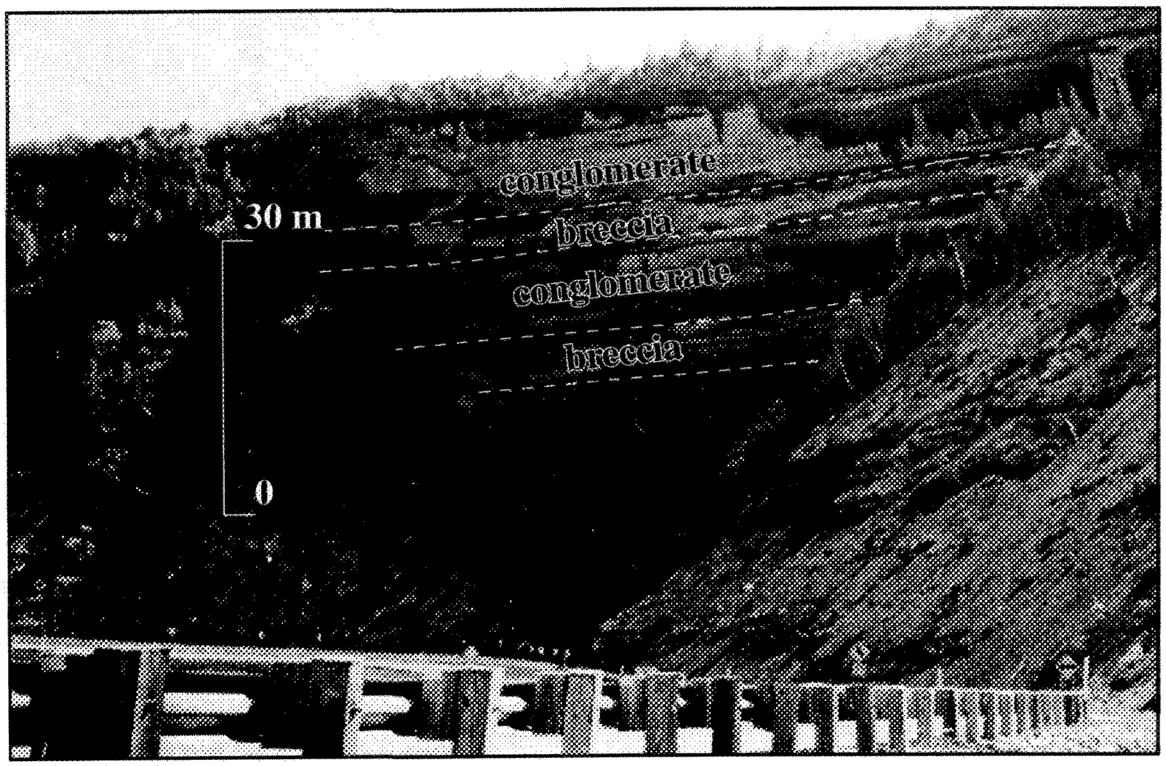

Fig. 2.15. Alternations of breccia and conglomerate beds in the Bonaventure Formation at Percé.

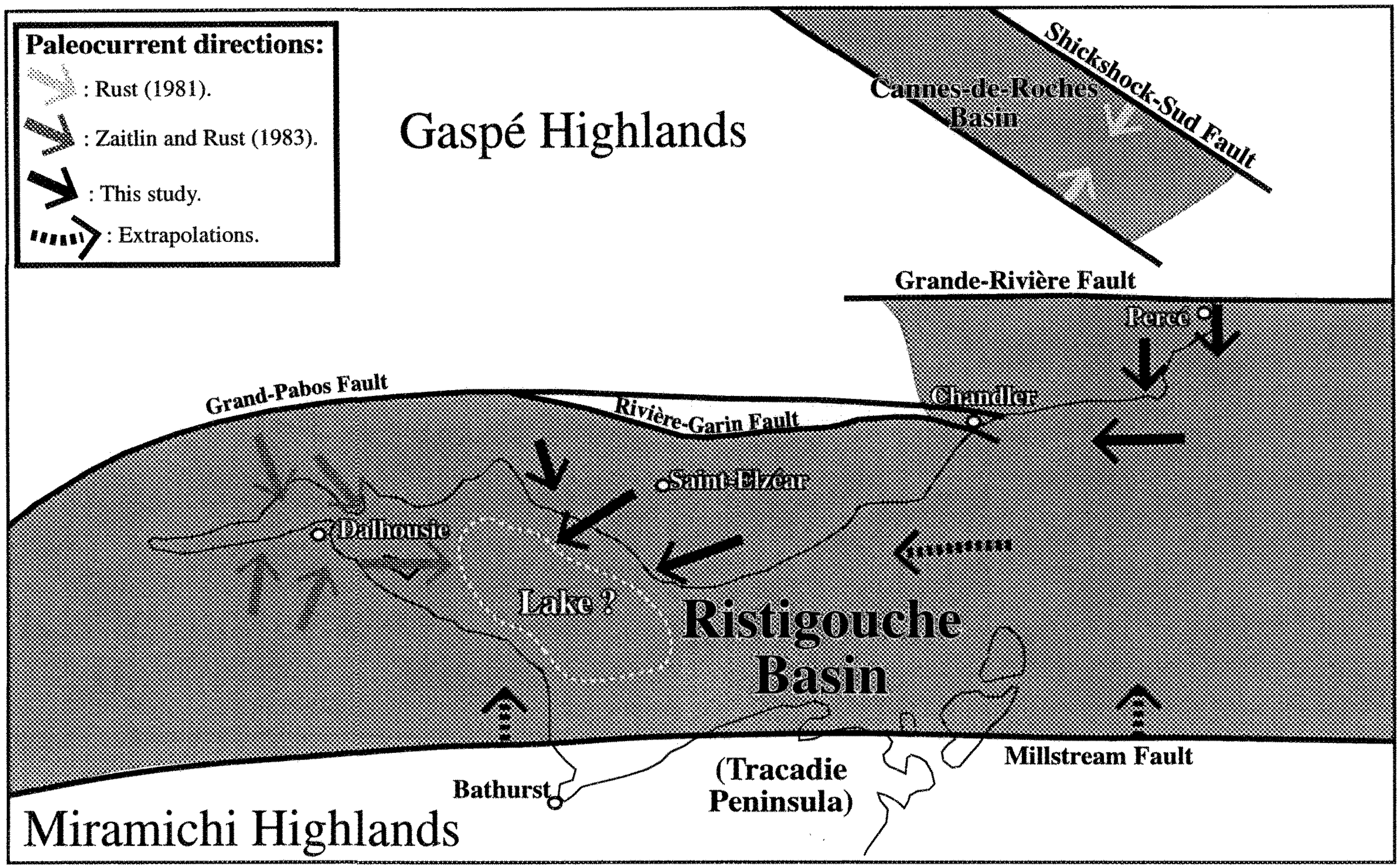

Fig. 2.16. Paleogeographic reconstruction of the Ristigouche, Cannes-de-Roches and Maritimes basins during sedimentation of the Bonaventure Formation. (des modifications à ce modèle sont apportées à l'intérieur du Chapitre 3 suite à l'obtention de nouvelles données dans le nord du Nouveau brunswickl esquelles suggèrent une équivalence des formations de Bonaventure et de Bathurst)

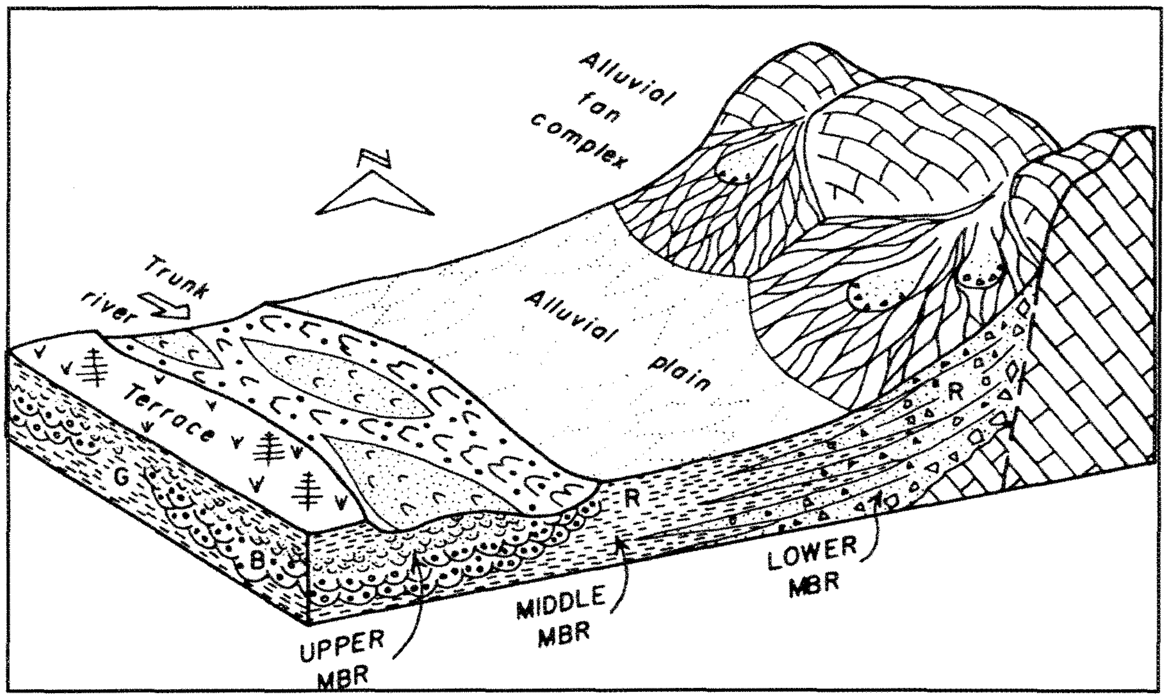

Fig. 2.17. Depositional model for the Cannes-de-Roches Formation by Rust (1981). R = red, B = buff, G = grey-green.

sample	unit	calcite (%)	quartz (%)	K-feldspar (%)	plagioclase (%)	muscovite (%)	chlorite (%)	hematite (%)
1	cal-LC	84,83	13,34	1,83	x	x	x	x
2	cal-LC	89,17	8,81	0,96	x	x	x	x
3*	cal-LC	90,91						
4	cal-Bon	95,47	3,46	x	0,19	x	x	0,19
5	cal-Bon	98,12	0,16	x	x	0,29	1,42	x
6*	cal-Bon	97,85						
7*	cal-Bon	91,51						
8*	cal-Bon	88,7						
9	cal-CdR	81,01	13,92	0,54	0,31	0,65	0,58	0,19
10*	cal-CdR	95,45						
11*	gss-LC	87,04						
12*	gss-LC	79,0						
13	rss-Bon	86,74	5,3	4,08	0,06	0,33	0,37	0,06
14	rss-Bon	11,6	77,71	1,67	x	0,35	x	0,27
15*	rss-Bon	36,8						
16*	rss-Bon	39,4						
17*	rss-Bon	28,4						
18*	rss-Bon	14,95						
19	rss-CdR	34,49	59,18	4,78	x	0,56	0,44	0,12
20*	rss-CdR	14,25						
21	gss-PS	38,4	54,71	0,46	1,15	1,15	2,99	x
22	gss-CdR	27,11	71,2	x	x	0,12	0,98	0,46
23*	gss-CdR	15,76						
24*	gss-CdR	16,09						
25	CP-trans	20,56	76,83	x	x	x	2,0	0,21
26*	CP-trans	9,11						
27*	CP-trans	6,79						
28	CP	x	97,6	0,07	0,12	0,16	1,58	0,23
29*	CP	0,2						
30*	CP	0,2						

Table 2.1. Mineralogical composition of various units in the Carboniferous series of the Gaspé Peninsula from calcimetry (*) and X-ray diffraction. cal-LC, thick basal calcrete in the grey clastics of the La Coulée Fm.; cal-Bon, thick calcrete underneath the Bonaventure Formation (Bon. Fm.); cal-CdR, thick calcrete underneath the Cannes-de-Roches Formation (CdR. Fm.); gss-LC, grey sandstone amid the conglomeratic facies of the La Coulée Fm.; rss-Bon, red sandstone of the Bon. Fm.; rss-CdR, red sandstone of the CdR. Fm.; gss-PS, grey sandstone with plant remains from Pointe Sawyer; gss-CdR, grey sandstone with plant remains from the Upper Member of the CdR. Fm.; CP-trans, transitional facies from the grey clastics with plant remains to the dark reddish-brown sandstones (pinkish-grey, cross-bedded sandstone) in the CdR. Cove; CP, dark reddish-brown sandstone from the CdR Cove.

CHAPITRE III

PALEOENVIRONMENTAL AND TECTONOSTRATIGRAPHIC CONTEXT OF THE PASPÉBIAC FORMATION (LATE DEVONIAN OR EARLY MISSISSIPPIAN), A NEWLY IDENTIFIED POST-ACADIAN RED CLASTIC UNIT IN THE SOUTHERN GASPÉ PENINSULA, QUÉBEC

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3.1 ABSTRACT

The Paspébiac Formation, a post-Acadian continental clastic unit that was previously mapped as the Bonaventure Formation (pre-Namurian unit), was recently identified in the southern Gaspé Peninsula of Québec. Remnants of the Paspébiac Formation are confined within two small NE-oriented grabens or half-grabens. The unit is characterized by oxidized and poorly-sorted detritus that underwent short transportation by debris flow and fluvial processes. The deposits buried a continental paleosurface dominated by pure limestone hogbacks, which suggests that the surface evolved under a dry tropical climate. The Paspébiac 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 (pre-Namurian unit). The calcrete has seemingly developed within the karstified upper beds of the Paspébiac Formation. Partial erosion of both the La Coulée and Paspébiac formations, as well as the massive groundwater calcretes, occurred prior to deposition of the Bonaventure Formation. The Bonaventure unconformably overlies these units in different sectors of the Gaspé Peninsula. Like the La Coulée and Bonaventure formations, the Paspébiac is undated. It unconformably overlies Acadian structures and pre-dates Mabou Group units, since it unconformably underlies the Bonaventure Formation. The latter unit is also undated, but is overlain by the grey clastics of the Pointe Sawyer Formation, which bear a spore assemblage corresponding to that of basal Mabou Group strata (earliest Namurian).

3.2 RÉSUMÉ

La Formation de Paspébiac, 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. Les vestiges de la formation de Paspébiac sont limités aux secteurs de deux petits grabens ou demi-grabens, orientés SW-NE. Cette unité est caractérisée par du matériel oxydé et mal trié ayant été soumis à un court transport par des processus fluviaux et par des coulées de débris. Ces dépôts ont enterré une paléosurface continentale dominée par de crêts de calcaire pur, lesquels suggèrent qu'elle ait évolué sous un climat tropical aride. La Formation de Paspébiac 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 semblerait s'être développée à l'intérieur de la partie supérieure karstifiée des lits de la Formation de Paspébiac. Les formations de La Coulée et de Paspébiac, ainsi que les calcrètes d'eau souterraine massives, ont été partiellement érodées avant que ne sédimente la Formation de Bonaventure. Le Bonaventure recouvre en discordance ces unités dans différents secteurs du sud de la Gaspésie. Tout comme les formations de La Coulée et de Bonaventure, le Paspébiac n'est pas daté. Elle recouvre en discordance les structures acadiennes et est antérieure au Groupe de Mabou, étant recouverte en discordance par la Formation de Bonaventure. Cette dernière unité est également non-datée, mais est recouverte par les lits clastiques gris de la Formation de

Pointe Sawyer, lesquels contiennent un assemblage de spore correspondant aux lits de base du Groupe de Mabou (Namurien inférieur).

3.3 INTRODUCTION

A review of the post-Acadian stratigraphy in the southern Gaspé Peninsula (Fig. 3.1) has led to the identification of a new unit, herein named the Paspébiac Formation (Appendix V), which was previously assigned to the Bonaventure Formation (Mississippian) (Logan, 1846; Alcock, 1935; McGerrigle, 1946; Bagdley, 1956; Ayrton, 1967; Skidmore, 1967; Bourque and Lachambre, 1980; De Broucker, 1987; Gosselin, 1988; Brisebois *et al.*, 1992; van de Poll, 1995). The two units bear similar successions of continental red clastics that contain no dateable fossils. The Paspébiac and Bonaventure formations are however separated by an unconformity and, locally, by erosional remnants of the La Coulée calcrete, another recently identified Carboniferous unit (Jutras *et al.*, 1999). Moreover, a few important petrographic differences clearly distinguish the Paspébiac Formation from the overlying Bonaventure Formation, and an ankerite veining event has affected the former unit prior to deposition of the latter.

This paper describes several sections of the post-Acadian succession in the southern Gaspé Peninsula, along two cross-sections (A-B and C-D-E on Fig. 3.1), in an attempt to clarify the stratigraphic relationships, the various environments of deposition and the morphology of the subbasins. Sedimentary petrology and geomorphology data are combined to reconstruct the paleogeography and to help further constrain unclear stratigraphic relationships. The new cartography and basin analysis data also shed new light on the complex post-Acadian tectonic history of the area.

3.4 REGIONAL POST-ACADIAN RECORD

In the Gaspé Peninsula, the oldest post-Acadian units described in published literature are the Late Devonian Fleurant and Escuminac formations of the Miguasha Group (Brideaux and Radforth, 1970; Hesse and Sawh, 1992; Prichonnet *et al.*, 1996). This group was tentatively correlated with the Horton Group of Atlantic Canada by Howie and Barss (1975) (Fig. 3.2) and is unconformably overlain by the Carboniferous succession in the western end of Chaleur Bay.

The narrow belt of Carboniferous sedimentary rocks that occupies the southern and eastern Gaspé Peninsula (Fig. 3.1; inset) is part of the Ristigouche Subbasin (van de Poll, 1995), the northwestern sector of the upper Paleozoic Maritimes Basin. The latter occupies much of southeastern Canada and comprises sedimentary and minor volcanic rocks of Late Devonian to the Early Permian age. The Carboniferous strata of Gaspé are relatively undeformed and, where not underlain by the Miguasha Group, 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; Kirkwood, 1989; van de Poll, 1995).

Alcock (1935) subdivided the Carboniferous rocks of Gaspé into two formations: namely, the Bonaventure and Cannes-de-Roches formations. He subdivided the latter unit into three informal members. Rust (1981) formally referred to these units as the Lower, Middle and Upper members of the Cannes-de-Roches Formation. The Upper Member was 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 (Jutras *et al.*, 2001).

The Pointe Sawyer Formation is the only local Carboniferous unit bearing plant remains and spores. It contains the SM Spore Zone assemblage, which was dated as late Viséan (Utting, 1987), but now considered early Namurian (J. Utting, pers. comm., 2001), and which is shared by basal units of the Mabou Group in the general upper Paleozoic stratigraphy of the Maritimes Basin (Fig. 3.2). The Pointe Sawyer Formation is, thus, the only reliably dated Carboniferous unit in the Gaspé Peninsula. Unfortunately, it only has limited exposure in the study area. In the eastern part of the Peninsula, near Percé (Fig. 3.1; inset), the Pointe Sawyer Formation is conformably and transitionally overlain by the red clastics of the Chemin-des-Pêcheurs Formation, another recently identified post-Acadian unit which is also included within the Mabou Group (Jutras *et al.*, 2001).

The La Coulée Formation was recently identified underneath both the Bonaventure (Jutras *et al.*, 1999) and the Cannes-de-Roches formations (Jutras et al. 2001) in the Percé area. A thick groundwater calcrete, typical of that affecting the base of the La Coulée clastics in Percé, overlies a paleo wave-cut platform in the Saint-Elzéar region (Fig. 3.1) and is thought to have succeeded a short-lived marine transgression (Jutras and Schroeder, 1999; Jutras *et al.*, 1999). Bearing thick and massive groundwater calcrete hardpans, it is inferred that the La Coulée Formation was deposited in the vicinity of an evaporitic basin (Jutras *et al.*, 1999). This is based on the assumed relationship between the formation of massive groundwater calcretes and the mixing of fresh and saline groundwaters (Mann and Horwitz, 1979; Arakel and McConchie, 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989; Wright and Tucker, 1991). The underlying wave-cut platform and the genetic association of thick and massive groundwater calcretes to evaporitic basins suggest that the La Coulée Formation is younger than the continental Horton Group and would therefore correlate with the partly marine and evaporite-rich Windsor Group (middle to late Viséan).

It is still unclear to date whether the angular unconformity that separates the La Coulée Formation from the overlying Bonaventure Formation represents the Windsor-Mabou contact, as was previously proposed (Jutras *et al.*, 2001), or a local unconformity within units that are time-equivalent to the Windsor Group. In support of the first hypothesis, the Bathurst, Shin, Hopewell Cape and Maringouin formations of New Brunswick, which are similar and possibly laterally equivalent to the Bonaventure Formation, have been considered to be basal Mabou Group units (C. St Peter, pers. comm., 2000). However, red beds attributed to the Hopewell Cape Formation are conformably overlying Middle Windsor Group limestones and are bearing the AT spore assemblage of Utting (1987), which characterizes the upper Windsor (C. St Peter, pers. comm., 2001). Moreover, similar red beds are not found within the type section of the Mabou Group in Cape Breton Island (P. Giles, pers. comm., 2001) Hence, the disconformity between the Bonaventure and Pointe Sawyer Formations may represent the local Windsor-Mabou contact, while the angular unconformity between the La Coulée and Bonaventure formations may be the local signature of a tectonic event within the Windsor Group time-slice. The continental Bonaventure, Bathurst, Shin, Hopewell Cape, Maringouin and Shepody formations are currently being investigated.

It is proposed in the present paper to map the post-Acadian red beds that are underlying the La Coulée calcrete, or that are unconformably underlying the Bonaventure Formation, as the Paspébiac Formation, which is named after the main exposures located between the towns of New-Carlisle and Paspébiac (Fig. 3.1).

3.5 PETROGRAPHIC DIFFERENCES BETWEEN THE PASPÉBIAC AND BONAVENTURE FORMATIONS

The Paspébiac clastics are brownish-red, with buff pedogenic nodules, and can be visually differentiated from the orange-red Bonaventure Formation, which bears green mineralization haloes and greenish pedogenic nodules. Green reduction is nowhere observed in the Paspébiac, while reduction banding is commonly observed within the Bonaventure beds. However, the red beds of the Paspébiac Formation are best differentiated from the overlying Bonaventure Formation by the absence of distantly derived clasts such as quartz pebbles and disseminated red jasper within their coarse fraction. The Bonaventure Formation clastics are also better sorted, even in the coarse breccia beds of the Percé area, ~100 km to the northeast of the study area (Jutras *et al.*, 2001). As a result, the fluvial conglomerates of the Paspébiac Formation are typically matrix- to clast-supported, while those of the Bonaventure Formation are typically clast-supported. These observations suggest that the Paspébiac detritus were subject to shorter transportation before deposition than those of the Bonaventure Formation.

Finally, in the area of New-Carlisle (Fig. 3.1), the Paspébiac clastics are permeated with ankerite issued from basalt bodies, while such ankerite can only be seen in the Bonaventure Formation in the form of clasts. On one of the rare exposures of the Paspébiac-Bonaventure contact, truncation of a sandy ankerite dyke by the Bonaventure Formation is observed, indicating that the latter unit is younger than the ankerite veining event.

3.6 THE CASCAPÉDIA REENTRANT AND BLACK CAPE SALIENT SECTIONS

3.6.1 Geomorphic and geological setting

The belt of post-Acadian strata in the southern Gaspé Peninsula locally ends as a north facing cuesta less than 10 km away from the north shore of Chaleur Bay on a low surface that Peulvast *et al.* (1996) refer to as the Cascapédia Reentrant (Fig. 3.3). The Reentrant is limited to the northwest by the Grande-Cascapédia Fault scarp and to the southeast by the Black Cape Salient. Carboniferous strata in the region were collectively mapped as the Bonaventure Formation by previous workers (Alcock, 1935; McGerrigle and Skidmore, 1967; Bourque and Lachambre, 1980; Gosselin, 1988; Brisebois *et al.*, 1992; van de Poll, 1995). The exhumed paleosurface that extends to the north of the Carboniferous cover shows a very irregular morphology. It is referred to as an 'inherited topography surface' (Fig. 3.4) 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 (the 'Gaspesian Plateau') that extends north of the Rivière-Garin Fault and west of the Grande-Cascapédia Fault (Fig. 3.3).

3.6.2 The Saint-Jules quarry section (Fig. 3.3a)

The post-Acadian strata near the town of Saint-Jules abut against the Grande-Cascapédia Fault scarp to the northwest (Fig. 3.3). Contact with the local Ordovician basement is not exposed. The Saint-Jules quarry section shows 7 m of Paspébiac red clastics overlain by a massive 8 m-thick calcrete hardpan (Fig. 3.3a), which is itself in erosional discontinuity with overlying red clastics of the Bonaventure Formation. Since the calcrete has the same facies and relative stratigraphic position as that of the La Coulée Formation, it is here referred to and mapped as a La Coulée calcrete. The underlying Paspébiac 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 thick and less than 10 m wide.

The conglomerates are monolithic, with a bimodal size distribution. The coarse clasts are typically less than 5 cm maximum diameter and exclusively composed of sub-angular to sub-rounded red calcilutite, set in a granular coarse-sand matrix of the same 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 they were oxidized after their deposition within the Paspébiac. Similar, but grey calcilutite forms the bulk of the Ordovician to Silurian White-Head Formation, which occupies the structural block located north of the E-W -striking Grand-Pabos Fault (Gosselin, 1988), less than 10 km north of the Saint-Jules quarry (Fig. 3).

The red Paspébiac 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, vertical aggradation and the absence of clay, along with the observed rounding of clasts, clearly suggest that they were deposited by aqueous processes (Harvey, 1984; Wells, 1984; Miall, 1996). The conglomerates are interpreted as high-energy sheet 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 run-off between flash flood events.

The uppermost conglomerate beds of the Paspébiac Formation in this section are marked by vertical and horizontal endokarstic conduits filled with non-calcareous, lithified gritty red clay, containing rounded quartz grains (Fig. 3.5). (Fig. 3.5). In some sectors of the quarry, the conglomerate beds are brecciated into large dislocated blocks floating within the karst-fill. The karst-fills, including those within vertical shafts, are sharply truncated by the overlying calcrete and therefore pre-date the calcretization event. According to Wright and Tucker (1991), calcrete hardpans thicker than 3m are non-pedogenetic and can only be formed by saturated groundwaters.

The contact between the uppermost conglomerate beds of the Paspébiac 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 suggest that the latter are blocks of host rock conglomerate, such as those floating in the red karst-fill below. As large blocks impede groundwater circulation, their preservation is often observed in otherwise massive La Coulée groundwater calcretes, while the matrix component is most easily digested (Jutras et al., 1999). 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. 3.6), but its cavities are filled with coarser sediments coming from the overlying Bonaventure Formation.

Locally, the La Coulée calcrete/Bonaventure Formation contact has been scoured by Quaternary glaciation, which left abundant striae on the calcrete surface and thin remnants of overlying Bonaventure red clastics (Fig. 3.7). The exposed calcrete surface shows a stepped topography underneath the Bonaventure Formation. The calcrete has a ~10° dip toward the south with a 095° strike. Its exposed surface dips less steeply south (~05°), which leads to a gradual thinning of the calcrete to the north. The exposed remnants of the overlying Bonaventure Formation never exceed 1 m in thickness within the quarry, but thicker sections are abundant immediately to the south. The dip of this unit is also to the south but never exceeds 05° in the area.

The upper surface of the groundwater calcrete is characterized by several pot-holes filled with polymictic red clastics, one of them still holding the large rounded pebble that probably served to carve it (Fig. 3.7). This indicates that the surface was sculpted by a strong current prior to being buried by fluvial deposits of the Bonaventure Formation.

3.6.3 The Saint-Edgar section (Fig. 3.3b)

The post-Acadian strata south of Saint-Edgar abut the Black Cape Salient to the southeast (Fig. 3.3). One poor roadside exposure shows 3 m of the La Coulée groundwater calcrete overlying (with a 3 m gap) 2 m of coarse monolithic conglomerate, identical to that at the Saint-Jules quarry (Fig. 3.3b). The succession dips 08° 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 ~01° 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. This outcrop strongly implies that the groundwater calcrete and the underlying Paspébiac Formation red clastics, observed at the Saint-Jules quarry, are continuous across the Cascapédia Reentrant.

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

3.6.4 The Black Cape Salient section (Fig. 3.3c)

A roadside outcrop on the Black Cape Salient reveals the contact between a flat-lying groundwater calcrete and overlying red clastics of the Bonaventure Formation (Fig. 3.3c). 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 3.3c on Transect A-B, shows the incompletely digested contact with sandstone of the Silurian Anse Cascon Formation, suggesting that the underlying Paspébiac Formation red clastics are absent in this sector.

Beds of the Bonaventure Formation, dipping 05° toward the south (180°) can also be observed at the northwest end of the Black Cape Salient, near New-Richmond, where it lies 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 70° 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. 3.3, cross-section A-B).

3.6.5 The Caplan section (Fig. 3.3d)

This section is separated from Location 3.3c by the Black Cape Fault, which strikes NE-SW between the towns of Black Cape and Caplan (Fig. 3.3). Analysis of this post-Acadian strike-slip fault is discussed elsewhere (Jutras and Prichonnet, submitted). On the southeastern foot of the Black Cape Salient and tilted on edge are 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 (latest Silurian to earliest Devonian) by Bourque *et al.*, (2000). These red clastics are overlain unconformably (~60° angular unconformity) by a 3 m thick groundwater calcrete, which is in turn overlain by an ~300 m-thick section of the Bonaventure Formation (Fig. 3.3d). The nature of the host sediment could not be determined for this mature 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 comprise ~11% of the gravels. The presence of ~17% rounded quartz pebbles and disseminated red jasper is, however, typical of this unit. Modal clast-size in the conglomerate beds ranges from 3 to 10 cm maximum diameter.

A continuous section exposing 192 m of Bonaventure strata between Black Cape and Caplan shows an abundance of conglomeratic beds alternating with sandstones and nodular mudstone paleosols in the lower 139 m and almost exclusively sandstone beds in the upper 53 m (Fig. 3.3d). Extrapolations from discontinuous coastline exposures between the towns of Caplan and Bonaventure (Fig. 3.1) 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 overlain by grey clastics of the Pointe Sawyer Formation at the town of Bonaventure (Fig. 3.1), giving an approximate thickness of 300 m for the Bonaventure Formation in this area.

3.7 THE NEW-CARLISLE - PORT-DANIEL AREA SECTIONS

3.7.1 Geomorphic and geological setting

The composite morphology of this southernmost sector of the Gaspé Peninsula (Figs. 3.4, 3.8, 3.9) was described by Jutras and Schroeder (1999). Several Carboniferous paleoenvironment implications arise from the geomorphic analysis. They are summarized here and developed in relation to the new stratigraphic data.

The paleosurface on which the Paspébiac clastics lie is partly exhumed and is included within the 'inherited topography surface' by Jutras and Schroeder (1999) (Figs. 3.4, 3.9). This paleosurface is characterized by the presence of limestone hogbacks (the 'Clemville Hogbacks'), which are an indication 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 *et al.*, 1999). The hogbacks are formed by only two units, the middle member of the La Vieille Formation and the coral reef complexes of the West Point Formation, which are the purest limestones in the local Silurian succession of the Chaleurs Group (Bourque and Lachambre, 1980). From the observation of subsurface karst (lapies) filled with lithified red clastics at all levels of the hogback surfaces, Jutras and Schroeder (1999) have concluded that the morphology of the Port-Daniel area was sculpted in Upper Devonian to Carboniferous time, was subsequently buried under the Carboniferous clastics, and was only karstified during eventual exhumation. The position of the Paspébiac clastics, abutting the hogbacks, supports this conclusion.

The irregular 'inherited topography surface' is limited to the northwest by the St-Jogues-Sud Fault scarp (Figs. 3.8, 3.9). The scarp demarks a topographically higher surface that truncates all formations, including the La Vieille and West Point formations. This 'perfectly truncated surface' (Figs. 3.4, 3.9) is limited to the north by a non-structural scarp (the 'Garin Scarp') near the village of Saint Elzéar (Figs. 3.8, 3.9). According to Jutras and Schroeder (1999), since the same rock successions are found on each side of the Garin Scarp, only coastal marine erosion could explain the morphogenesis of that scarp and the flat surface that it delimits. The latter geomorphic units are therefore considered as, respectively, a coastal cliff and a wave-cut platform. Less than 1 km south of the Garin scarp, on the wave-cut platform, stands a residual hill of Carboniferous rocks, providing an upper age limit for that surface (Figs. 3.8, 3.9). At the base of the hill, there is an ~10 m concealed interval between the steeply dipping Silurian strata of the basement and a 6 m section of flat-lying groundwater calcrete, sharply overlain by red clastics of the Bonaventure Formation (Jutras *et al.*, 1999). The calcrete is tentatively estimated at 10-12 m thick, but the actual contact with the basement has not been observed.

Northwest of the Garin Scarp (Figs. 3.8, 3.9) stands the Gaspesian Plateau (Gray and Hétu, 1985) (Fig. 3.4), which corresponds to the main peneplain surface of the Canadian Appalachians (Grant, 1989). A Jurassic age was proposed by Jutras and Schroeder (1999) for this peneplain from correlations with an apatite fission track model by Ryan and Zentilli (1993). Following the opening of the Atlantic Ocean, the peneplain has been gradually uplifted and dissected under a generally more humid climate than that prevailing in Carboniferous times, which led to a preferential erosion of the La Vieille Formation limestones, deeply incised between more siliciclastic hogback-forming rocks (Jutras and Schroeder, 1999) (Fig. 3.9).

The composite morphology of the southernmost Gaspé Peninsula therefore shows, from south to north, three unrelated surfaces (Fig. 3.4, 3.9). On the inherited topography surface, the pure limestones of the La Vieille Formation stand as resistant rock monoliths; on the perfectly truncated marine surface, they are levelled; and on the Gaspesian Plateau they are incised between hogbacks (Fig. 3.9).

3.7.2 The New-Carlisle-West section (Fig. 3.8a)

This section is located on the west side of an inlier of Silurian rocks at New-Carlisle (Fig. 3.8a). Undated intrusions affect the inlier (Bagdley, 1956). The New-Carlisle-West section exposes a small erosional remnant of Paspébiac 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 Paspébiac beds form a stepped topography beneath the disconformably overlying Bonaventure beds (Fig. 3.10). At the east end of the section, the Paspébiac is 2m thick. Less than 10 m to the west, it thins out and the overlying Bonaventure Formation sits directly on the Silurian basement.

The basal 0.5 m of the Paspébiac clastics is a red granular breccia, overlain by 1.5 m of nodular, pebbly sandstone. Calcareous nodules in the sandstone are buff in color. A sandstone dyke with carbonated cement cuts the mudstone basement and the Paspébiac clastics, but is truncated by the Bonaventure Formation (Fig. 3.11). Similar sandstone dykes will be further defined in the next section.

The remaining section, above the thin wedge of Paspébiac beds, has been described in detail by Jutras *et al.* (2001). Hence, it is only briefly summarized here.

The lower 20 m of the Bonaventure Formation is mainly composed of sandstone, with a few conglomeratic channel fills. The conglomerates are mainly composed of locally derived sedimentary clasts, along with ~15% quartz pebbles, minor black volcanics and disseminated red jasper. In the channel fills that are closest to the New-Carlisle inlier, large clasts of red sandstone, which possibly came from the underlying Paspébiac Formation, are also abundant, along with porphyric albitite and ankerite clasts, which are derived from rocks of the New-Carlisle inlier. The clasts are sub-rounded to well-rounded and are typically less than 5 cm maximum diameter.

The upper 30 m of the Bonaventure here mostly comprises horizontally bedded sandstone along with thick planar cross-stratified sandstone beds from transverse bars (Fig. 3.8a) (Jutras *et al.*, 2001). The upper 30 m also show several paleosol intervals with green mineralized haloes and greenish calcareous nodules. Some oblique hardpans up to 20 cm thick are formed towards the top of the sequence and are believed to be the result of minor groundwater calcretization (Jutras *et al.*, 2001).

The uppermost sandstone beds of the Bonaventure Formation are sharply cut by channel fills of the Pointe Sawyer Formation. Recent removal of slope detritus by coastal erosion at Pointe Sawyer reveals that the basal grey channel fill of the Pointe Sawyer Formation, which was the only element of that unit previously observed in this section (Jutras et al. 2001), is itself partly cut by a red conglomerate channel-fill. As the grey conglomerate, the red conglomerate disconformably overlies fine red beds that comprise the upper half of the Bonaventure Formation. It is interpreted that the red matrix of this conglomerate is derived from the eroded upper beds of the Bonaventure Formation, rather than from post-depositional oxidization.

The contact between the Bonaventure Formation and the overlying Pointe Sawyer Formation, from lateral extrapolations, is only 50-55 m above the observed contact with the underlying Paspébiac clastics at New-Carlisle-West. However, the observed contact is on the flank of a paleorelief, which has been gradually onlapped by the Bonaventure clastics. The Bonaventure Formation is therefore probably much thicker than 50-55 m at the area of the Pointe Sawyer channel, 5 km away from the New-Carlisle inlier, as expressed on Transect-C-D-E (Fig. 3.8). A thickness of about 300 metres is achieved between the towns of Caplan and Bonaventure, a few kilometres to the northwest (Fig. 3.1, 3.3d)

3.7.3 The New-Carlisle-Paspébiac section (Fig. 3.8b, b')

A continuous section of the Paspébiac Formation is exposed between New-Carlisle-East and the town of Paspébiac, on the eastern side of the New-Carlisle inlier (Figs. 3.8b, b'). In contrast with the overstepping relationship of the Bonaventure Formation with respect to the inlier on the west side, the Paspébiac beds are tilted away from the inlier and were obviously uplifted along with it. Large north-south oriented bimodal dykes, ranging from 1.5 to over 50 m wide, are concentrated in the New-Carlisle inlier and are most likely responsible for the local uplift.

Ankerite veining issued from basalt bodies has massively invaded the Paspébiac clastics in the area of New-Carlisle. Ankerite veins, siding the dykes below the unconformity, are invading the beds of the Paspébiac above the unconformity, mobilizing sand (Fig. 3.12). Away from the basalt and sandstone dykes, ankerite is also thoroughly permeating the basal breccia beds of the Paspébiac Formation in this area. The basalts are truncated by the Paspébiac beds, which include identical basalt clasts. However, truncation does not always occur exactly at the level of the unconformity, as exampled by the dyke of Figure 3.12, which is truncated over 2 m above the unconformity line between the Indian Point and Paspébiac formations. Also, some basalt clasts in the basal Paspébiac are welded to sub-rounded sedimentary rock clasts with contact aureoles, suggesting that basalt invaded a conglomeratic unit and was subsequently brecciated. The possibility that the basalts are younger than the Paspébiac, although they barely penetrate this unit, is currently being investigated. The basal breccia beds are chaotic, with clasts floating in ankerite. It is possible that the basalts barely invaded the Paspébiac, perhaps on account of high porosity and groundwater content at the level of the unconformity, and were subsequently truncated by massive circulation of ankeritic fluids in the basal Paspébiac beds.

The first 12 m of the New-Carlisle - Paspébiac section, above the unconformity, comprises four massive beds of structureless breccia, 1.5 to 3 m each, separated by massive sandstone beds, 20 to 50 cm each (Fig. 3.8b). The breccia includes angular clasts of ankerite and basalt, and sub-rounded clasts of fine grained sedimentary rocks. The lowest beds of section 3.8b' are laterally equivalent to the highest beds of section 3.b, but include laminated sandstones, poorly-sorted granular breccia and poorly-sorted pebbly conglomerate that do not include basalt and ankerite clasts. Clasts are sub-rounded to sub-angular in the pebbly conglomerate, but mainly sub-angular in the granular breccia. Numerous paleosol overprints partly mask primary sedimentary structures in the 7-15 m interval of section 3.8b' (first 8 m of this section). The paleosols contain buff calcareous pedogenetic nodules.

The 15-30 m interval is dominated by horizontally-bedded sandstones with a few channels of conglomerate or sandstone in the lower 5 metres (Fig. 3.8b'). The 30-35 m interval shows thick planar cross-beds of sandstone. Their lateral persistency on a few hundred metres and their vertical succession imply that they were deposited on transverse bars. The 35-45 m interval is dominated by horizontally-bedded sandstone with minor mudstone and a few rare channel fills of conglomerate and sandstone. The conglomerate channel fills are exclusively composed of sedimentary rock clasts. The planar sandstone beds, laterally persistent for several kilometres, locally show parting lineation, indicating that they were deposited by upper-flow regime sheet floods. Trace fossils, desiccation cracks and abundant rain drop marks suggest that the alluvial plain sediments were exposed between sheet floods.

A broad channel of orangish polymictic conglomerate, with abundant rounded quartz pebbles and disseminated jasper pebbles, disconformably overlies the brownish-red Paspébiac beds in the west-end of the section near the town of Paspébiac and is assigned to the Bonaventure Formation (Fig. 3.13).

3.7.4 The Ritchie Point section (Fig. 3.8c)

The stratigraphic level of the Ritchie Point section (Fig. 3.8c) is not clear. Extrapolations from nearly continuous shore-cliff exposures between this section and the town of Paspébiac suggest that the top of the Ritchie Point section should correspond approximately with the top of the New-Carlisle - Paspébiac section. Extrapolations with Smith Point (Fig. 3.8d) imply that the lowest beds of the Ritchie Point section should be close to basement level. The Paspébiac Formation therefore may be considerably thinner at Ritchie Point than at Paspébiac.

The Paspébiac beds are lenticular and discontinuous at the Ritchie Point section, which results in considerable lateral variability. Figure 3.8c is therefore very generalized. Coarse clasts are exclusively derived from the local Chaleurs Group succession in the Paspébiac of the Ritchie Point section. The lowest 5 m are mainly composed of sub-angular to sub-rounded pebbly sandstone with isolated or floating clasts up to 10 cm in diameter. These beds are followed by a paleosol in muddy sandstone which is up to 2 m-thick and contains buff calcareous nodules. The paleosol is succeeded by 5 to 6 m of coarse and poorly sorted conglomerate with sub-rounded clasts. The conglomerate shows stratified granulometric successions, suggesting flow velocity variations, and a few sandstone lenses (Fig. 3.14a). Although vertical aggradation clearly defines the conglomerate as fluvial, it is in part matrix-supported, which is uncommon in 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 conglomerates suggests deposition by flash floods engorged with sediments. Sudden high-energy events are also suggested by the partial erosion of sandstone beds beneath some of the conglomeratic breccia beds (Fig. 3.14b). The uppermost 5 m of the Paspébiac in the Ritchie Point section show alternating beds of sandstone and pebbly conglomerate.

3.7.5 The Smith Point section (Fig. 3.8d)

The unconformable contact between the subvertically dipping calcareous mudstone strata of the Indian Point Formation and the overlying Paspébiac Formation is well exposed at Smith Point (Figs. 3.8d, 3.15). The Paspébiac clastics are resting on a planar surface of relatively unweathered calcareous mudstone basement.

The base of the succession comprises about 1 m of pebbly sandstone with sub-angular clasts, passing upward into 5 to 6 m of horizontally-bedded sandstones, which are overlain by 4 m of laterally persistent and thick planar cross-stratified sandstones, that are once again interpreted as deposits from transverse bars. The top of the section comprises 4 m of horizontally-bedded sandstones.

3.7.6 The Indian Point section (Fig. 3.8e)

Contact between the Paspébiac Formation and the basement at Indian Point is very similar to that at Smith Point, with the red bed succession resting on a planar surface that truncates subvertical strata of the Indian Point Formation (Fig. 3.8e). However, a few hundred metres to the east of the section, the Paspébiac clastics abut against the basement rocks of Daniel Hill, one of the Clemville Hogbacks (Fig. 3.8). This hill is a limestone-reef monolith of the Silurian West Point Formation, which stratigraphically underlies the Indian Point Formation (Bourque and Lachambre, 1980).

The Indian Point section shows three successive 2 to 3 m-thick lenticular conglomerate beds of the Paspébiac Formation, exclusively composed of reddened, sub-angular to sub-rounded sedimentary rock clasts. Sorting is poor and clasts range from fine sands to 50 cm blocks, with no clearly defined matrix. Finer fractions may have been partly replaced by calcite cement, which represents about 2% of the rock volume. From the lack of fine muds and from the observed channeling of conglomerate lenses, this matrix- to clast-supported conglomerate is interpreted as fluvial, rather than mass flow related. Poor rounding and sorting suggest that they were deposited by ephemeral flash floods.

Even coarser detritus is found in sedimentary breccia abutting the northern flank of Daniel Hill, with clasts greater than 50 cm diameter (Fig. 3.16). The clasts are large pieces of coral reef derived from the West Point Formation.

3.7.7 The Gascons section (Fig. 3.8f)

This small erosional outlier of the Paspébiac clastics is the easternmost section identified to date. It unconformably lies on subvertical strata of the Silurian Gascons Formation (Bourque and Lachambre, 1980) (Fig. 3.8f). The Paspébiac here is 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 to the north of the section. The coastal cliff exposure is inaccessible and can only be observed from about 10 m below, at the beach level. Modal clast size seems to be 10-15 cm in diameter.

A few kilometres to the north-west of the Rivière-Port-Daniel Fault (Fig. 3.8), polymictic conglomerates of the Bonaventure Formation rest directly on the Hadrynian to Cambrian Maquereau Group (Brisebois *et al.*, 1992).

3.8 PALEOCURRENTS IN THE PASPÉBIAC FORMATION

Clearly defined clast imbrication is lacking in the chaotic conglomerates of the Paspébiac Formation. Paleocurrent measurements were taken from oriented 1 to 2 m-wide trough channel fills of sandstone at the Saint-Jules quarry (Fig. 3.17a) and from orientated 0.5 to 10 m-wide trough channel-fills of conglomerate and sandstone in the New-Carlisle - Paspébiac section (Fig. 3.17b). The measurements indicate that braided streams flowed toward the south at Saint-Jules and toward the south-southeast at New-Carlisle and Paspébiac.

It is inferred that the very coarse breccia that is found on the northwest flank of Daniel Hill was derived from a paleoscarp associated with the north-south oriented fault (mapped by Bourque and Lachambre, 1980) that cuts the hogback (Fig. 3.17b). The coarse breccia at Gascons (Fig. 3.8f) dips away from the Rivière Port-Daniel Fault and its deposition was probably controlled by a paleoscarp associated with movement on that fault.

Paleocurrent measurements were also taken from the cross-sets of laterally persistent and 0.5 to 3m-thick planar cross-strata. Following the conclusion that these beds are deposits from transverse bars, their cross-sets are 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, southwest flow east of Paspébiac, and west-northwest flow at Smith Point (Fig. 3.17b).

Parting lineation in the sandy sheet flood deposits are roughly parallel (SW-NE) to the dip of transverse bar cross-sets in the New-Carlisle - Paspébiac section, and parallel to trough channel axis (NW-SE) in the braided sandstone systems of the same area.

3.9 SEDIMENTARY ENVIRONMENTS OF THE PASPÉBIAC FORMATION

The lenticular beds of the Paspébiac succession in the Cascapédia Reentrant (Fig. 3.3a, b), with coarse sub-angular to sub-rounded clasts, are typical of fault-related subaerial alluvial fans as defined by Rust (1981, 1984). 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 off the Grand Pabos Fault escarpment located to the north.

The coarse angular clasts and chaotic deposits of the Gascons section (Fig. 3.8f) and of the northern flank of Daniel Hill (Fig. 3.16) are clearly related to debris flows. Fault-scarp sources are proposed above. Deposits of the Ritchie Point and Indian Point sections (Fig. 3.8c, e) are mainly fluvial and not related to debris flows. However, their high lateral variability suggests that they are also related to an alluvial fan environment (Wasson, 1977; Zaitlin and Rust, 1983; Rust, 1984).

The basal beds of the New-Carlisle – Paspébiac section (Fig. 3.8b) are also quite coarse, but not lenticular. It is not clear to what degree the ankeritic fluids that invaded these beds have reworked the sedimentary deposits (research in progress). Until this question is resolved, the sedimentary environment of these deposits cannot be determined.

As was mentioned earlier, the horizontally bedded sandstones of the New-Carlisle - Paspébiac (Fig. 3.8b') and Smith Point (Fig. 3.8d) sections are interpreted as sheet flood deposits on an alluvial plain. Truncation of some planar beds by sandstone and conglomerate channel fills is interpreted as the product of an alternation between sheet floods and channelized sandy or gravelly stream deposits. Planar cross-bedded and horizontally bedded sandstones both indicate a flow direction that is perpendicular to the flow of channelized deposits and are interpreted as being related to large ephemeral trunk rivers draining parallel to the basin axis and source-uplifts. The Bonaventure Formation has similar fluvial systems with similar trends (Jutras *et al.*, 2001), which suggests that the general paleogeography was not significantly different during the two sedimentation events.

The abundance of coarse and chaotic detritus within the Paspébiac Formation, along with the generally unsorted nature of the sediments, suggest that source-relief was frequently rejuvenated by a very active fault system. Deep oxidization of the entire sequence, numerous paleosol overprints and abundant fluvial deposits clearly define the depositional environment as continental.

Jutras *et al.* (2001) have 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. The coarser fractions of the Paspébiac Formation in the New-Carlisle - Port-Daniel area, which contain larger and more angular clasts than the overlying Bonaventure Formation beds in this area, were probably derived from much closer sources. The coarse debris flow breccias in the Gascons section and around Daniel Hill (Fig. 3.16) (Figs. 3.8e, f) are especially proximal, no more than a few hundred metres away from their source scarp.

3.10 CHRONOLOGY OF POST-DEPOSITIONAL EVENTS AND STRATIGRAPHIC RELATIONSHIPS

To form an aquiclude for karst formation, the upper Paspébiac beds in the Saint-Jules quarry had to have been already cemented when karstification took place. 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. Since thick groundwater calcrete hardpans are only known to occur within unconsolidated sediments with a water-table that is less than 5 m from the surface (Mann and Horwitz, 1979; Wright and Tucker, 1991), and because non-calcretized blocks of Paspébiac red clastics are found high within the groundwater calcrete profile, it can be inferred that the calcrete may have developed entirely within the karst-related regolith of the Paspébiac Formation. Replacement of a Paspébiac Formation regolith by a groundwater calcretization front suggests that the resulting calcrete may be older than the grey clastics of the La Coulée Formation in Percé (Fig. 1; inset), where sedimentation and groundwater calcretization were demonstrably coeval (Jutras *et al.*, 1999).

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 in Percé. In both cases, the calcretization front was incomplete, leaving 'undigested' oversize clasts (unweathered blocks of Paspébiac breccia, in the case of the regolith), which remain as floating windows within the calcrete mass.

The erosional surface that separates the La Coulée calcrete of the Saint-Jules quarry from the overlying Bonaventure Formation is similar to the contact relationship between these two units seen elsewhere in the southern and eastern Gaspé Peninsula (Jutras *et al.*, 1999, 2001). 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 Paspébiac Formation and the Frasnian Escuminac shales. This suggests that the pre-Bonaventure erosion event has not substantially affected pre-Frasnian basement rocks. The absence of calcrete between the Paspébiac and underlying basement rocks further differentiates this unit from the Bonaventure. In this regard, a groundwater calcrete has recently been identified unconformably below the Bathurst Formation in northern New Brunswick (S. McCutcheon, pers. comm., 2000). This adds to other lines of evidence suggesting that the Bathurst may be equivalent to the Bonaventure (research in progress).

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 Paspébiac Formation, this view no longer stands. This calcrete provides proof that the presence of a groundwater calcrete underneath 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 Paspébiac from the Bonaventure: (1) Prior to being calcretized, the Paspébiac underwent cementation and subsequent karstic weathering, which requires a prolonged period of exposure above base-level, and (2) subsequent erosion occurred after the calcretization event and 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 (a) above the

Paspébiac Formation, (b) within the La Coulée Formation, and (c) beneath the Bonaventure or Bathurst formations.

To date, there is no data challenging the postulate that all the massive groundwater calcretes of the Gaspé Peninsula are penecontemporaneous with deposition of the La Coulée Formation, which is demonstrably the case for the groundwater calcrete in Percé (Jutras et al., 1999). 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.

3.11 INTEGRATION OF STRATIGRAPHIC AND GEOMORPHIC DATA

The Cascapédia Reentrant, bordered by the Grande-Cascapédia and New-Richmond faults, and the Black Cape Salient, bordered by the New-Richmond and Black Cape faults (Fig. 3.3), can be considered from tectonostratigraphic constraints as, respectively, graben and horst structures that are younger than the Bonaventure Formation. The absence of Paspébiac clastics on the Black Cape Salient leads to the hypothesis that the New-Richmond Fault also experienced pre-La Coulée displacement, either limiting Paspébiac deposition to the Cascapédia Reentrant graben or causing erosion of the Paspébiac on the salient. 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. 3.3). The second scarp is parallel to stratigraphic contacts and most likely developed from recession of the incompetent Pabos Formation mudstones by differential erosion. The Paspébiac clastics of the Cascapédia Reentrant 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 Paspébiac clastics on the Black Cape area could then result from non-deposition.

The irregular surface that underlies the Paspébiac Formation in the Cascapédia Reentrant is similar to that of the New-Carlisle - Port-Daniel area. Both surfaces were included within the 'inherited topography' geomorphic unit of Jutras and Schroeder (1999), which is interpreted as continental. However, the groundwater calcrete that forms the base of the residual hill located near Saint-Elzéar (Figs. 3.8 and 3.9) sits directly on a marine wave-cut platform. There is, therefore, an incompatibility between the deposition surface of the Paspébiac Formation and that of the La Coulée host sediment in the New-Carlisle - Port-Daniel area. If the geomorphic conclusions of Jutras and Schroeder (1999) are correct, a marine erosion event must separate them. The Cascapédia Reentrant lay beyond the reach of the postulated transgressing sea, but the New-Carlisle - Port-Daniel area, featuring the Clemville Hogbacks, was well within the reach of that sea.

It was proposed in Jutras *et al.* (2001) to correlate the wave-cut platform with the maximum marine transgression of the Windsor Group, which occurred during the very first transgression cycle according to some workers (P. Giles, pers. comm., 2000). Other workers believe that the Upper Windsor transgressions are more extensive (R. Ryan, pers. comm., 2001), but only the Lower to Middle Windsor is represented as far to the northwest as New Brunswick (P. Giles, pers. comm., 2001). Therefore, although the Upper Windsor transgressions may have been more extensive in other areas of the Maritimes Basin, the preserved wave-cut platform and coastal cliff in the southern Gaspé Peninsula (north-westernmost sector of the Maritimes Basin) probably correlate with Lower Windsor time. The related deposits, in this peripheral and ephemeral marine zone, would have been very thin and could have been calcretized by groundwaters following regression. An analogue is suggested by thorough groundwater calcretization of recent marine carbonate sediments following regression in the Gulf of Mexico (Sanborn, 1991).

To explain preservation of the Clemville Hogbacks and several fault scarps, which are topographically lower than the horizontally-cut marine surface, a model was proposed in which a fault-controlled clastic event would have buried the hogbacks prior to the overlapping marine transgression (Jutras and Schroeder, 1999). Identification of the Paspébiac Formation on that lower surface, stratigraphically below the units that overlie the marine platform (the La Coulée calcrete and Bonaventure Formation), further supports the geomorphic hypothesis. Post-Acadian red beds underlying the maximum Windsor transgression can be correlated with either the Hillsborough Formation (basal Windsor; mid-Viséan) or the Horton Group (uppermost Devonian to Tournaisian) of the Maritimes Basin. (Howie and Barss, 1975 ; C. St. Peter, pers. comm., 2001).

3.12 TECTONOSTRATIGRAPHIC MODEL

The following model gathers information from the available literature on the upper Paleozoic stratigraphy of the Gaspé area. It goes beyond what can be firmly demonstrated, but it underlines some constraints and presents what can be regarded as the most probable scenario considering the available data.

3.12.1 The pre-Paspébiac events

Synorogenic molasse of the Acadian Orogeny were deposited in the Gaspé Clastic Wedge in the Lower and Middle Devonian (Rust, 1984; Rust *et al.,* 1989). The coarse clastics of the post-Acadian Fleurant Formation (Frasnian) are probably the last deposits resulting from destruction of the Acadian Chain, mountainous relief being most likely absent during sedimentation of the overlying lacustrine or estuarine shales of the Escuminac Formation (Frasnian) (Prichonnet *et al.,* 1996). The Frasnian strata were deformed by a mild compressive event that has not affected the overlying Carboniferous strata (Zaitlin and Rust, 1983; Hesse and Sawh, 1992). This deformation event is possibly coeval to that separating the mid-Devonian McAdam Lake Formation, which is also considered post-Acadian, from the Carboniferous Horton Group in the Sydney Basin (Pascucci et al., 2000). The almost peneplained 'inherited topography surface' was probably developed subsequently to this post-Frasnian deformation event.

3.12.2 The Paspébiac Formation (Fig. 3.18)

Part of the mature post-Frasnian surface was buried by the Paspébiac Formation (Fig. 3.18). Sedimentation of the Paspébiac Formation in the southern Gaspé Peninsula seems to have been confined within two small grabens or half-grabens limited by the Grand-Pabos Fault, in the Cascapédia Reentrant (Figs. 3.3, 3.18), and by the convergence of the Rivière-Port-Daniel and Saint-Jogues-Sud faults in the New-Carlisle - Port-Daniel area (Figs. 3.8, 3.18). Paleocurrent data suggest that scarps associated with these faults generated the Paspébiac sediments (Figs. 3.17a and 3.18).

Paleocurrents in basal beds have a westerly trend at the Daniel-Hill Fault (Fig. 3.17b), which suggests that this small subordinate fault may have laid southeast of the depocentre of the graben. This observed fault trend inversion, a mere 15 km away from the fault that limits the graben to the northwest (the Saint-Jogues-Sud Fault), is an indication of its narrowness. A large fault parallel to the Saint-Jogues-Sud Fault and affecting Carboniferous strata beneath Chaleur Bay was identified by Syvitski (1992) on seismic reflection profiles. This fault, which we will refer to as the Chaleur Fault, possibly limited the basin to the southeast (Fig. 3.18). Connection of these small continental grabens to the ocean was unlikely during deposition. Hence, the west- to southwest-flowing trunk river system (Fig. 3.17) was possibly connecting to an ephemeral recurrent lake located southwest of the exposed sections, beneath present-day Chaleur Bay (Fig. 3.18), although sedimentary evidence for the presence of such a lake is lacking.

The environment of deposition attributed to the Paspébiac Formation is analogous to that of the Horton Group, which was deposited during late Devonian and Tournaisian times in numerous similarly oriented (SW-NE) grabens and half-grabens throughout the Maritimes Basin, and which were subsequently overlapped by more extensive Windsor Group strata and younger units (Durling and Marillier, 1990, 1993; Calder, 1998; Pascucci *et al.,* 2000). Moreover, the lack of sorting within the fluvial deposits of the Paspébiac Formation suggests that the related rivers were engorged with sediments, which accords with the high sedimentation rate recorded for the Horton Group (St. Peter, 1993). Finally, the pre-calcretization karstic weathering of the Paspébiac beds in the Cascapédia Reentrant also gives support to the hypothesis that the Paspébiac Formation is a pre-Windsor Group unit. The Paspébiac Formation is therefore possibly a correlative of the Horton Group, which is separated from the basal Windsor Group by a ~5 m.y. hiatus in all sectors of the Maritimes but Newfoundland (J. Utting, pers. comm., 2001). However, considering that hiatuses can be more numerous in peripheral sectors of a basin, the hiatus between the Paspébiac Formation and the groundwater calcrete may be an intra-Windsor Group break. In this view, the Paspébiac may correlate with the basal Windsor Hillsborough Formation (lower or middle Viséan), which was also deposited in small continental grabens prior to being overlapped by marine Windsor strata (C. St. Peter, pers. comm., 2001).

3.12.3 The marine transgression event (Fig. 3.19)

The wave-cut platform at Saint Elzéar (Jutras and Schroeder 1999), locally covered by an erosional remnant of the La Coulée calcrete and Bonaventure Formation, is taken as geomorphic evidence of the former presence of the Carboniferous Windsor Sea (Viséan) in the southern Gaspé Peninsula (Fig. 3.19), although no related deposits have been found. The epicontinental marine transgression has cut its way above the buried hogbacks and through the uplifted block of the St-Jogues-Sud Fault (Fig. 3.19). The Garin Scarp locally marks maximum transgression and is interpreted as a coastal cliff (Jutras and Schroeder, 1999). Overlapping of the Windsor Sea above and beyond a Paspébiac graben is further indication that the Paspébiac Formation is most likely related to the either the Horton Group or the Hillsborough Formation, for such basement onlap of marine Windsor Group strata is a common observation (Durling and Marillier, 1990, 1993; Pascucci *et al.,* 2000).

3.12.4 The groundwater calcrete event (Fig. 3.20)

Sea regression was possibly coeval with the tectonic event responsible for sedimentation of the La Coulée Formation grey clastics (mid-Viséan?) in the Percé area (Jutras *et al.*, 1999). Evaporitic basins must have remained within the Chaleur Bay region following regression to account for the development of thick and massive groundwater calcretes in that area (Fig. 3.20).

No host sediments have been preserved above the groundwater calcretes and below the Bonaventure Formation in the southern Gaspé Peninsula. It is therefore not clear if any coarse clastics were deposited in southern Gaspé while the La Coulée clastics were deposited in eastern Gaspé. The groundwater calcrete in the Cascapédia Reentrant seems to have developed within a Paspébiac regolith and the stratiform groundwater calcretes at Saint-Elzéar (Figs. 3.8, 3.9) (Jutras *et al.*, 1999) and at Caplan (Fig. 3.3d) are so mature that they leave no clue as to the nature of their host sediment.

Post-marine sedimentation was possibly very thin in the southern Gaspé Peninsula, or even non-existent outside of the postulated evaporitic basins. The groundwater calcretization event may have mainly affected the marine deposits, if any, that were previously deposited on the wave-cut platform, as well as the pre-Windsor regolith that remained outside the reach of the transgressing sea.

3.12.5 The pre-Bonaventure deformation event (Fig. 3.21)

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, where a 50 m section 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 La Coulée calcrete.

Since the Bonaventure Formation buried a deeply eroded post-La Coulée surface, it can be postulated that the products of that pre-Bonaventure erosion were deposited in a more limited basin, which did not extend northward within the Gaspé Peninsula (Fig. 3.21).

3.12.6 The Bonaventure Formation (Fig. 3.22)

Regional uplift and erosion was followed by a new episode of fault-controlled sedimentation, giving rise to the continental red beds of the Bonaventure Formation (late Viséan?) (Fig. 3.22). Paleogeographic reconstruction of the Bonaventure Formation in the northwestern section of the Maritimes Basin was modelled by Jutras *et al.* (2001) (Fig. 3.22). The southernmost part of the model has been modified to take into account recent findings that suggest an equivalence between the Bonaventure Formation of Gaspé and the Bathurst Formation of eastern New-Brunswick (research in progress).

3.13 CONCLUSIONS

Flat-lying post-Acadian red beds, which are older than the La Coulée calcretes, occupy two small grabens or half-grabens in the southern Gaspé Peninsula and are attributed to the newly described Paspébiac 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, which characterizes the Paspébiac Formation, are mainly matrix-supported and exclusively derived from proximal sources. On the other hand, the similar Bonaventure Formation conglomerates are clast-supported and include clasts that are derived from distal sources. The latter unit sits disconformably on the former in the southernmost sector of the Gaspé Peninsula, while a several metres-thick groundwater calcrete separates the two units northwest of this area. The upper beds of the Paspébiac Formation underwent cementation and karstification prior to being calcretized by saturated groundwaters. The resulting calcrete underwent erosion prior to sedimentation of the Bonaventure Formation.

Since the Paspébiac Formation does not seem to have been affected by the deformation event that has gently folded the beds of the 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 Paspébiac is fixed by the dated Pointe Sawyer Formation, which yields late Viséan to early Namurian spore assemblages (Jutras *et al.*, 2001). From various geomorphic and tectonostratigraphic constraints, the continental Paspébiac Formation is probably older than the first marine units of the Windsor Group. This correlates it with either Horton Group units (uppermost Devonian to Tournaisian) or the Hillsborough Formation (lower or middle Viséan), which bear many similarities in terms of their depositional environments.

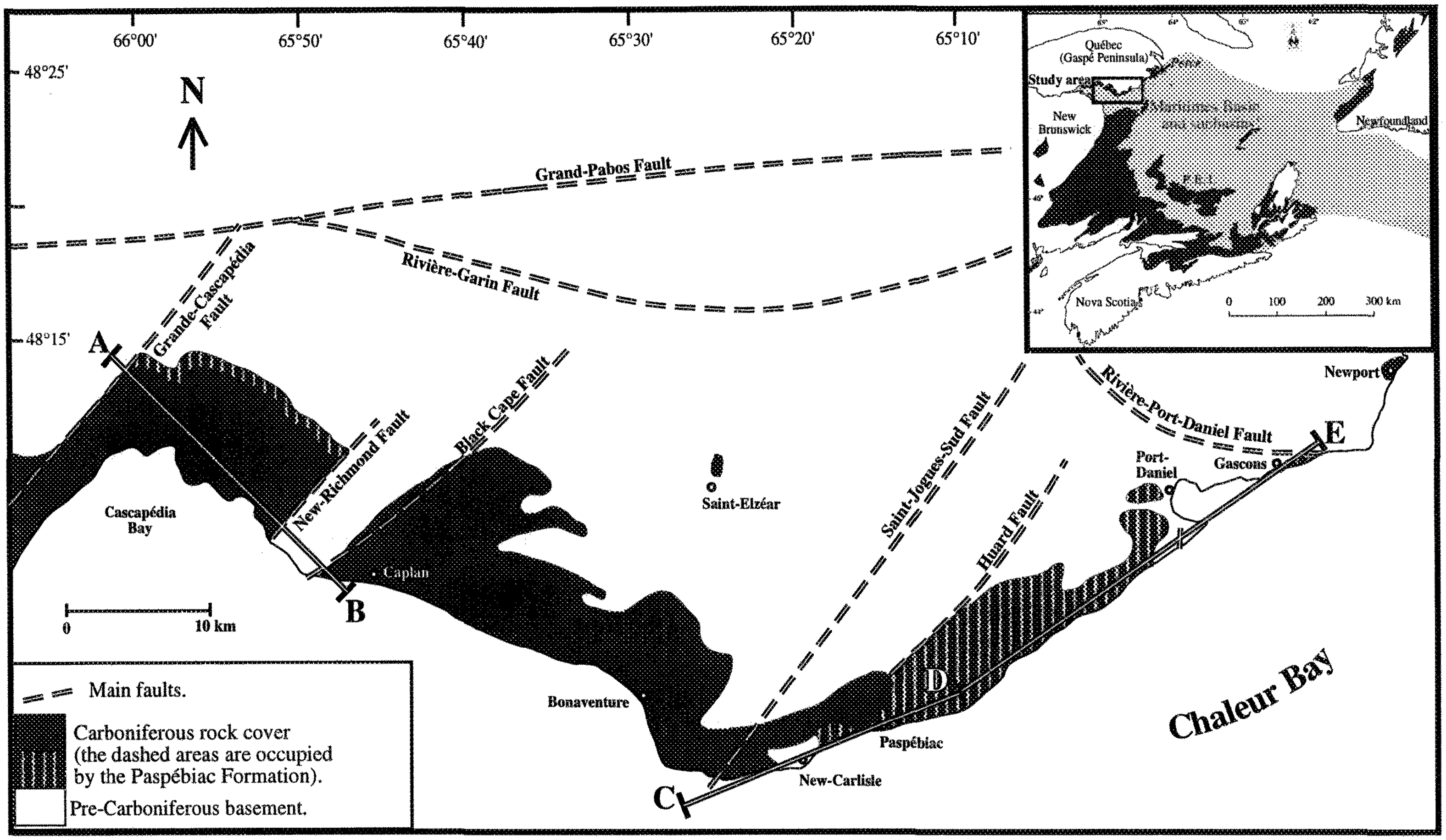

Fig. 3.1. Carboniferous rock cover in the southern Gaspé Peninsula with location of transects A-B and C-D-E. Modified from Brisebois *et al.* (1992). The Maritimes Basin inset is modified from Gibling *et al.* 1992. Pale grey fill in the inset represents the estimated underwater extension of the Carboniferous cover.

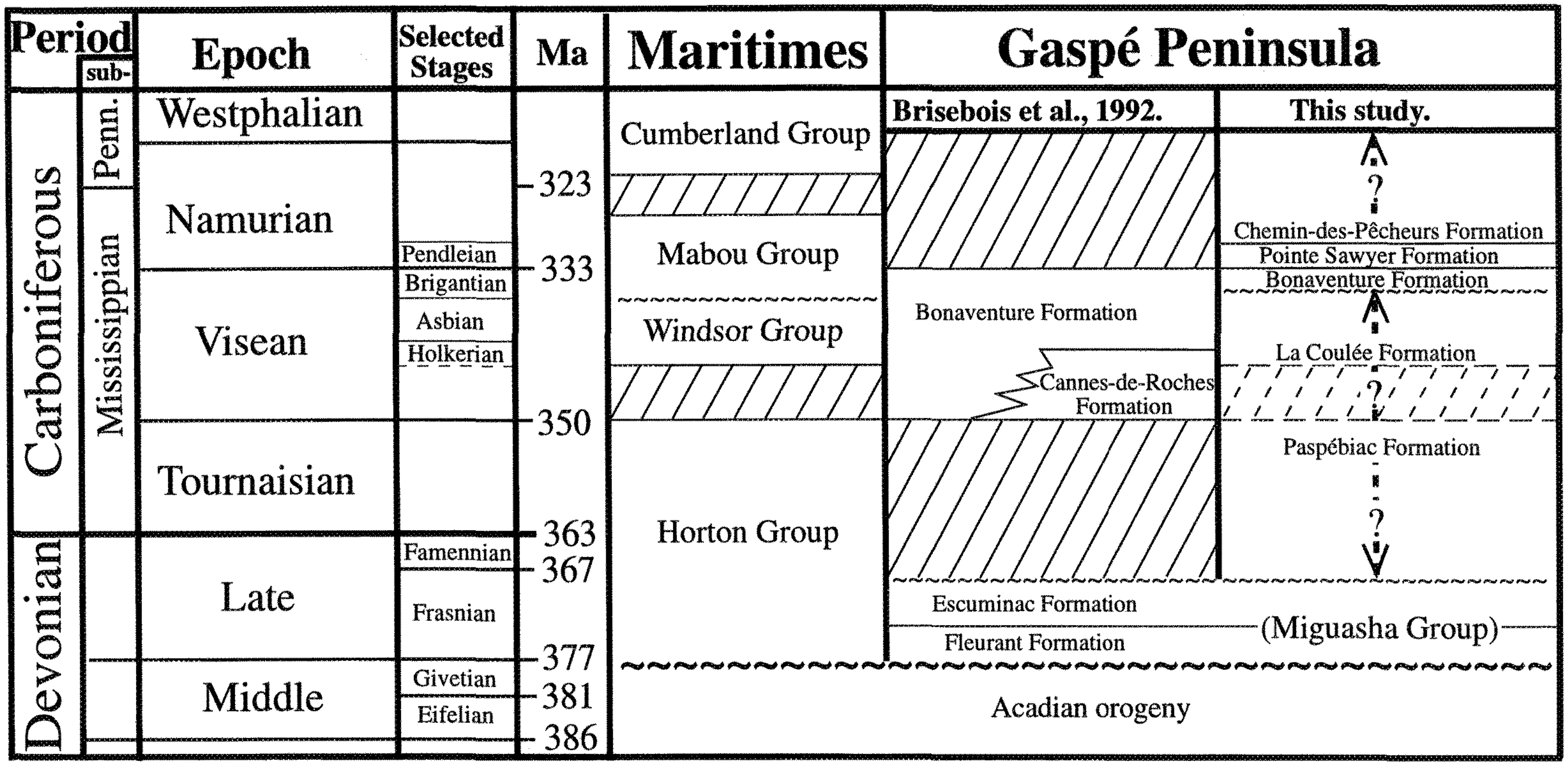

Fig. 3.2. Upper Paleozoic stratigraphic record in the Maritimes and in the Gaspé Peninsula. Time-scale after Harland *et al.* (1990). Wavy lines represent unconformities with no major hiatus and dashed areas represent unconformities with a major hiatus. Stratigraphy of the Maritimes is modified from Bell (1944), Howie and Barss (1975), Utting (1987), Utting *et al.* (1989b), and Ryan *et al.* (1991).

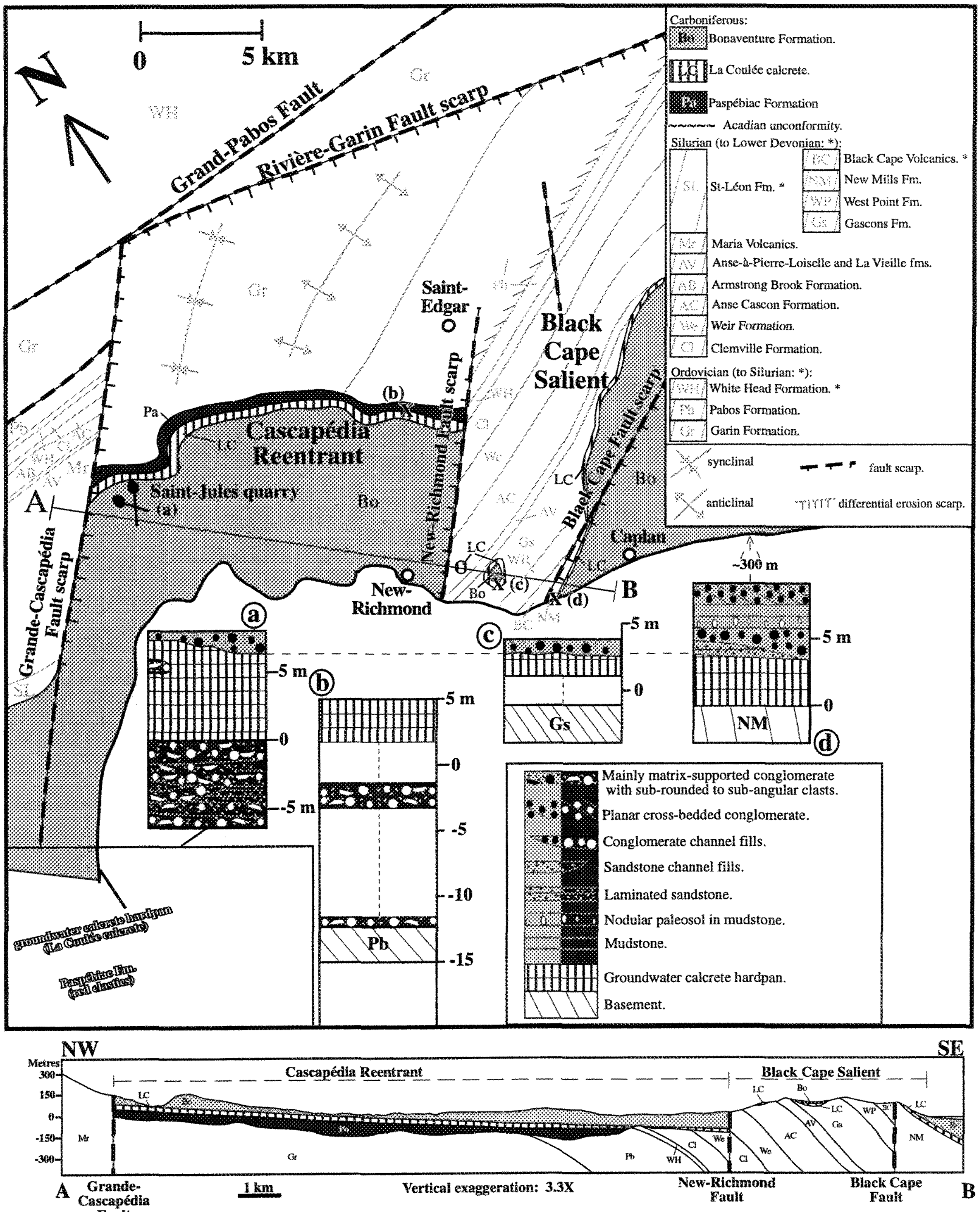

Fig. 3.3. Geology of the Cascapédia Reentrant and Black Cape Salient, with cross-section A-B and composite columns a to d (pre-Carboniferous data by Bourque and Lachambre, 1980, Gosselin, 1988 and Brisebois *et al.*, 1992).

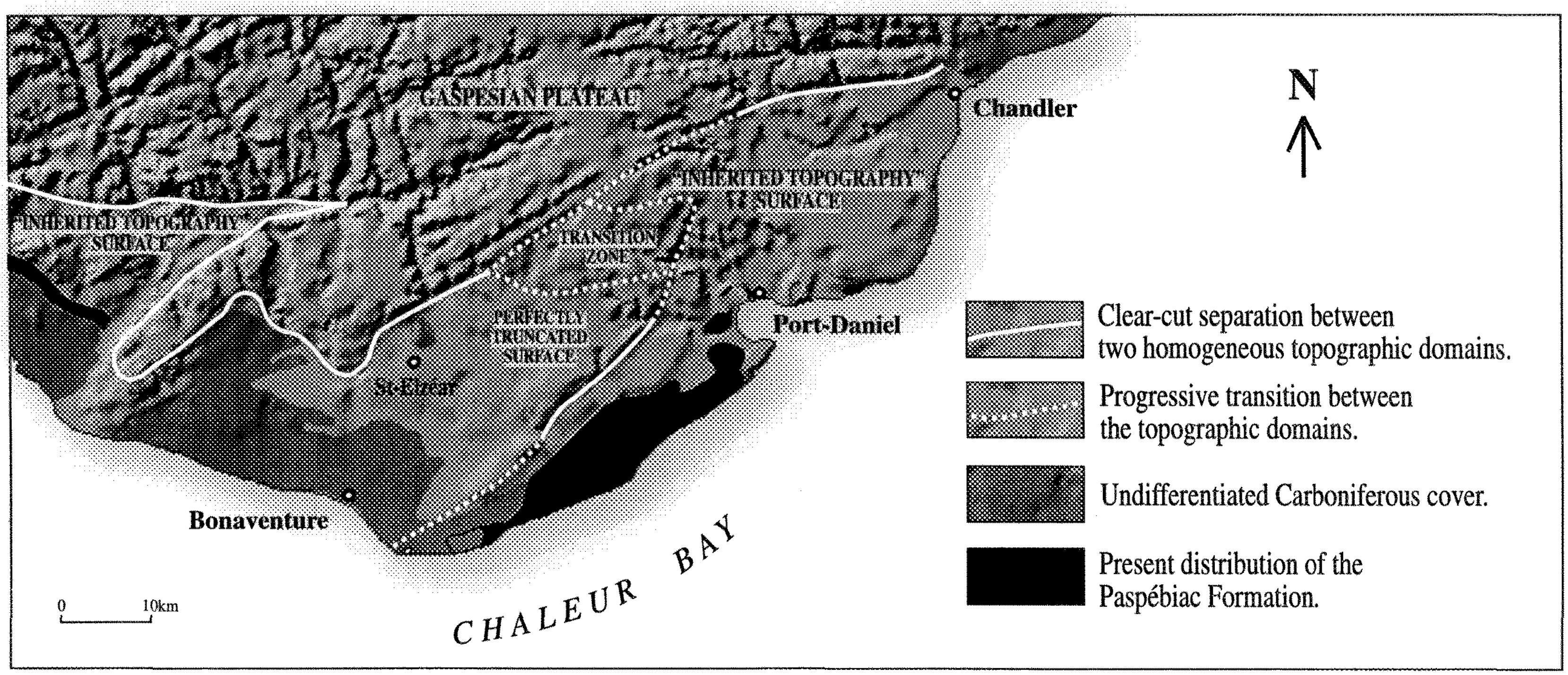

Fig. 3.4. Distribution of the erosional remnants of the Paspébiac Formation in relation to the different topographic domains of the exhumed Carboniferous paleosurface. Modified from Jutras and Schroeder, 1999.

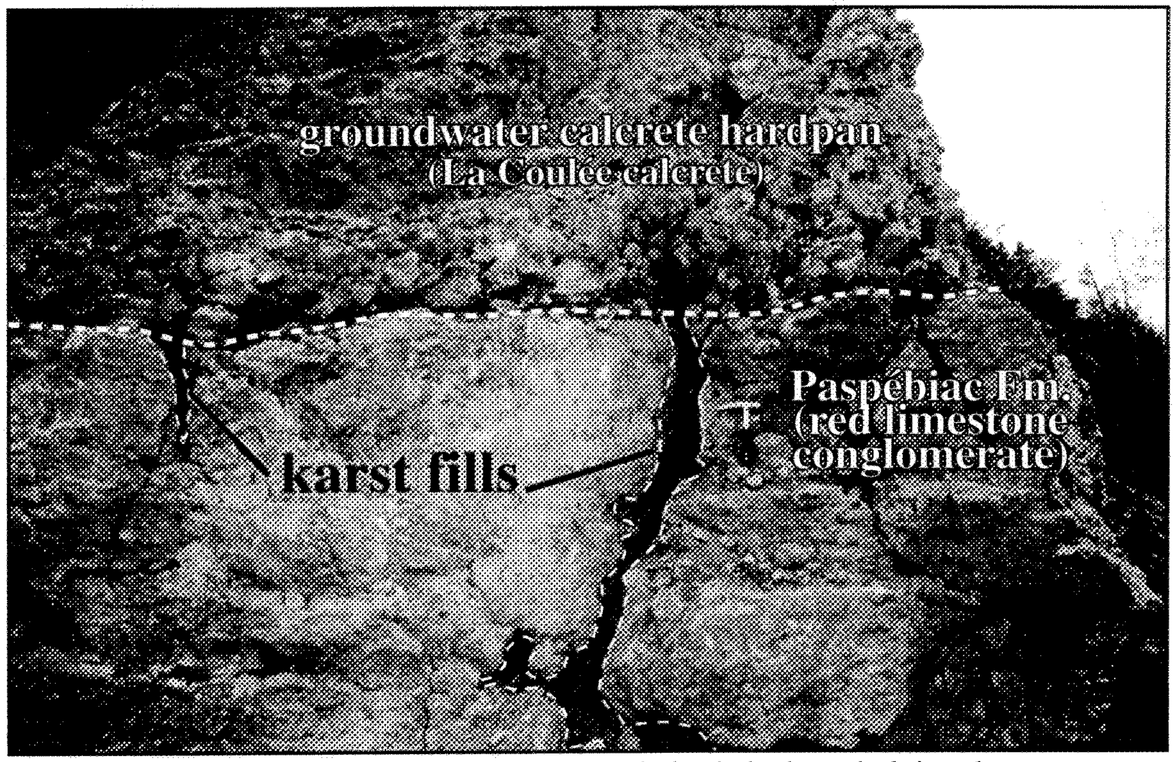

Fig. 3.5. Karst filled with red clay within the red clastic beds underlying the groundwater calcrete in the Saint-Jules quarry. The latter unit truncates the karst fills.

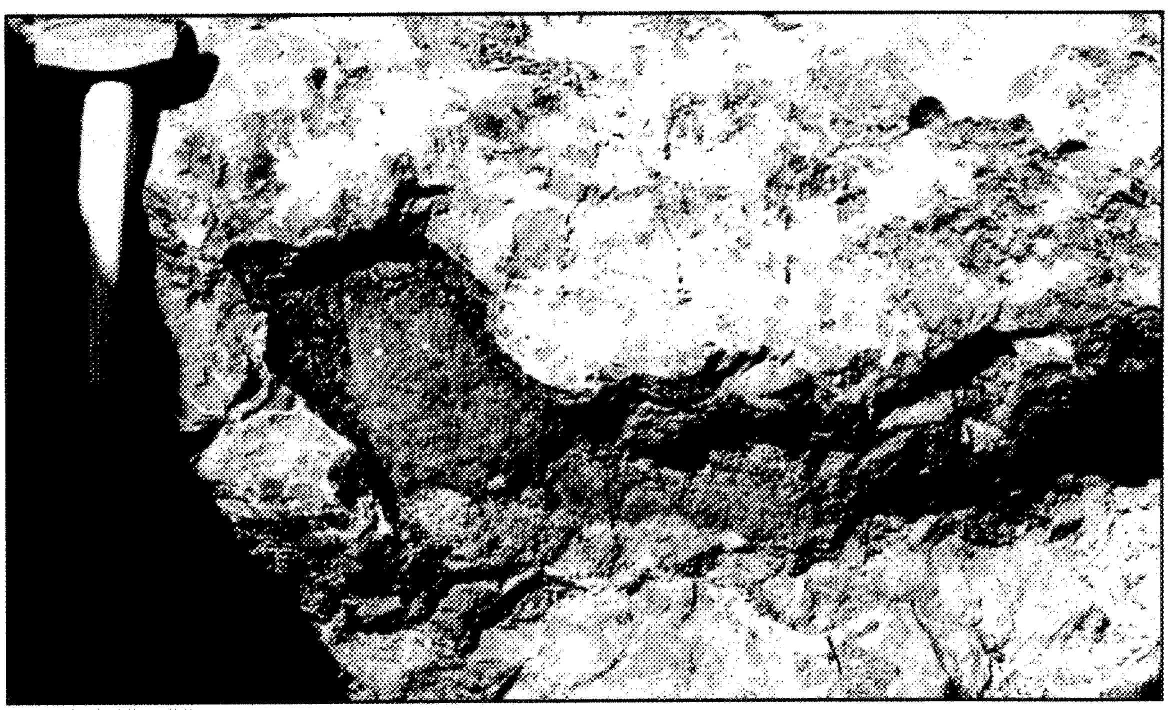

Fig. 3.6. Endokarstic conduit filled with Bonaventure Formation red clastics within the groundwater calcrete of the Saint-Jules quarry (cross-section view).

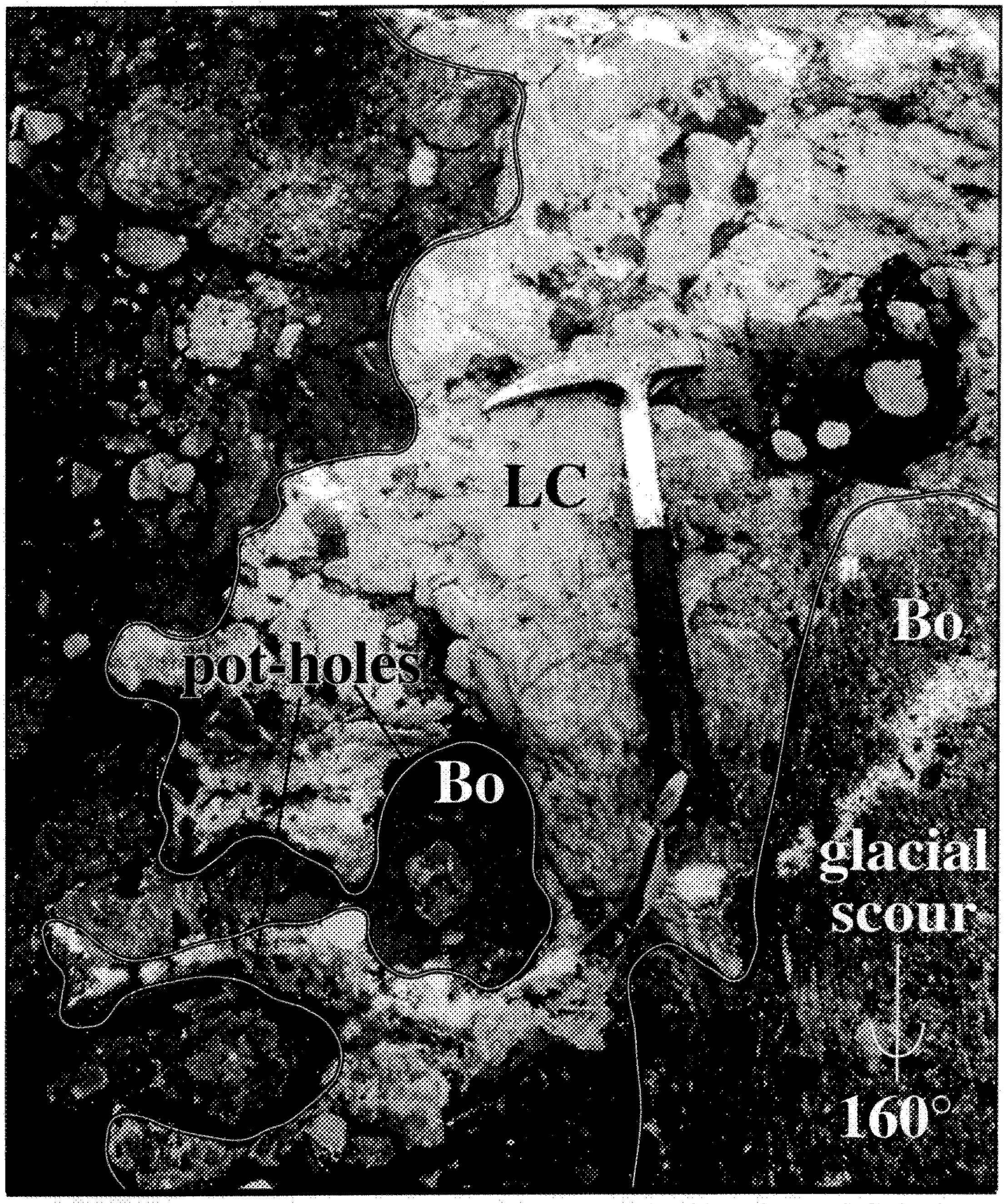

Fig. 3.7 Irregularities in the upper surface of the La Coulée calcrete (LC) in the Saint-Jules quarry, including pot-holes filled with red clastics of the Bonaventure Formation (Bo) (plan view). Both the clastic filling and calcrete upper surface are affected by glacial scouring.

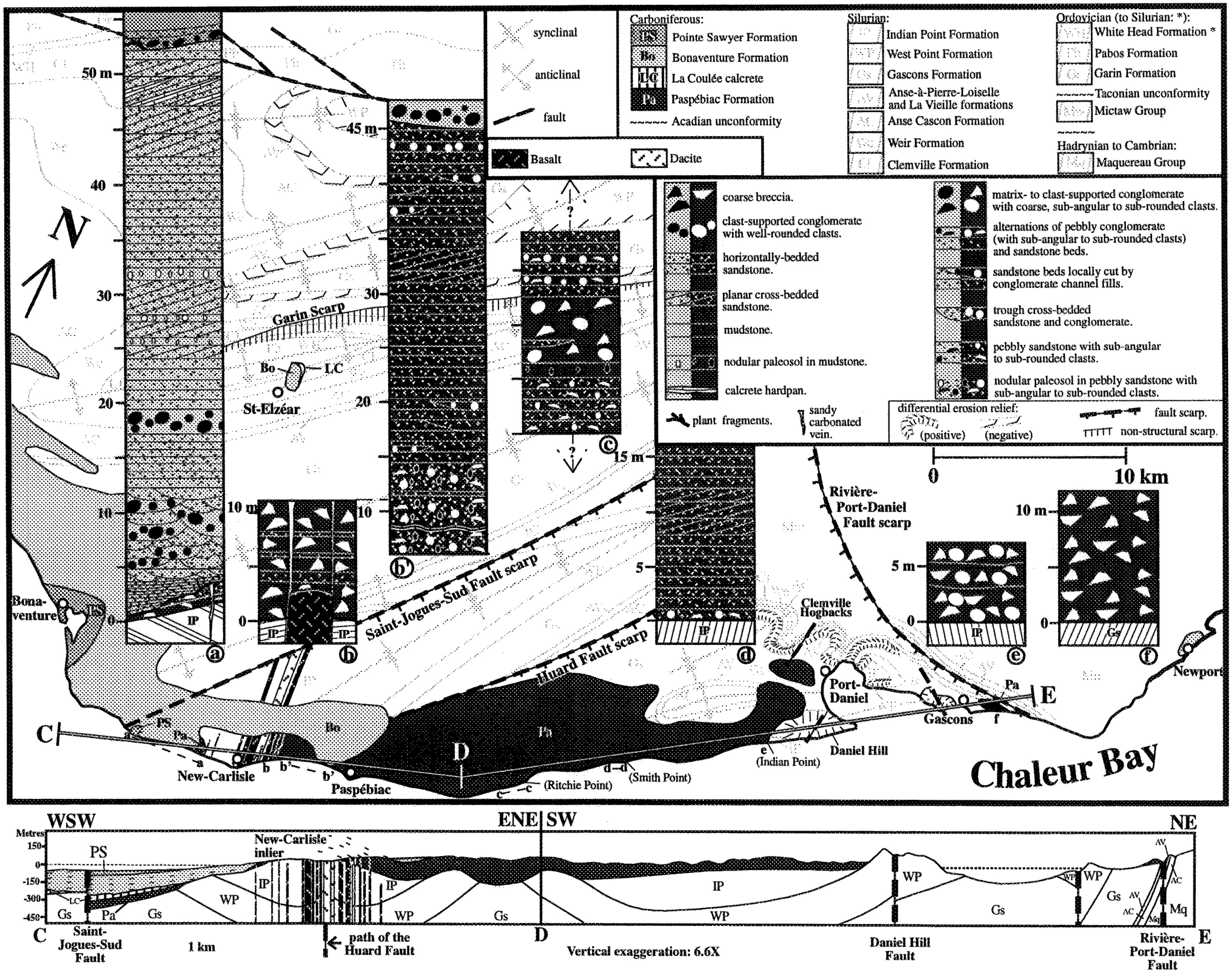

Fig. 3.8. Geology of the New-Carlisle - Port-Daniel area, with cross-section C-D-E and composite columns a to f (pre-Carboniferous data by Bourque and Lachambre, 1980).

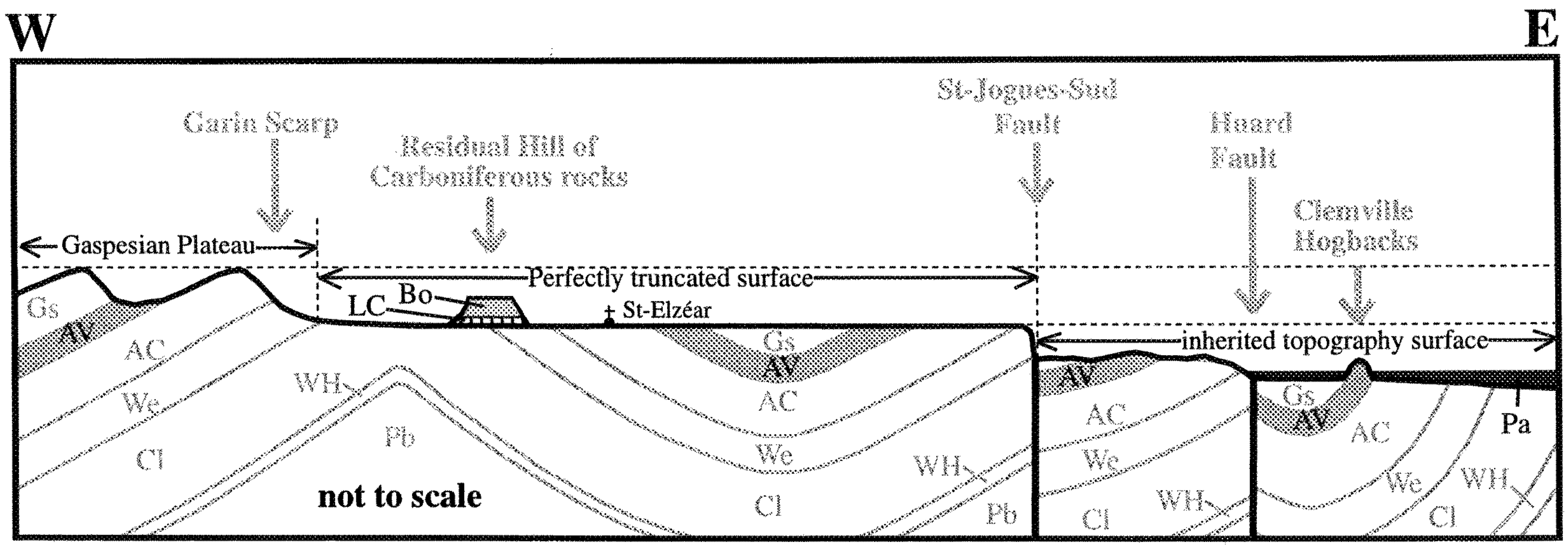

Fig. 3.9. Schematic cross-section of an approximate transect between the Saint Elzéar and Port-Daniel areas. Refer to legend on Fig. 3.8.

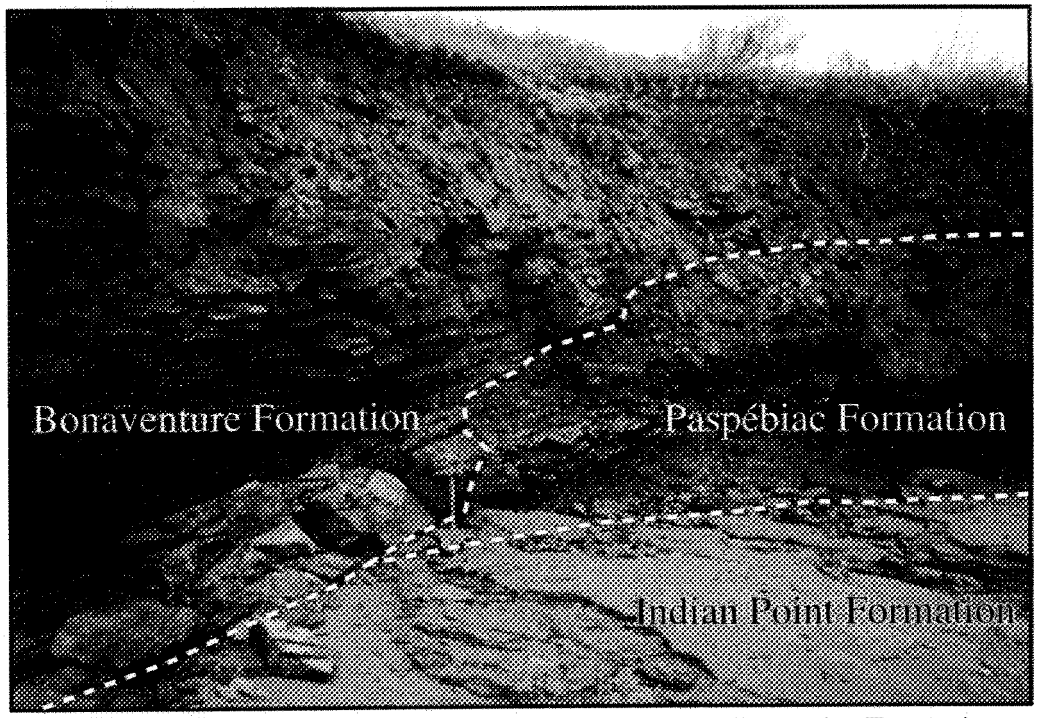

Fig. 3.10. Angular unconformity between the Silurian Indian Point Formation and the post-Acadian Paspébiac and Bonaventure formations. The contact between the Paspébiac clastics and the overlying Bonaventure Formation is an erosional disconformity.

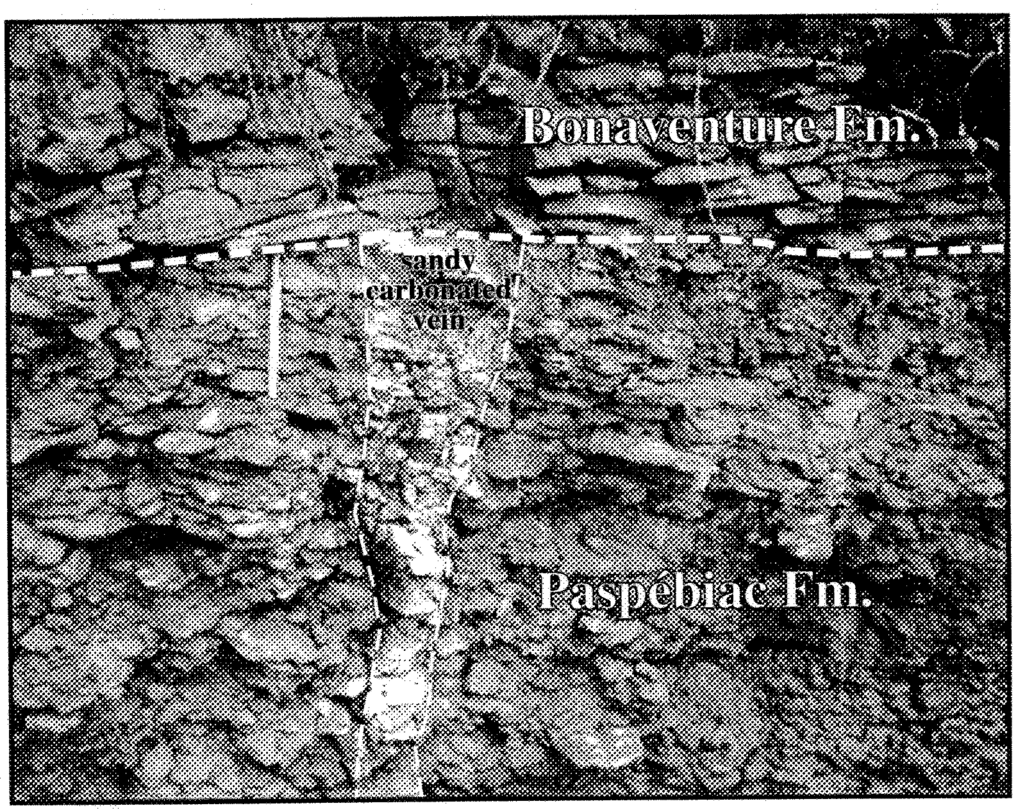

Fig. 3.11. Truncation of a sandy carbonated vein by the red clastics of the BonaventureFormation.

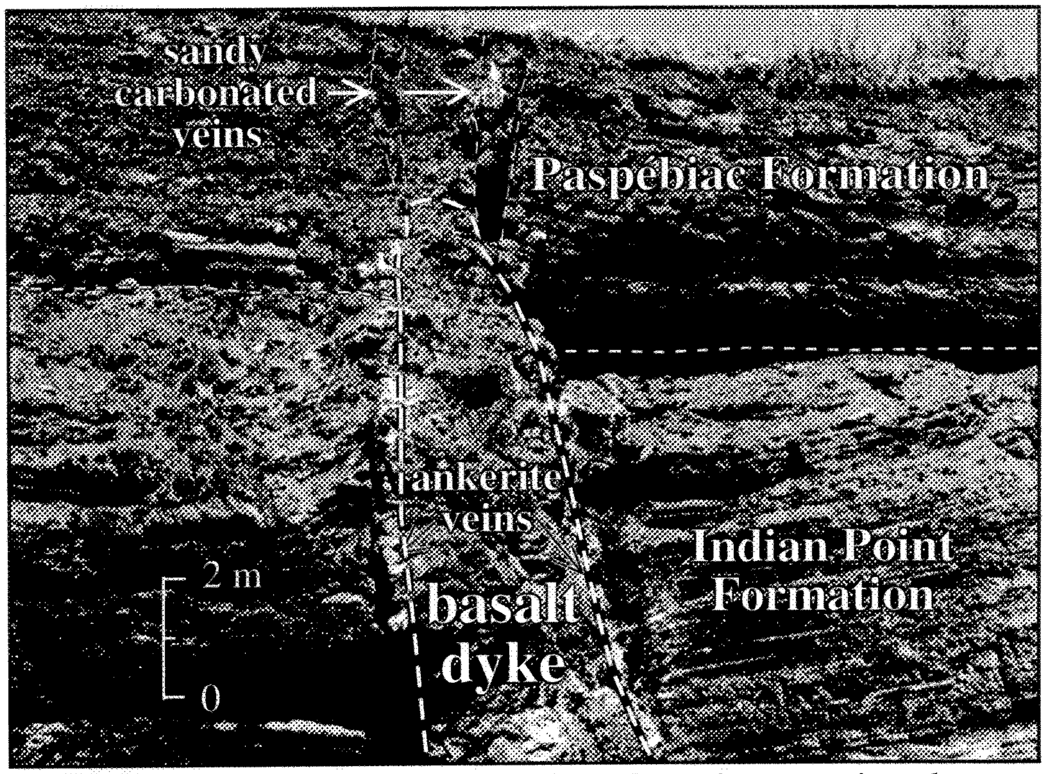

Fig. 3.12. Basalt dyke truncated by the Paspébiac Formation approximately one metre above the unconformity with the Silurian Indian Point Formation. Ankerite veins siding the basalt dyke are intruding the Paspébiac Formation, becoming increasingly large and sandy as they go up the profile.

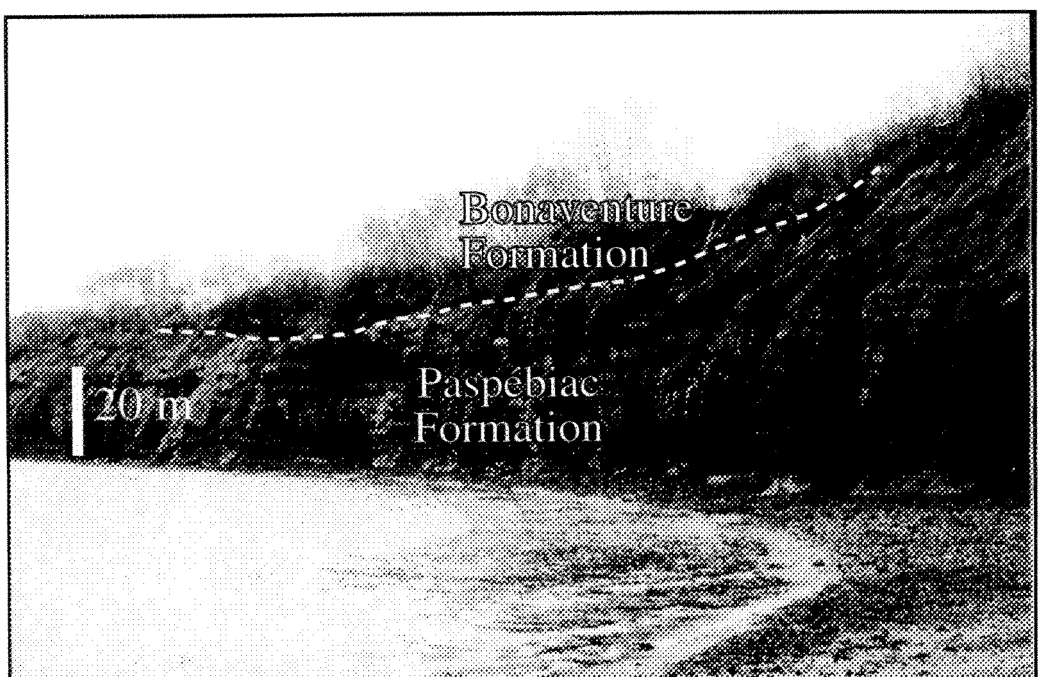

Fig.3.13. Large channel fill of Bonaventure Formation red clastics overlying the Paspébiac Formation near the town of Paspébiac.

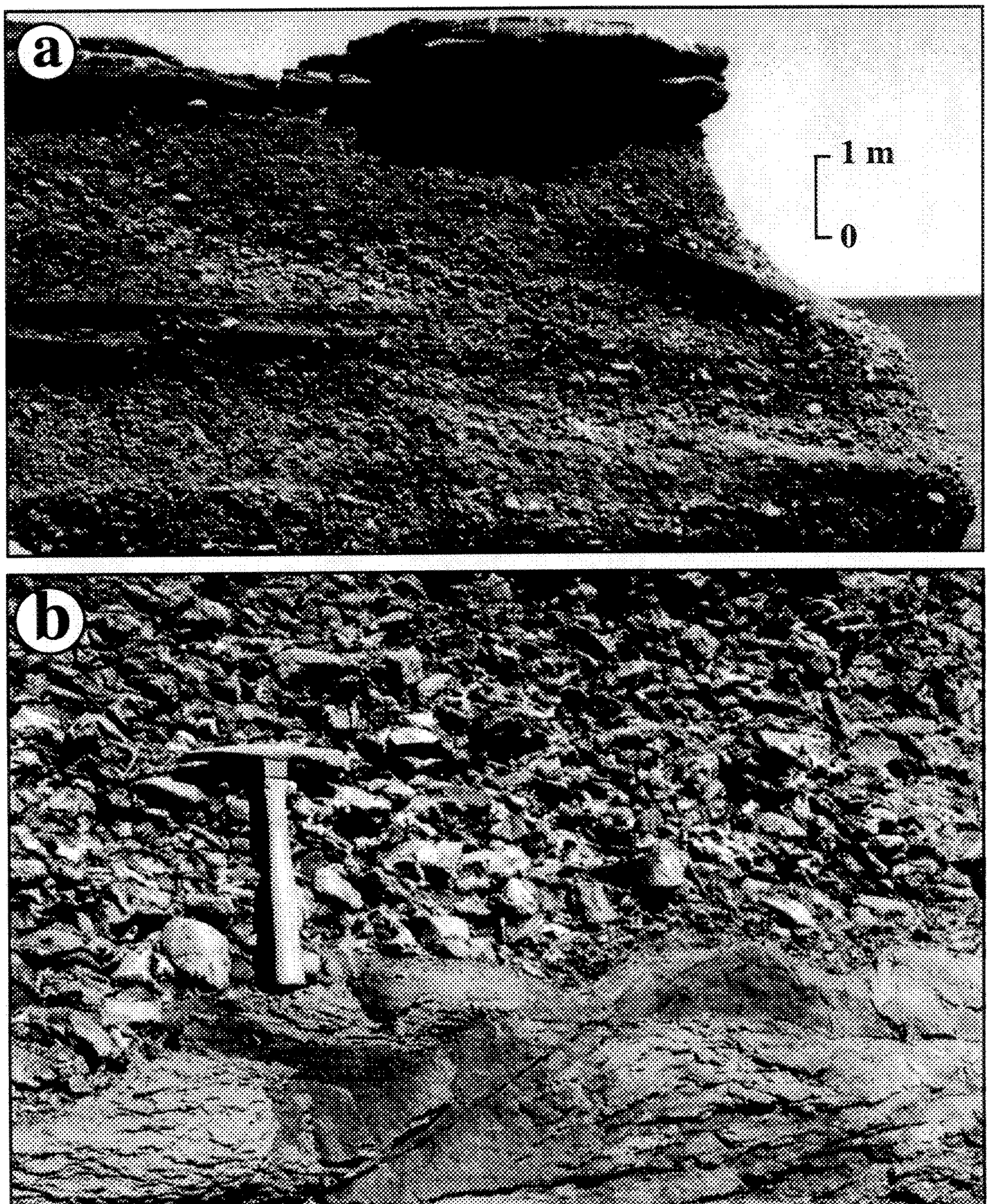

Fig. 3.14. (a) Coarse, stratified and poorly-sorted Paspébiac conglomerate with a few sandstone lenses at Ritchie Point. (b) Partial erosion of a sandstone bed by the subsequent conglomeratic event.

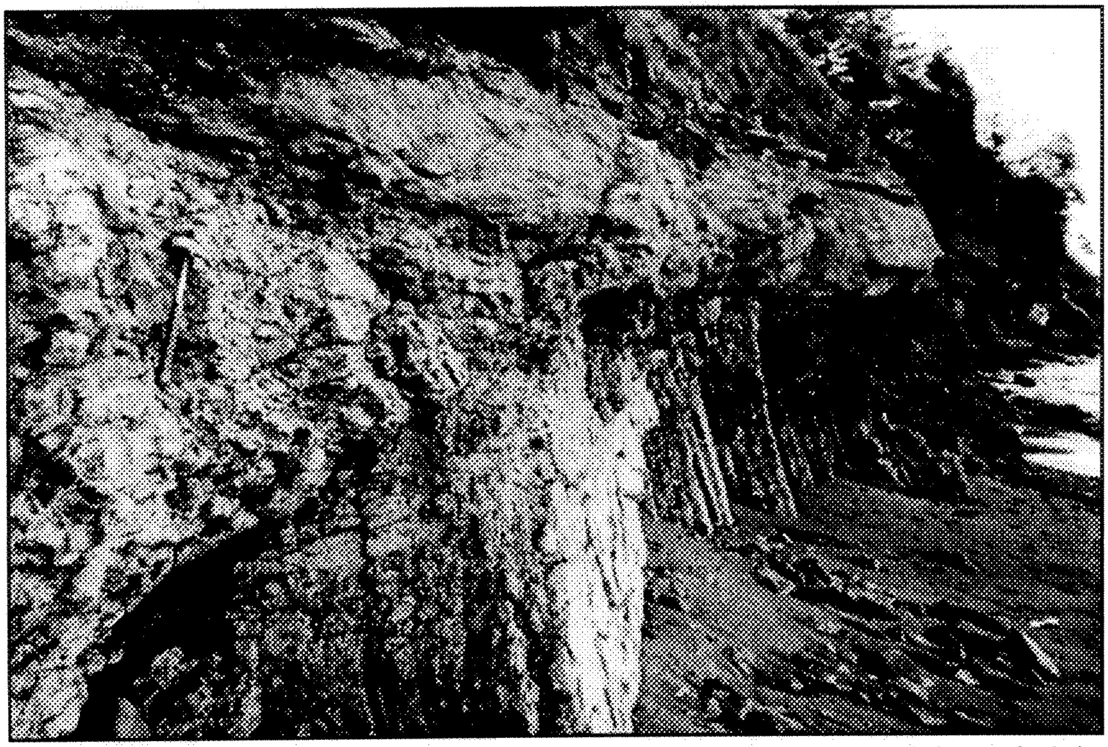

Fig. 3.15. Angular unconformity between the Paspébiac clastics and the underlying Indian Point Formation at Smith Point.

Fig. 3.16. Massive Paspébiac breccia on the northern flank of Daniel Hill.

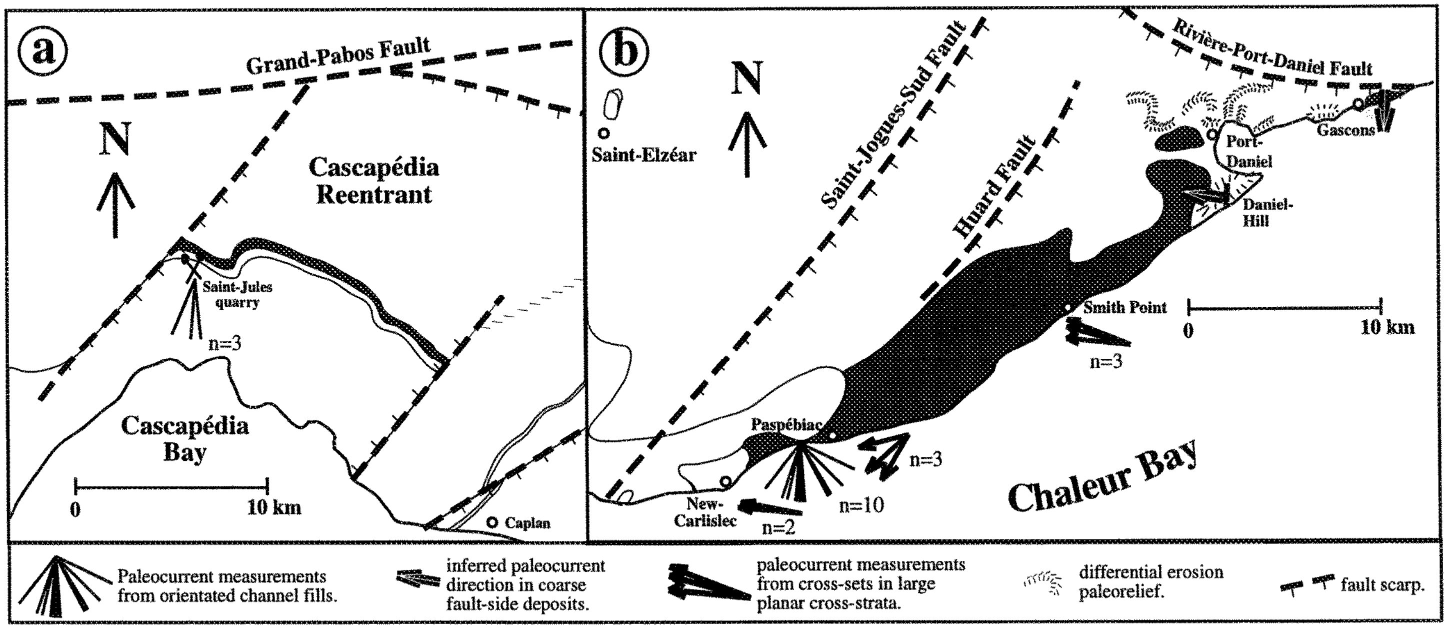

Fig. 3.17. Paleocurrents in the PaspébiacFormation. (a) The Cascapédia Reentrant area. (b) The New-Carlisle - Port-Daniel area.

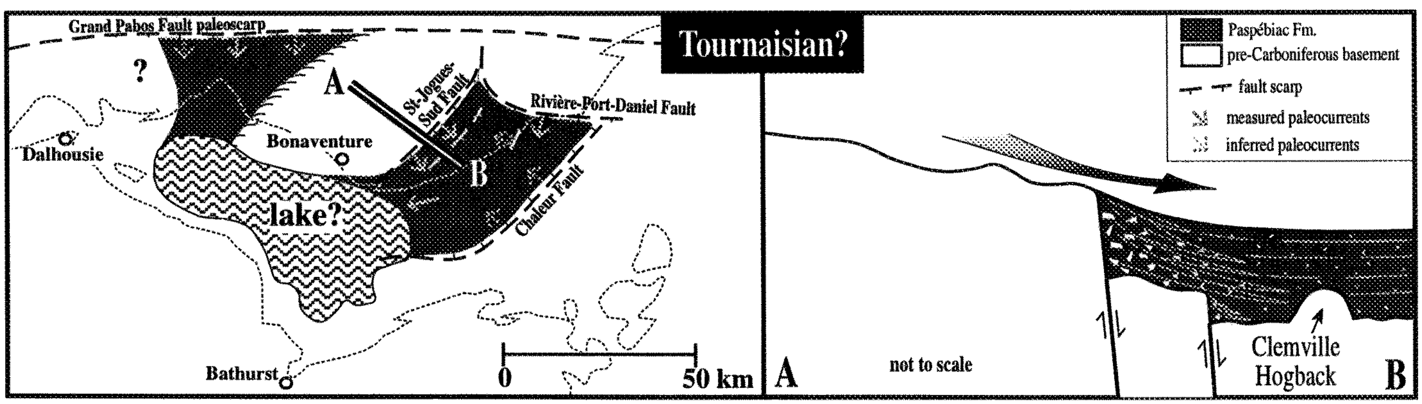

Fig. 3.18. Graben- or half-graben-bound sedimentation of the Paspébiac Formation.

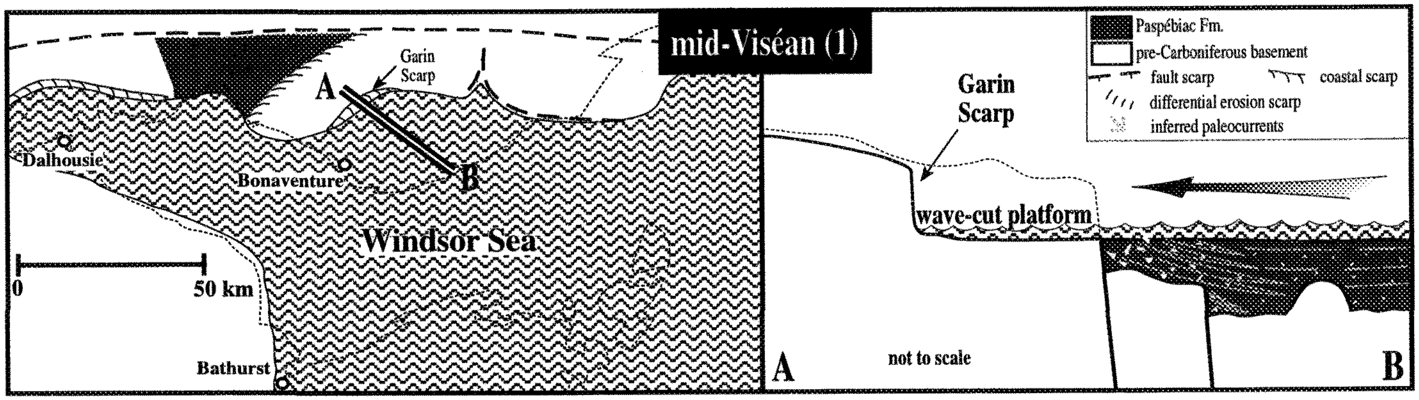

Fig. 3.19. Maximum Windsor Sea transgression.

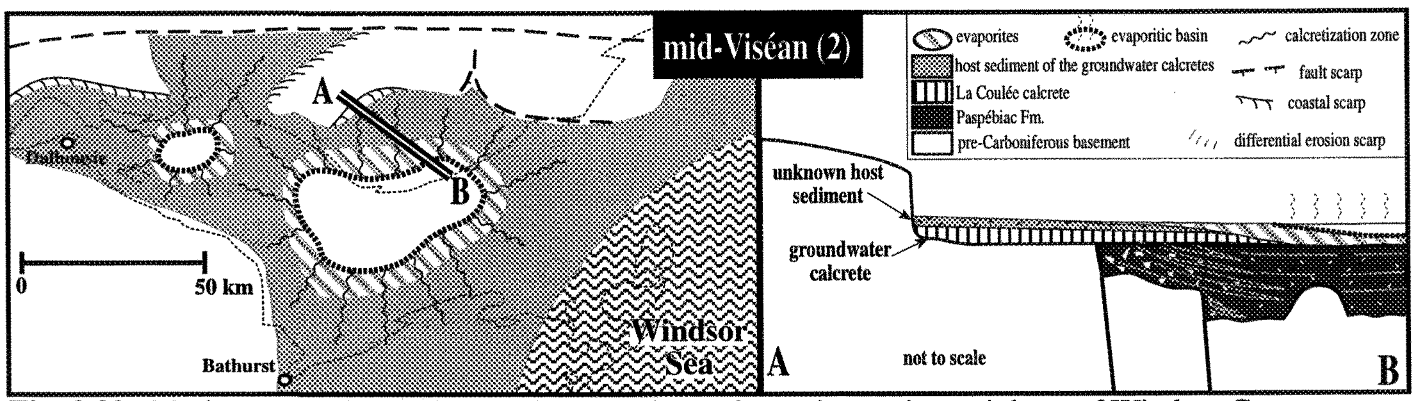

Fig. 3.20. Marine regression and groundwater calcrete formation at the periphery of Windsor Group lowstand evaporitic basins, following the depositional model proposed by Jutras *et al.* (1999, 2001).

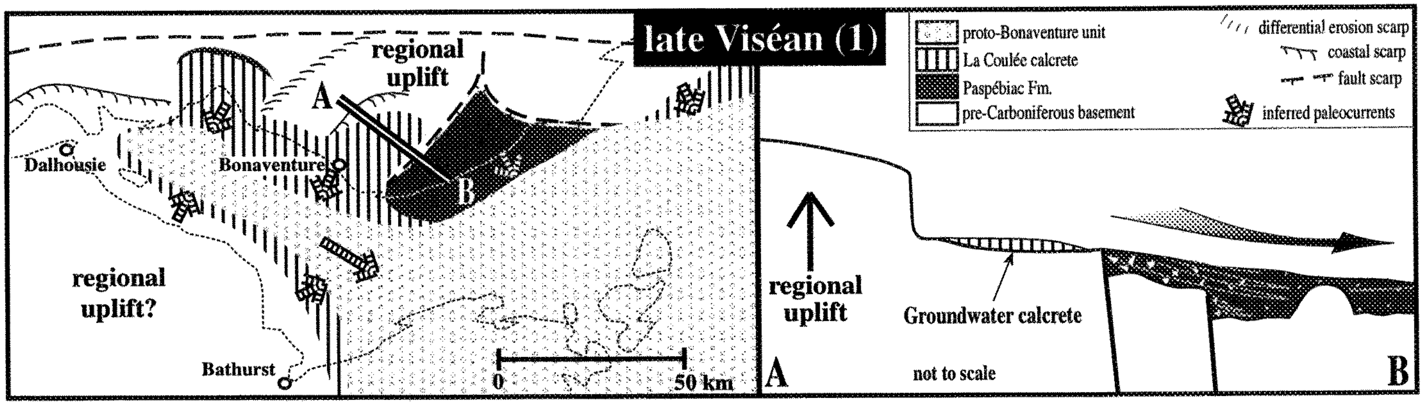

Fig. 3. 21. Pre-Bonaventure erosional phase and postulated deposition of a proto-Bonaventure unit.

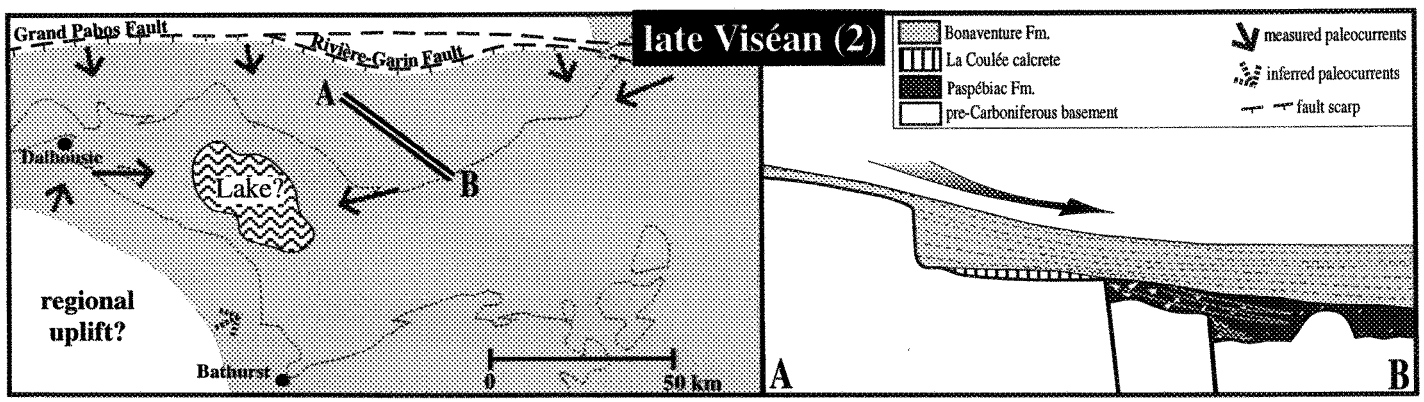

Fig. 3.22. Depositional basin of the Bonaventure Formation (modified from Jutras et al., 2001).

CHAPITRE IV

TRANSPRESSIVE DEFORMATIONS AFFECTING CARBONIFEROUS ROCKS OF THE GASPÉ PENINSULA, QUÉBEC

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4.1 ABSTRACT

Sinistral faults with a NE-SW strike affect Carboniferous rocks in the southwestern Gaspé Peninsula, while major dextral strike-slip faults affecting the same units with a NW-SE to E-W strike are mainly found in the eastern part of the peninsula. These two fault sets could be a response to the same paleostress trends and are possibly coeval. In some cases, fault activity was demonstrably transpressive. Juxtaposition of the Carboniferous Ristigouche and Cannes-de-Roches subbasins occurred through large dextral movements along the Grande-Rivière Fault and other subordinate faults. The NW-SE to E-W striking faults are truncated by small NNW-SSE striking dextral strike-slip faults. This study provides the first indications in eastern Québec for significant post-Acadian block displacement, other than normal faulting.

4.2 RÉSUMÉ

Des failles senestres orientées NE-SW affectent des roches d'âge Carbonifère dans le sud-ouest de la Gaspésie, alors que d'importantes failles coulissantes dextres affectent les mêmes unités dans la partie-est de la péninsule, selon une orientation NW-SE à E-W. Ces deux systèmes de failles pourraient être reliées au même paléostress et sont possiblement synchrones. Dans quelques cas, les failles ont selon toutes évidences évolué dans un contexte tectonique transpressif. La juxtaposition des sous-bassins de Ristigouche et de Cannes-de-Roches s'est faite au profit de larges mouvements dextres le long de la faille de

Grande-Rivière et d'autres failles subordonnées. Les failles orientées NW-SE à E-W sont tronquées par des petites failles dextres orientées NNW-SSE. La présente étude offre les premiers indices suggérant que des déplacements post-acadiens significatifs de blocs structuraux ont affecté l'est du Québec autrement que par des failles normales.

4.3 INTRODUCTION

Prior to a study by Faure *et al.* (1996a), post-Acadian (post-Devonian) deformation in the Gaspé Peninsula (Fig. 4.1), a large segment of the Canadian Appalachians, was thought to be limited to Carboniferous syn-sedimentary dip-slip faulting (Rust *et al.*, 1989) and to minor post-sedimentary normal fault readjustments (Alcock, 1935; St-Julien and Hubert, 1975; Bernard and St-Julien, 1986; Kirkwood, 1989; Bourque *et al.*, 1993; Peulvast *et al.*, 1996). Faure *et al.* (1996a) have provided the first indications for post-Acadian compressive paleostresses from micro-structures in southern Québec, including the Gaspé Peninsula, but large strike-slips like those affecting Carboniferous rocks of the nearby Maritime Provinces, and which are attributed to the Alleghanian orogenic phase (Permo-Carboniferous), were not until now recognized on the north shore of Chaleur Bay.

A recent project dedicated to reviewing Carboniferous units in the Gaspé Peninsula has led to the identification of several strike-slip faults affecting them, along with some associated compressive features such as reverse faults and drag folds. Some of the initial findings are reported in this paper. Field data are presented for three sectors of the general study area: (1) Percé, (2) New-Carlisle - Port-Daniel and (3) Carleton - New-Richmond (Fig. 4.1).

The structural features recorded in Carboniferous rocks of the Chaleur Bay area exhibit brittle fabrics with scarce kinematic indicators. The main fault traces are commonly eroded and rarely exposed. When faults are exposed, the deformation corridor mainly consists of strongly cataclastic material offering little clue about motion vectors. Subordinate Riedel structures and reverse faults locally contain slickensided calcite fibers, providing diagnostic kinematic indicators, the summary of which is presented in Appendix VI.

4.4 GEOLOGICAL SETTING

Late Precambrian to Ordovician rocks in the Gaspé Peninsula were deformed by major thrust faults during the Middle Ordovician Taconian Orogeny (St-Julien and Hubert, 1975). These rocks, together with Late Ordovician to Middle Devonian rocks, were affected by the Middle Devonian Acadian deformation, which is characterized by open folding and major dextral strike-slip faults formed in a transpressive regime (Malo and Béland, 1989; Malo *et al.*, 1992, 1995; Malo and Kirkwood, 1995; Kirkwood *et al.*, 1995). The open folds affecting the Frasnian Miguasha Group, which unconformably overlies pre-Late Devonian units, are thought to have been formed during a late stage of the

Acadian Orogeny (Brideaux and Radforth, 1970; Rust, 1982; Zaitlin and Rust, 1983; Hesse and Sawh, 1992).

Erosional remnants of uppermost Devonian to Carboniferous rocks in the Gaspé Peninsula are limited to a narrow zone, less than 20 km wide, on the north shore of Chaleur Bay (Fig. 4.1). They are relatively undeformed and unconformably overlie late Precambrian to Late Devonian rocks (Alcock, 1935; Rust, 1982; van de Poll, 1995).

The oldest post-Acadian unit (if the Miguasha Group is considered syn-Acadian), on the north shore of Chaleur Bay, is the Paspébiac Formation (Fig. 4.2). In the New-Carlisle area (Fig. 4.1), this graben-fill unit of continental red clastic rocks is overlain with an erosional disconformity by the Bonaventure Formation, a similar unit deposited within a larger graben (Jutras and Prichonnet, submitted). In its westernmost exposures, north of the town of New-Richmond (Fig. 4.1), a surface regolith of the Paspébiac Formation has been invaded by a thick and massive groundwater calcrete underneath the unconformity with the Bonaventure Formation. Such thick and massive groundwater calcretes affect the base of the La Coulée Formation, a grey clastic unit which unconformably underlies the red clastics of the Bonaventure Formation (Jutras *et al.*, 1999). The numerous exposures of thick groundwater calcrete hardpans all occupy the same relative stratigraphic position and are postulated to represent one single event, coeval with the La Coulée Formation clastics, which are only observed in the Percé area (Fig. 4.1).

The Paspébiac (Jutras and Prichonnet, submitted), La Coulée (Jutras *et al.*, 1999) and Bonaventure (Rust *et al.*, 1989) formations are interpreted as fault-controlled sedimentary units. The two latter units are locally in fault contact with each other, which implies that fault activity also occurred after deposition of the Bonaventure Formation (Jutras *et al.*, 1999).

Renewed fault activity is thought to have controlled sedimentation of the Pointe Sawyer Formation, which was dated as late Viséan to early Namurian (Jutras *et al.*, 2001) from a spore assemblage (the SM Zone of Utiing, 1987) that is now considered to be exclusively Namurian (J. Utting, pers. comm., 2001). This unit, which was formerly called the Upper Member of the Cannes-de-Roches Formation, not only overlies the Lower and Middle members of that abandoned formational unit but also disconformably overlies the Bonaventure Formation in the New-Carlisle area (Fig. 4.1). The conformably overlying Chemin-des-Pêcheurs Formation, consisting of undated sandstones, marks the onset of sedimentation from distal sources and is thought to be related to uplift of the Alleghanian Orogen, south of the study area (Jutras *et al.*, 2001).

The spore assemblage of the Pointe Sawyer Formation corresponds to that of the basal Mabou Group units in the Maritimes Basin (Jutras *et al.*, 2001). No solid correlation with the Maritimes Basin stratigraphy has been established for the underlying post-Acadian units in the Gaspé Peninsula, which are undated. From biostratigraphic constraints, they are known to be younger than the Frasnian and older than the Namurian (Jutras and Prichonnet, submitted). From tectonostratigraphic and paleoenvironmental constraints, Jutras *et al.* (submitted) proposed that the Paspébiac, La Coulée and Bonaventure formations may be time-equivalent to, respectively, the Horton Group or Hillsborough Formation, the Lower or Middle Windsor, and the Middle or Upper Windsor. Showing a transitional contact with the underlying Pointe Sawyer Formation, the Chemin-des-Pêcheurs Formation is probably also a Mabou Group equivalent of Namurian age.

Faure *et al.* (1996a) record evidence within Late Devonian plutons of southern Québec and within Carboniferous rocks of the Gaspé Peninsula for three minor post-Acadian brittle fault trends in cross-cutting relationship with each other, but no significant block displacements were recorded. Prior to the present study, all the macroscopic strike-slip faults affecting Siluro-Devonian rocks in the Gaspé Peninsula, whether ductile or brittle, were correlated with late stages of the Acadian Orogeny (Malo and Kirkwood, 1995; Kirkwood *et al.*, 1995) and had not been recognized within Carboniferous rocks.

4.5 POST-SEDIMENTARY STRUCTURES AFFECTING CARBONIFEROUS ROCKS OF THE PERCÉ AREA (FIG. 4.3)

Basin reconstruction, through paleocurrent, petrographic and facies distribution data, indicates that the Carboniferous successions of the Mal Bay and Chaleur Bay depressions (Fig. 4.1) were deposited in two different basins which are respectively referred to as the Cannes-de-Roches (Jutras *et al.*, 2001) and Ristigouche (van de Poll, 1995) basins. Both basins include the La Coulée, Bonaventure and Pointe Sawyer formations, but no graben-fill of the Paspébiac Formation has been identified in the Cannes-de-Roches Basin and no remnant of the Chemin-des-Pêcheurs has been identified within the Ristigouche Basin, although these mature and distally derived sands most likely covered the whole region prior to their subsequent erosion.

The red clastics of the Cannes-de-Roches Basin (Fig. 4.1), which were previously attributed to the Lower and Middle members of the Cannes-de-Roches Formation (Alcock, 1935), are now included within the Bonaventure Formation (Jutras *et al.*, 2001). If the Carboniferous beds of the Gaspé Peninsula had only been deformed by minor dip-slip faulting, there would be a thickness incompatibility in this correlation, the Bonaventure Formation being less than 50 m thick in the Cannes-de-Roches Cove section (Figs. 4.3, 4.4e) of the Cannes-de-Roches Basin, but at least 350 m thick in the Percé section (Figs. 4.3, 4.4d) of the Ristigouche Basin, 500 m away. Furthermore, the Bonaventure Formation in the Percé section includes coarse clastics up to the top of the succession and is probably only time-equivalent to the first 16 to 20 m of that unit in the Cannes-de-Roches Cove section, which comprises what was originally referred to as the Lower Member of the abandoned Cannes-de-Roches Formation. If the subvertically tilted strata of the Cannes-de-Roches Cove section (Fig. 4.4e) were to be restored to horizontal, they would literally touch rocks of the Percé section (Fig. 4.4d), which are many times thicker and bear opposite paleocurrent trends (Jutras *et al.*, 2001). Another problem raised by the close proximity of the two sections is the observation that the host sediment of the La Coulée Formation calcrete in the Cannes-de-Roches Cove section bears abundant volcanic clasts while this formation is exclusively composed of calcareous clasts in the Percé section, suggesting that the two host sediments were not fed by exactly the same sources (Jutras *et al.*, 2001).

The thickness, petrographic and paleocurrent differences, while no source area remains between the two successions, imply that a large post-sedimentary lateral displacement has occurred. A large fault system separating rocks of the two basins was identified in the Percé area (Figs. 4.3, 4.4). The main fault is the south-eastern extension of the Grande-Rivière Fault, an extensively studied dextral strike-slip (Malo and Béland, 1989; Kirkwood, 1989; Malo *et al.*, 1992, 1995; Malo and Kirkwood, 1995; Kirkwood *et al.*, 1995) that was exclusively attributed to the Acadian orogeny prior to this study. This fault and three other sub-parallel faults are defined below.

4.5.1 The Grande-Rivière Fault

The Grande-Rivière Fault directly separates the thin and steeply dipping Cannes-de-Roches Cove succession from the thick flat-lying Percé succession to the south.

The fault corridor barely touches the northern end of Bonaventure Island, which is marked by massive calcite veins (Figs. 4.3, 4.5A) and where red fault breccia can be observed (Figs. 4.3, 4.5B), plastered on flat-lying Bonaventure strata. The breccia comprises a mixture of pulverized Bonaventure Formation clastics and very sharp clasts of Devonian limestones. Large displaced blocks (1 to 10 m^3) of red fault breccia and

Devonian limestones are caught in laminated calcite veins. The blocks are also affected by older but similar calcite veins. It is interpreted that this section of the deformation corridor has been affected at a late stage of its structural history by multi-episodic hydrothermal activity.

The Percé Rock (Rocher Percé) (Figs. 4.3, 4.5C), which comprises vertical beds of Forillon limestones and Shiphead sandstones (Early Devonian), reddened and affected by numerous laminated calcite veins, is interpreted as a large slab caught in the deformation corridor from the observation that it lines up with a series of similar slabs that are separated from pre-Carboniferous basement rocks by red fault breccia: the second and third 'Sisters' (of the 'Trois Soeurs' monoliths) (Figs. 4.3, 4.5D) and Pic de l'Aurore (formerly called " Devil's Peak ") (Fig. 4.3, 4.5E). All these slabs show vertical beds oriented at high angle to the structural trend of the pre-Carboniferous basement.

The northern flank of Pic de l'Aurore is plastered by a red, 2 to 3 m-thick *in situ* fault-breccia (Fig. 4.5F) that can best be observed within large fallen blocks lying on the beach (Fig. 4.5G). Cataclastic shear structures, absence of sedimentary structures, higher compaction and sharper clasts clearly differentiate this breccia from the sedimentary breccia of the Bonaventure Formation, which is lying horizontally near the top of Pic de l'Aurore (Fig. 4.5H). Red fault breccia is also observed on the southern flank of Pic de l'Aurore, separating horizontal beds of the Bonaventure Formation from vertical beds of the Shiphead Formation, which constitute the fault slab (Figs. 4.5E).

The fault turns inland in an E-W strike at the westernmost end of Pic de l'Aurore (Figs. 4.3, 4.5I, J, K) and resumes a NW-SE strike ~2 km further on a fault line that is considered by Kirkwood (1989) as the southern extension of the Troisième-Lac Fault, which is attributed to the Acadian deformation (Béland, 1980). Just west of the hamlet of Coin-du-Banc (Fig. 4.3, locality 1), the trace of the Grande-Rivière Fault makes another E-W turn and is sided by an anticlinal drag fold affecting strata of the La Coulée and Bonaventure formations on the north side of the fault (Fig. 4.5L). The fold is convex towards the east-south-east (plunge 60°, trend 110°), which, from its position on the northern fault block, is an indicator of dextral movement (Biddle and Christie-Blick, 1985).

The sharp bend in the fault trajectory, at Pic de l'Aurore, may be responsible for the large reverse fault affecting rocks of the Carboniferous succession on the south shore of Mal Bay (Figs. 4.3A, 4.6). The Carboniferous succession on the hanging wall of the reverse fault is tilted on edge and the beds are contorted, creating small secondary thrusts. Carboniferous strata in the footwall of this fault, exposed at Cannes-de-Roches Point, are nearly horizontal.

These compressive features, associated with a left bend (sensu Twiss and Moore, 1995), also indicate that movement of the fault was dextral. Sinistral movement would have rather created extension in association with a left bend (Woodcock and Fischer, 1986). The thrusted block thus corresponds to a " strike-slip duplex " (sensu Woodcock and Fischer, 1986) within a "positive flower structure" (Fig. 4.7).

Although the Carboniferous conglomerates are poor hosts to record striae, one set of dextral slickenside lineations (trend 020°, plunge 42°) was found on a small fault surface within Carboniferous strata along a brook draining the west side of 'Pic de l'Aurore', in the Grande-Rivière Fault corridor (Fig. 4.3, locality 2; Appendix VI). This further indicates dextral motion, which corroborates most studies carried out along the western extension of the Grande-Rivière Fault (Malo and Béland, 1989; Kirkwood, 1989; Malo *et al.*, 1992, 1995; Malo and Kirkwood, 1995; Kirkwood *et al.*, 1995).

The Grande-Rivière Fault is truncated by several small NNW-SSE striking dextral faults, three of which are included in Figure 4.3. These faults were considered to represent late Acadian fault movement by Kirkwood (1989). Since they cut a fault system affecting rocks that are as young as Namurian, both sets of faults have demonstrably experienced post-Viséan motion.

4.5.2 The Mont-Sainte-Anne Fault

The Mont-Sainte-Anne Fault parallels the Grande-Rivière Fault (Fig. 4.3) and was inferred by Jutras *et al.* (1999) to accommodate a line of abrupt stratigraphic breaks. The latter fault is clearly observable on air photos but it is not exposed. Although kinematic indicators are lacking, it is postulated that this fault is part of the flower structure associated with the left bend in the Grande-Rivière Fault system at Pic de l'Aurore.

4.5.3 The Cap Blanc Fault

The Cap Blanc Fault parallels the Grande-Rivière and Mont-Sainte-Anne faults, and separates the Matapedia Group from the Bonaventure Formation on the south side of Cap Blanc (Fig. 4.3). It was interpreted as a normal fault by Alcock (1935) and Kirkwood (1989). Its large deformation corridor (Fig. 4.8A, B) includes a 2 m thick slab of vertically dipping Matapédia Group limestone and a 20 m large cataclastic drag fold (plunge ~45°, trend 330°) developed within the Bonaventure Formation. This fold is convex towards the NNW on the SW fault block, which is an indication of dextral movement (Biddle and Christie-Blick, 1985). The core of the fold is affected by numerous small thrusts with slickensided calcite fibers (Fig. 4.3B; Appendix VI). Small thrusts with slickensided calcite fibers are also registered in the groundwater calcrete of the La Coulée Formation on the coastline south of Percé (Fig. 4.3B; Appendix VI).

On both sides of the Cap Blanc Fault, slickensided calcite fibers in the subordinate thrusts are nearly perpendicular to the fault trace. This suggests that the Cap Blanc Fault, although subvertical, has experienced a reverse movement component, which has led to uplift of the NE block and the 15° tilting of the Carboniferous strata. This 15° dip of the Carboniferous beds, perpendicular to the Cap Blanc Fault, is also observed at the southern end of Bonaventure Island (Fig. 4.3).

The extension of the Cap Blanc fault has been recognized in outcrops alongside Murphy Creek, 13 km to the NW (locality 3 on Fig. 4.3), where several R structures affecting the basal calcrete of the La Coulée Formation and the overlying Bonaventure Formation show dextral slickensided calcite fibers (Fig. 4.3D; Appendix VI). These subordinate faults indicate that the Cap Blanc Fault has recorded dextral strike-slip motion in post-Viséan time, age of the Bonaventure Formation. As suggested by the drag fold, the subordinate thrusts and the uplift of the NE block, movement of the fault was oblique and had a compressive component.

4.5.4 The Percé-Sud Fault

Numerous normal faults sub-parallel to the Cap Blanc Fault are found within the Bonaventure Formation along the coastline on the first 15 km south of that fault. Some of these fault planes include both normal and horizontal striae, but their relative chronology could not be determined. One normal fault is truncated by a small thrust, which indicates that these subordinate faults do not postdate the transpressive deformation and have either accompanied or preceded it, or both.

The largest of these sub-parallel faults is the previously unnamed Percé-Sud Fault (Figs. 4.3, 4.9A, B), which was mapped as a normal fault by Kirkwood (1989). Although there are no stratigraphic markers on this particular fault, normal displacement can be determined on several other sub-parallel faults. Also, since the local succession of red beds is gradually fining upward, the sandstone and conglomerate on the NE block of the fault are probably lower stratigraphically than the fine sandstone and mudstone of the SW block (Fig. 4.9A). However, if normal displacement is probable, so is transcurrent motion, none of the beds in the ~200 m thick succession of the SW block being as coarse as those in the NE block. The succession in the SW block is therefore probably more distal than that of the NE block and, since the source area of the Bonaventure Formation is to the north (Jutras *et al.*, 2001), this suggests that the Percé-Sud Fault may have been the locus of dextral displacement within the Ristigouche Basin. It possibly acted as an R structure of the Cap Blanc and Grande-Rivière faults.

4.6 POST-SEDIMENTARY STRUCTURES AFFECTING CARBONIFEROUS ROCKS OF THE NEW-CARLISLE - PORT DANIEL AREA (FIG. 4.10)

The New-Carlisle - Port Daniel area is characterized by a rugged Carboniferous paleosurface dominated by the Clemville Hogbacks, which are sculpted in the Silurian limestones of the La Vieille and West Point formations (Bourque and Lachambre, 1980; Bail, 1981; Jutras, 1995; Peulvast *et al.*, 1996; Jutras and Schroeder, 1999), and which were buried by red clastics of the Paspébiac Formation from the late Devonian or early Carboniferous activity of the Saint-Jogues-Sud, Huard and Rivière-Port-Daniel faults (Jutras and Prichonnet, submitted). Karstic features in these limestone hogbacks are filled with red clastics closely resembling those of the Bonaventure Formation. According to Jutras and Schroeder (1999), the limestones were first sculpted into hogbacks by differential erosion, were later buried by red clastics, and only developed karstic features during subsequent exhumation. Material derived from the Carboniferous cover synchronously filled the karsts.

The Paspébiac Formation graben is thought to have been overlapped by the Windsor Sea on account of a paleowave-cut platform extending immediately beyond its limits, north of the Saint-Jogues-Sud Fault (Fig. 4.10). A 10-12 m thick La Coulée calcrete overlies the platform and is disconformaby overlain by red clastics of the Bonaventure Formation. Within the limits of the Paspébiac graben, the Bonaventure Formation disconformably overlies the Paspébiac Formation with no remnants of La Coulée calcrete in between. Two channel fills of the Pointe Sawyer Formation disconformably overlie the Bonaventure Formation between the towns of Bonaventure and New-Carlisle (Fig. 4.10).

Two strike-slip faults affecting at least part of the local Carboniferous succession were identified in the New-Carlisle - Port-Daniel area.

4.6.1 The Saint-Jogues-Sud Fault

The Saint-Jogues-Sud Fault forms a well defined linear feature on air photos, cutting the Bonaventure Formation west of New-Carlisle (Fig. 4.10A; Appendix VI), but it is not exposed within this unit. However, four ENE-WSW striking subordinate fault planes, two of which include sinistral slickensided surfaces, are postulated to represent P structures associated with a sinistral splay of the Saint-Jogues-Sud Fault in post-Bonaventure time.

The lack of major facies differences in the Bonaventure Formation strata, across the trace of the Saint-Jogues-Sud Fault, suggests no large lateral displacement on that fault, although this is difficult to establish within horizontal clastic beds that typically show a high lateral variability.

4.6.2 The Port-Daniel Fault

A limestone quarry in one of the Clemville Hogbacks, on the northeastern side of Port-Daniel, exposes a dense network of interweaving NNE-SSW fault planes affecting both the limestones of the La Vieille Formation and the red clastics within the karsts (Fig. 4.10B; Appendix VI). Slickensided calcite fibers on several fault planes indicate sinistral movement. From the observation that karst is preferentially developing in the fault planes, while the kart-fill is also sheared, it is concluded that fault activity, karst formation and karst infill are contemporaneous in this sector. If correlation of the karst-fill with the Bonaventure Formation detritus is correct, the deformation is post-Bonaventure.

4.7 POST-SEDIMENTARY STRUCTURES AFFECTING CARBONIFEROUS ROCKS OF THE CARLETON - NEW-RICHMOND AREA (FIG. 4.11)

The topography of this region is dominated by the Mount Carleton and Mount Maria horst to the west, and by the Black Cape Salient horst to the east, with the Cascapédia Reentrant graben in between (Fig. 4.11) (Peulvast *et al.,* 1996; Jutras and Prichonnet, submitted). The Paspébiac Formation and La Coulée calcrete were recently recognized in the Cascapédia Reentrant (Jutras and Prichonnet, submitted). The latter unit is unconformably overlain by the Bonaventure Formation in this sector. On the Black Cape Salient and east of that horst, the La Coulée calcrete lies unconformably on the pre-Carboniferous basement with no Paspébiac Formation in between.

Steeply dipping strata of the Bonaventure Formation in the Carleton area have been related to a ~600 m normal splay of the Petit-Montréal and Mont-Saint-Joseph faults (Fig. 4.11) by Bernard and St-Julien (1986) with no documented kinematic indicators. Gosselin (1988) also postulates that the Bonaventure Formation has been affected by a normal splay of the Grande-Cascapédia Fault on account of its steep tilt perpendicular to the fault scarp (Fig. 4.11). This author considered the Petit-Montréal, Mont-St-Joseph and Grande-Cascapédia faults as steeply dipping late Acadian reverse faults that were active subsequent to the regional Acadian folds, but also reports evidence for sinistral and, to a lesser degree, dextral movement along subordinate structures of the deformation corridor. The possibility that the present disposition of the Carboniferous strata could have been related to that reverse splay, rather than to a subsequent normal splay, has never been mentioned.

Jutras *et al.* (submitted) identified and named the New-Richmond and Black Cape faults (Fig. 4.11), which limit the Black Cape Salient on each side and which affect the local Carboniferous succession. No kinematic markers were found in the unexposed New-Richmond Fault trace apart for a vertical splay of 50 (minimum) to 920 (maximum) metres.

Given below are evidences indicating that the Black Cape and Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault systems have experienced post-Acadian transcurrent displacement.

4.7.1 The Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system

West of Carleton, Carboniferous beds are tilted subvertically and strike approximately 040° with respect to the nearby Petit-Montréal Fault trace (Figs. 4.11-13), which does not crop out in the Carboniferous rocks. Locally, the beds are slightly overturned (Fig. 4.13A) and affected by small internal thrusts, as well as by small vertical fault planes plastered with sinistral slickensided calcite fibers (Figs. 4.11A, 4.13B; Appendix VI).

Such transpressive features are incompatible with the normal fault hypothesis formulated by previous authors (Bernard and St-Julien, 1986; Gosselin, 1988) and are here interpreted as being related to a strike-slip drag fold, which, being convex towards the NE on the SE block, suggests sinistral movement (Biddle and Christie-Blick, 1985) of the Petit-Montréal Fault. Moreover, two small east-striking reverse faults were identified in the La Coulée calcrete of the Saint-Jules-de-Cascapédia quarry (Fig. 4.11B; Appendix VI). It could not be determined whether these reverse faults were formed before or after the Bonaventure Formation, but they are most probably coeval with the above-mentioned deformation features west of Carleton. The reverse faults probably indicate the main principal stress vector ($\sigma1$), which is nearly N-S and at a ~30° angle with the nearby Grande-Cascapédia Fault.

From their disposition with respect to the Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system, the transpressive features observed within Carboniferous strata in the west side of the Cascapédia Reentrant can be best correlated with an oblique sinistral movement along that system in post-Acadian times, with perhaps a strong reverse fault component to account for the steep tilt of Bonaventure beds along the fault; which is not unlike the conclusions drawn by Gosselin (1988) apart for the timing of displacement.

4.7.2 The Black Cape Fault

The south-eastern sector of the Black Cape Salient (Fig. 4.11) is affected by brittle shearing associated to the newly identified Black Cape Fault. Brittle faulting affects the Early Devonian Black Cape-Dalhousie Volcanics and an underlying clastic unit that is at least 100 m thick according to available exposure, and which was recently correlated with the latest Silurian to earliest Devonian New Mills Formation (Bourque *et al.*, 2000).

On both sides of the Black Cape Fault shear zone, the pre-Carboniferous rocks are unconformably overlain by a La Coulée calcrete, which is itself disconformably overlain by the Bonaventure Formation (Fig. 4.14). On the SE block, a 3 m thick remnant of the La Coulée calcrete separates the New-Mills clastics from a nearly 300 m thick succession of

Bonaventure Formation red beds, which is overlain by the grey clastics of the Pointe Sawyer Formation near the town of Bonaventure (Fig. 4.10), ~10 km southeast of the Black Cape Salient (Jutras *et al.* submitted).

No exposure of Carboniferous rocks was found on the Black Cape Fault trace. However, as shown on cross-section G-H (Fig. 4.14), the Carboniferous succession is tilted to a 25° dip on the SE block of the Black Cape Fault, but lies flat on the NW block, which suggests that it has been affected by activity of that fault. It is postulated that the brittle deformation features observed within the pre-Carboniferous basement rocks, which are defined below, are related to post-Bonaventure fault activity.

The Black Cape Fault is a cataclastic structure of unknown displacement that was identified within the New-Mills clastics on the side of route 132, which crosses the Black Cape Salient (Fig. 4.11; inset). The fault is oriented SW-NE (045° -230°) and bears no kinematic indicators. The continuity of the Black Cape fault on the coast line corresponds to an incompletely exposed cataclastic fold affecting the New Mills clastics and bringing a 35° change of dip orientation within a 100 m distance (Fig. 4.11; inset). The orientation of this cataclastic drag fold, convex toward the SW, suggests sinistral shearing.

Less than 1 km west of the Black Cape Fault, a small succession of red clastics intercalated between two lava flows of the Black Cape Volcanics, and which Bourque and Lachambre (1980) refer to as the Lazy Cove sedimentary unit, is almost entirely pulverised in a cataclastic corridor that bears no reliable kinematic indicators. However, at the contact between this deformed sedimentary unit and the subsequent lava flow, small NNE-oriented slickensided sinistral fault planes are well defined (Fig. 4.11C; Appendix VI) and are interpreted as P structures of the Black Cape Fault. ~750 m west of the Black Cape Fault, an east-striking reverse fault (Fig. 4.11D; Appendix VI) has developed within the Black Cape Volcanics. 100 to 150 m west of the Black Cape Fault, a dense network of small NE-oriented slickensided sinistral fault planes (Fig. 4.11E; Appendix VI), interpreted as P structures, is truncated by a less dense network of NW-oriented slickensided dextral fault planes (Fig. 4.11F; Appendix VI), which are nearly perpendicular to the Black Cape Fault trace and are therefore interpreted as R' structures.

Kinematic indicators around the Black Cape Fault all pertain to sinistral movement on that fault, whereas the small reverse fault indicates that the regime was transpressive. The Black Cape Fault, as the Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system, probably had a reverse fault component to account for the uplift of the Black Cape Salient and the tilting of Carboniferous strata.

4.8 TENSILE FRACTURES

Vertical tensile fractures filled with calcite, ranging from a few millimetres to more than 10 cm in thickness, are commonly found throughout the Carboniferous succession in the southern Gaspé Peninsula. The calcite is either laminated or massive. Orientation of the tensile fracture-cast veins is extremely regular, from one end of the peninsula to the other, where they strike 040°-220° (+/- 5°). They are not concentrated in the above-mentioned fault zones, which suggests that they are not syn-tectonic. The tensile veins are perfectly parallel to a large Triassic (or younger) mafic dyke that extends for more than 100 km in the Tracadie Peninsula of Northern New Brunswick (Potter *et al.*, 1979). Both features are probably related to extension stresses associated with the opening of the also parallel Fundy Rift in Triassic to Jurassic time.

4.9 SYNOPSIS OF FAULT MOTION AFFECTING CARBONIFEROUS ROCKS IN THE GASPÉ PENINSULA

Carboniferous rocks of the Gaspé Peninsula are affected by three sets of faults: NE-SW striking sinistral faults, NW-SE to E-W striking dextral faults, and minor NNW-SSE striking dextral faults. Reverse fault movement, on both main and subordinate faults, and associated drag folds, indicate that the sets of sinistral NE-SW striking faults and dextral NW-SE to E-W striking faults evolved under a transpressive regime. Displacement of the NW-SE to E-W striking Grande-Rivière Fault trace by the set of small NNW-SSE striking dextral faults suggests that the latter faults were active subsequent to the former fault.

The SW-NE striking sinistral faults affect rocks as young as the Bonaventure Formation (late Viséan?). The NW-SE to E-W dextral strike-slips affect rocks as young as the Chemin-des-Pêcheurs Formation (Namurian), while the minor NNW-SSE striking dextral strike-slips have not been observed within Carboniferous rock exposures. Only Quaternary sediments overlap the three sets of faults, giving a very poorly constrained upper age limit for each of them.

Both the sinistral SW-NE and dextral NW-SE to E-W striking faults could be related to the first post-Acadian main principal paleostress trend ($\sigma 1$) determined by Faure *et al.* (1996a), which they refer to as NNW-SSE, but which is estimated as nearly N-S on most of their diagrams. The subsequent NNE-SSW $\sigma 1$ trend determined by these authors possibly accounts for the NNW-SSE dextral faults and the NNE-SSW to NE-SW oriented thrusts on each side of the Cap Blanc Fault (Fig. 4.3B, C). Since these small thrusts are restricted to the sides of the fault and range from a N-S to NE-SW oriented striated fiber trend, it is interpreted that paleostress orientation has gradually rotated clockwise during a continuous tectonic event, which is not unlike the conclusions drawn by Faure *et al.* (1996a).

The third post-Acadian $\sigma 1$ trend determined by Faure *et al.* (1996a), which is WNW-ESE, is not well represented in the Gaspé Peninsula, apart for one locality (76a) reported by these authors near the town of Chandler (Fig. 4.1). The small WSW-ENE oriented dextral fault planes that are reported at that locality could represent P structures of the Grand-Pabos - Raudin - Rivière Garin fault system.

It has been proposed that the Grand Pabos Fault cuts the Bonaventure Formation north of Chandler (Fig. 4.1) (Bourque and Lachambre, 1980; Brisebois *et al.*, 1992), but this interpretation comes from the fact that coarse facies of the Precambrian Maquereau Group was mistakenly mapped as the Bonaventure Formation. We have failed to find any evidence for a Carboniferous splay of the Grand-Pabos Fault in this area. However, the Raudin Fault (named Rivière-Garin Fault in its western extension), which parallels the Grand Pabos Fault to the south and which eventually merges with it (Fig. 4.1), clearly truncates the post-Acadian paleosurface with a roughly E-W strike (Jutras and Schroeder, 1999).

Further west, Bernard and St-Julien (1986) and Gosselin (1988) observe that the sinistral NE-SW striking Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system is deflected to the right and truncated by the E-W striking Grand-Pabos Fault. On account of this cross-cutting relationship with faults demonstrably affecting Carboniferous rocks, it is here proposed that the Grand-Pabos Fault, one of the main Acadian structures of southeastern Canada, and the associated Raudin and Rivière-Garin faults, have been reactivated as dextral strike-slips in post-Acadian time. This fault system goes from a nearly E-W orientation near Chandler to a NE-SW orientation west of the study area, and could possibly be related to the third post-Acadian $\sigma 1$ trend (WNW-ESE) determined by Faure *et al.* (1996), mainly within late Devonian plutons from other localities of southern Québec.

Correlation of post-Acadian deformation trends is limited by the weak stratigraphic control. The WSW-ENE oriented fold axis affecting the Late Devonian Miguasha Group (Brisebois *et al.*, 1992) correlate well with the first post-Acadian $\sigma 1$ trend (NNW-SSE) of Faure *et al.* (1996a), although these folds do not affect the overlying Bonaventure

Formation, while this unit is itself affected by faults pertaining to a NNW-SSE $\sigma1$ trend. Hence, the three post-Acadian main principal paleostress trends determined by Faure *et al.* (1996a) could represent more than one event each, while stress orientation may also rotate during one continuous event. Combined data from Faure *et al.* (1996a) and the present study are therefore not sufficient to allow a detailed reconstruction of the post-Acadian tectonic history in the Gaspé Peninsula.

The largest post-Acadian strike-slip displacement seems to have occurred on the Grande-Rivière Fault on account of the observed juxtaposition of the Cannes-de-Roches and Ristigouche subbasins (Fig. 4.15A, B). Malo and Béland (1989) measured a 22 km displacement along the Grande-Rivière Fault based on reliable pre-Carboniferous stratigraphic markers. From the present position of the Ristigouche and Cannes-de-Roches basins (Fig. 4.15C), with no source area separating them, a large portion of this total displacement must have occurred in post-Acadian times.

The extension of the Grande-Rivière Fault within the Gulf of St-Lawrence can be observed in the geophysical map of Durling and Marillier (1990), where it separates the structural blocks of Laurent and Bradelle (Fig. 4.16). Since the fault system cuts through kilometres-thick Carboniferous strata, this geophysical map itself clearly suggests that the Grande-Rivière Fault, previously attributed exclusively to Acadian deformation, is actually part of the main Carboniferous structures affecting the Maritimes Basin.

4.10 GENERAL DISCUSSION

Based on the current data, it must be emphasized that all the strictly brittle strike-slip structures that have been recognized in the Gaspé Peninsula, and that Malo and Kirkwood (1995) and Kirkwood *et al.* (1995) associate with the " Acadian Phase III ", are possibly post-Acadian, while only ductile-brittle deformation may pertain to the Acadian event. In support of this hypothesis, it is unlikely that strictly brittle faulting would have occurred along with ductile-brittle folding at the same depth, during the same deformation event. Post-orogenic uplift and erosion necessarily separate the ductile-brittle from the strictly brittle deformation events.

Contrary to conclusions drawn by Faure *et al.* (1996a), post-Acadian deformation in the Gaspé Peninsula is not limited to "minor mesoscopic structures (...) scarcely affecting older structures and the regional map pattern" (p. 1468, par. 1), as indicated by the large post-Acadian displacement observed on the Grande-Rivière Fault.

Post-Acadian fault activity in the Chaleur Bay region seems to have been influenced by a pre-existing fault system, which most likely formed during the Acadian Orogeny. Jutras *et al.* (1999, 2001) suggested that fault scarps developed on the Grande-Rivière and Grand-Pabos - Raudin - Rivière Garin fault systems, inherited from the Acadian orogeny, may have controlled regional Carboniferous sedimentation. Jutras *et al.* (1999) also suggested that the Cap-Blanc Fault was active during a tectonic event that followed sedimentation of the La

Coulée Formation and preceded sedimentation of the Bonaventure Formation, to account for the perpendicular tilt of La Coulée Formation beds, which are covered with a 20° unconformity by the Bonaventure Formation red beds.

During the post-sedimentary tectonic events described here, these syn- and post-Acadian inherited structures may have been partly responsible for the observed fault trace deviations. Folding of Carboniferous strata at the Lemieux Road outcrop (Fig. 4.5L and locality 1 on Fig. 4.3), thrusting at the Cannes-de-Roches Point (Figs. 4.3, 4.6), and the tight set of parallel faults (the Mont Sainte-Anne, Cap Blanc and Percé-Sud faults), which have accommodated part of the strain, are probably altogether the result of wrenching caused by fault bends in a transpressive tectonic regime.

The angular and coarse-grained Bonaventure Formation alluvial fan beds that are found in the Mont Blanc section (Fig. 4.4, column d) indicate that the source, and thus the northern fault that has controlled sedimentation in the Ristigouche Basin, was very close. However, the Bonaventure Formation beds at the northern end of Bonaventure Island (Fig. 4.3), which are at the same stratigraphic level, on the same structural block and at the same distance from the post-sedimentary fault, are less coarse, more rounded, better stratified and already correspond to a gravelly braidplain environment. This suggests that, in this area, the post-sedimentary Grande-Rivière Fault does not follow the trace of the fault from which sedimentation of the Bonaventure Formation originated, which would have an E-W strike according to the paleogeographic model proposed by Jutras *et al.* (2001) based on paleocurrent data and facies distribution (Fig. 4.15A). The long E-W section of the Grande-Rivière Fault, west of Coin-du-Banc (Fig. 4.3), may correspond to a section of the original northern fault boundary of the Ristigouche Basin, still according to the paleogeographic model proposed by Jutras *et al.* (2001).

In summary, several post-Acadian tectonic events are recorded in the Gaspé Peninsula, before, during and after Carboniferous sedimentation, and can be approximately or tentatively time constrained: folds affecting the Late Devonian Miguasha Group preceded Carboniferous sedimentation (Jutras and Prichonnet, submitted); normal or oblique fault activity controlled sedimentation of the Paspébiac Formation (Jutras and Prichonnet, submitted), while different normal or oblique faults controlled sedimentation of the subsequent La Coulée Formation (Jutras *et al.,* 1999); tectonic uplift and normal or oblique fault activity preceded sedimentation of the Bonaventure and Pointe Sawyer formations (Jutras *et al.,* 1999), which were themselves controlled by two subsequent normal or oblique faulting episodes (Jutras *et al.,* 2001); the whole regional Carboniferous succession, including the distally derived sands of the Chemin-des-Pêcheurs Formation, was later affected by large NW-SE to E-W dextral shear in the eastern Gaspé Peninsula (this study), which is postulated to be coeval with large SW-NE oriented sinistral shear in the western sector and with the first post-Acadian $\sigma 1$ trend (NNW-SSE) of Faure *et al.* (1996a). If the latter correlations are correct, the two subsequent post-Acadian $\sigma 1$ trends (NNE-SSW and WNW-ESE) determined by Faure *et al.* (1996a), which were recorded within the

Bonaventure Formation and to which larger fault movements were tentatively correlated in the present study, are also younger than the Chemin-des-Pêcheurs Formation (Namurian).

Post-Acadian tectonic history in the Gaspé Peninsula is therefore very complex, although never orogenic in nature. It is postulated that these deformation events are all associated with late Appalachian phases (Hercynian-Alleghanian), which ended in Permian time, although compressive features are also registered within Cretaceous rocks of southern Québec, with a NE-SW $\sigma 1$ trend (Saull and Williams, 1974; Gélard *et al.*, 1992; Faure *et al.*, 1996b).

Since the main NW-SE to E-W dextral strike-slip faults affect rocks that are as young as Namurian, they are possibly related to the deformation event that has taken place in Westphalian B time, prior to deposition of the Pictou Group, and which corresponds to the most important Alleghanian phase to have affected the Maritimes (Piqué, 1981; Ruitenberg and McCutcheon, 1982; Plint and Van de Poll, 1983; Yeo and Gillis, 1984; Nance, 1987; Nance and Waner, 1986; Gibling *et al.*, 1987; Yeo and Ruixiang, 1987; Ryan *et al.*, 1988; Thomas and Schenk, 1988; Reed *et al.*, 1993). The Carboniferous succession of the northern Chaleur Bay area (the Paspébiac, La Coulée, Bonaventure, Pointe Sawyer and Chemin-des-Pêcheurs formations) is roughly time-equivalent to the Lower Megasequence (Horton to Mabou groups) of the Sydney Basin, which is separated from Westphalian C to Permian strata by a 22 m.y. hiatus (Gibling *et al.*, 1987). On the south shore of Chaleur Bay, the Bathurst Formation, a red clastic unit possibly equivalent to the

Bonaventure Formation (C. St-Peter, pers. comm., 2000), is unconformably overlain by the Westphalian to Stephanian Clifton Formation (Alcock, 1935; Ball *et al.*, 1981; Legun and Rust, 1982), which has been correlated to the Pictou Group and is time-equivalent to the Upper Megasequence of the Sydney Basin.

If some subbasins of the Maritimes were uplifted and partly eroded during the Westphalian B event, others, like the Cumberland Basin (Reed *et al.*, 1993) and the Stellarton Gap (Yeo and Ruixiang, 1987), were receiving their sediments, while being simultaneously deformed. Sedimentation in the Cumberland Basin was thickest in synclinal structures contemporaneous with the Westphalian B deformation (Reed *et al.*, 1993). Transpressive deformation is also reported for the end of the Namurian (Piqué, 1981; Waldron *et al.*, 1989; Pe-Piper *et al.*, 1991; St.-Peters, 1993), separating the Mabou and Cumberland groups, but is less widespread.

Although pre-Westphalian C deformation cannot be ruled out, the extension of the Grande-Rivière Fault in the Gulf of St. Lawrence (Fig. 4.16) cuts through strata of the Pictou Group (post-Westphalian B) according to offshore mapping by Sanford and Grant (1990). Post-Acadian activity of this fault has therefore possibly extended into late Pennsylvanian or early Permian time, which would correlate it with the recently documented Donkin Episode (Pascucci *et al.*, 2000; Gibling *et al.*, in press). It is also to be noted that the Grande-Rivière Fault ranges among the main faults affecting the Maritimes Basin and that some of these faults are thought to have remained intermittently active until Triassic time (Donohoe et Wallace, 1988; St. Peter, 1993; Withjack *et al.*, 1995).

Upper Paleozoic deformation in southeastern Canada is mainly concentrated in the area of the Minas Geofracture (Cobequid-Chedabucto Fault), which separates New Brunswick and northern Nova Scotia (Avalon Composite Terrane) from southern Nova Scotia (Meguma Terrane). To explain the formation of the Maritimes Basin, some authors favor the hypothesis of an aborted rift related to post-orogenic extension (Belt, 1968; Ruitenberg *et al.*, 1973; Ruitenberg and McCutcheon , 1982; Howie and Barss, 1975; Poole, 1976; Fyffe and Barr, 1986; McCutcheon and Robinson, 1987; Durling and Marillier, 1993), while others favor the hypothesis that the crustal extension may have been associated with the transcurrent shearing occurring in the area of the Minas Geofracture (Ramsbottom, 1973; Arthaud and Matté, 1977; McMaster *et al.*, 1980; Fralick and Schenck, 1981; Bradley, 1982; Keppie, 1982; Gibling *et al.*, 1987; Ryan *et al.*, 1988; Pe-Piper *et al.*, 1989; Rust *et al.*, 1989; Reed *et al.*, 1993; Murphy *et al.*, 1995).

The latter interpretation fits better with the general Appalachian setting in upper Paleozoic time, since Late Devonian extension affecting the Maritimes, leading to the emplacement of numerous granitic plutons and to the onset of graben-bound Horton Group sedimentation, is coeval with orogenic uplift in New-England, source area of the uppermost Devonian Catskill clastic wedge (Rust *et al.*, 1989; Condie and Sloan, 1998). Rust *et al.* (1989) observed a gradual source area displacement within the Lower to Middle Devonian clastic wedge of eastern Gaspé, and proposed a model to correlate this succession with the Late Devonian Catskill clastic wedge within one continuous wrench tectonic event.

While terrane accretion occurred throughout the lower Paleozoic on the eastern margin of Laurentia (Keppie, 1985), it is not clear when the last accretions occurred, which would be those of Avalonia and Meguma. It was recently proposed that Avalonia and Meguma would have separated from Gondwana as one terrane in the Early Ordovician, to eventually collide with Laurentia in Late Ordovician to Early Silurian time (Keppie and Krogh, 2000). Following this scenario, the Late Silurian to Middle Devonian Acadian orogeny would be related to the closing of the ocean that still separated Laurentia from Baltica and Gondwana after the accretion of the proposed Avalonia-Meguma composite terrane. This hypothetic ocean is increasingly referred to as the Rheic Ocean, while the term Iapetus may be restrained to the oceanic basin that closed with the accretion of Avalonia to Laurentia (C. Van Stall, pers. comm. 1999; J. Waldron, pers. comm. 2001).

The use of the term Rheic for this post-Avalonian-accretion ocean is problematic because it has been used in the past to define an ocean separating Gondwana from Baltica (Rodgers, 1988). In our view, the accretion of a terrane is insufficient to justify the use of a new name for the remaining oceanic basin. Hence, the term Rheic is used here *sensu* Rodgers (1988), as well as the terms Iapetus and Theic, which are used by the same author to define the oceans separating Laurentia from, respectively, Baltica and Gondwana.

According to some paleomagnetic studies, final closure of Iapetus only occurred in Middle to Late Devonian time (Kent and Opdyke, 1985; Briden *et al.*, 1988; Kent and Keppie, 1988; McKerrow, 1988), with the apogee of Acadian deformation. According to Rodgers (1988), Rheic is also closed at that time, although the suture may be incomplete.

Although Iapetus and Rheic closed prior to the end of the Devonian, an oceanic basin (Theic or Phoibic, depending on the author) remained between Gondwana and southeastern North America during Mississippian time. Gondwana would have then rotated with respect to the assembled Euramerican landmass (Laurussia), causing dextral shear from central Europe to northeastern North America (Kent and Keppie, 1988), while the West African craton was still converging with southern North America (Lefort and van der Voo, 1981; Sacks and Secor, 1990; Piqué and Skehan, 1992) (Fig. 4.17A). This culminated with the Alleghanian Orogeny (Pennsylvanian to early Permian), which came from the final closure of Theic (Arthaud and Matté, 1977; Piqué, 1981; Lefort and Van der Voo, 1981; Russell and Smythe, 1983; Haszeldine, 1984; Kent and Opdyke, 1985; Lefort *et al.*, 1988; Kent and Keppie, 1988; Rodgers, 1988; Sacks and Secor, 1990; Piqué and Skehan, 1992) (4.17B).

Within this general context, the triple-junction zone between Laurentia, Baltica and Gondwana may have acted as a pivot during Late Devonian and Mississippian times, while Theic was still in the process of closing, to the south, causing extension and graben-bound sedimentation in the area of the Maritimes Basin, to the north (Fig. 4.17A). It may have also caused extension at the level of the Rheian suture, leading to the formation of the Hercynian Sea.

When the West African craton and southeastern North America started colliding, in Pennsylvanian time, the peripheral Maritimes Basin mainly experienced transpressive accommodation (Fig. 4.17B), concentrated along major faults, while being simultaneously buried by sediments coming from the Alleghanian Orogen, which was being constructed to the south (Thomas and Schenk, 1988; Gibling *et al.,* 1992). The Rheian suture may have also been reactivated at that time with the closing of the Hercynian Sea and the formation of the Hercynian Chain (Condie and Sloan, 1998).

In summary, while the Minas Geofracture may have been active as a strike-slip throughout the Carboniferous, the Maritimes Basin as a whole may have evolved from a transtensional to a transpressive tectonic regime at approximately the Mississippian-Pennsylvanian boundary to accommodate plate readjustments between the components of an incompletely assembled Pangea.

The upper Paleozoic geology of the Gaspé Peninsula supports this regionally observed transition from mainly extensional or transtensional tectonism during Late Devonian and Mississippian times, leading to successive sedimentary basins, to mainly transpressive tectonics and general subsidence during Pennsylvanian and early Permian times, leading to their subsequent deformation and burial. According to Lefort and Van der

Voo (1981), the combination of sinistral SW-NE faults and dextral E-W faults, which is reported in the present study, is the general pattern within upper Paleozoic structures of the Appalachian-Variscan Belt.

Conjunction of the three post-sedimentary fault strike orientations identified in this study would tend to form prismatic fault traps, which is an important element to consider in future evaluation of the petroleum potential in Chaleur Bay. According to extrapolations from Ryan and Zentilli (1993), the whole area should have been covered by Pennsylvanian to Permian strata (the Upper Megasequence of Gibling *et al.*, 1987) prior to the 1 to 4 km removal of upper Paleozoic rocks from the Maritimes Basin by erosion. Spore alteration within the Pointe Sawyer Formation, in both the Cannes-de-Roches and Ristigouche subbasins, suggests burial conditions that were within the 'oil window' (Jutras *et al.*, 2001). The brittle cataclastic deformations reported in the present study are compatible with these shallow burial conditions.

4.1 CONCLUSION

Several sinistral NE-SW strike-slip fault movements are recorded in the Carboniferous strata between the towns of Carleton and Port-Daniel in the southwestern Gaspé Peninsula. Another set of possibly coeval strike-slip faults, with a dextral trend, strikes NW-SE to E-W in the eastern Gaspé Peninsula and has been involved in the juxtaposition of the Cannes-de-

Roches and Ristigouche basins. This dextral fault system is truncated in many places by NNW-SSE striking dextral faults.

Namurian is the lower age limit of these three post-sedimentary fault sets, which evolved under a transpressive regime. Although the flat-lying Carboniferous succession does not provide precise stratigraphic markers, significant lateral displacement on the Grande-Rivière Fault is necessary to justify the present absence of a source rock area between the juxtaposed strata of the Cannes-de-Roches and Ristigouche basins in the Percé area. Significant lateral displacement along the Petit-Montréal – Mont-Saint-Joseph – Grande-Cascapédia fault system is also necessary for the formation of the large cataclastic drag fold affecting rocks of the Bonaventure Formation in the Carleton area.

This is the first time that post-Acadian deformation involving significant lateral displacement is demonstrated in the Gaspé Peninsula. From this, age determination should be reconsidered for the strictly brittle strike-slips of the Peninsula, which are possibly all post-Acadian and related to phases of the Alleghanian deformation in Permo-Carboniferous times.

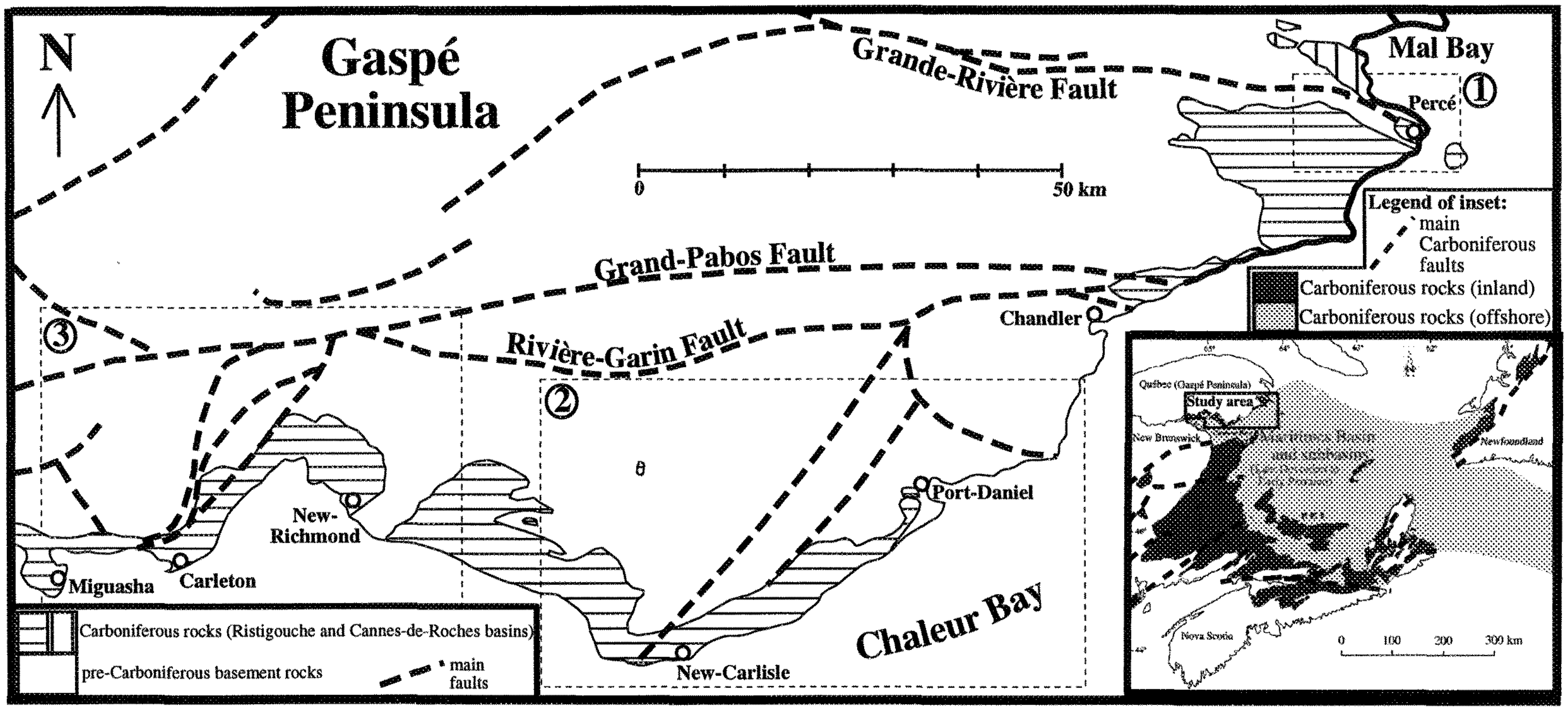


Fig. 4.1. Study area (modified from Brisebois *et al.* 1992) with (1) map area of Fig. 4.3, (2) map area of Fig. 4.10, and (3) map area of Fig. 4.11. Inset is modified from Gibling *et al.* (1992).

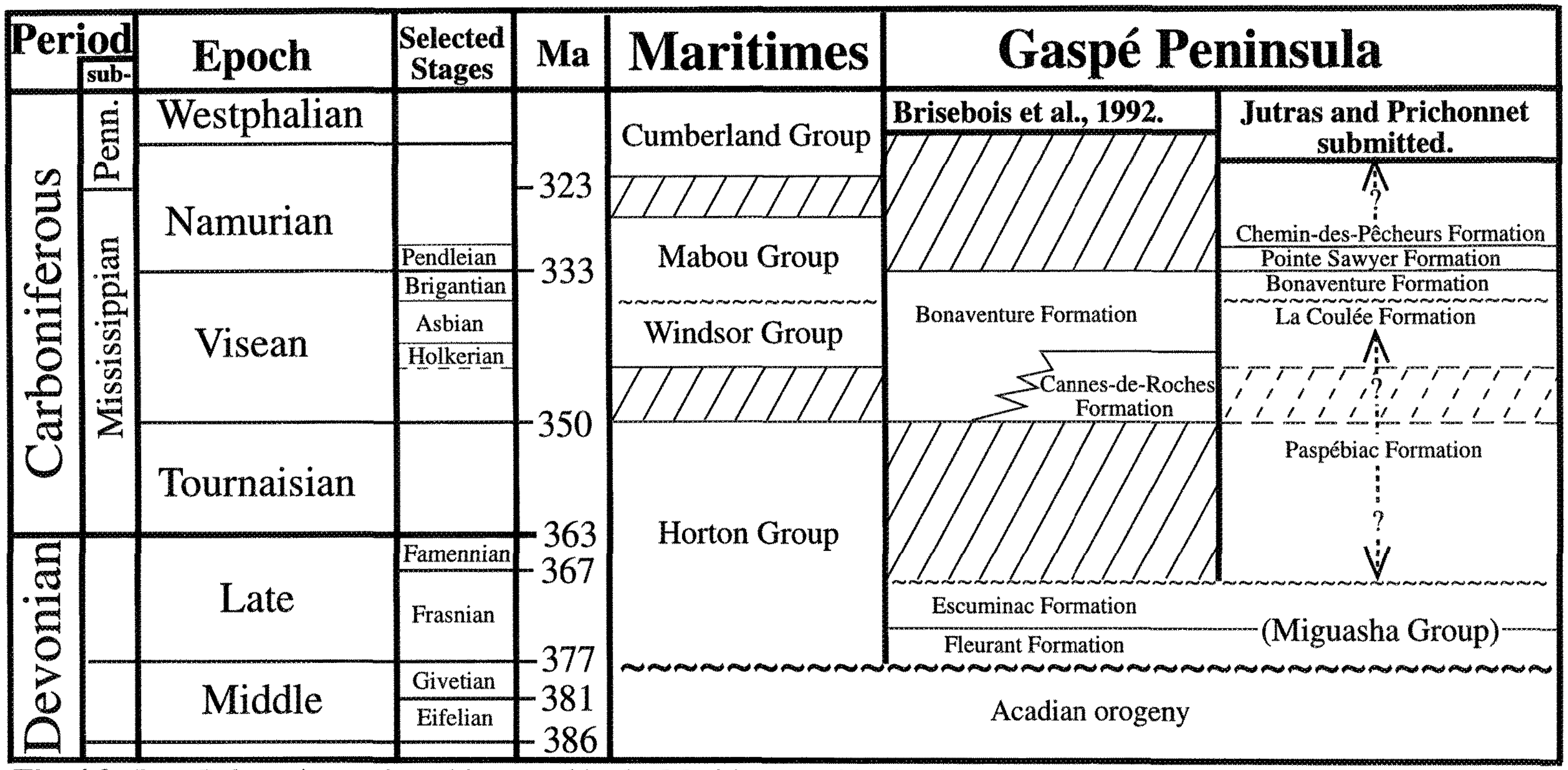


Fig. 4.2. Late Paleozoic stratigraphic record in the Maritimes and in the Gaspé Peninsula. Time-scale after Harland *et al.* (1990). Wavy lines represent unconformities with no major hiatus and dashed areas represent unconformities with a major hiatus. Stratigraphy of the Maritimes is modified from Bell (1944), Howie and Barss (1975), Utting (1987), Utting *et al.* (1989b), and Ryan *et al.* (1991).

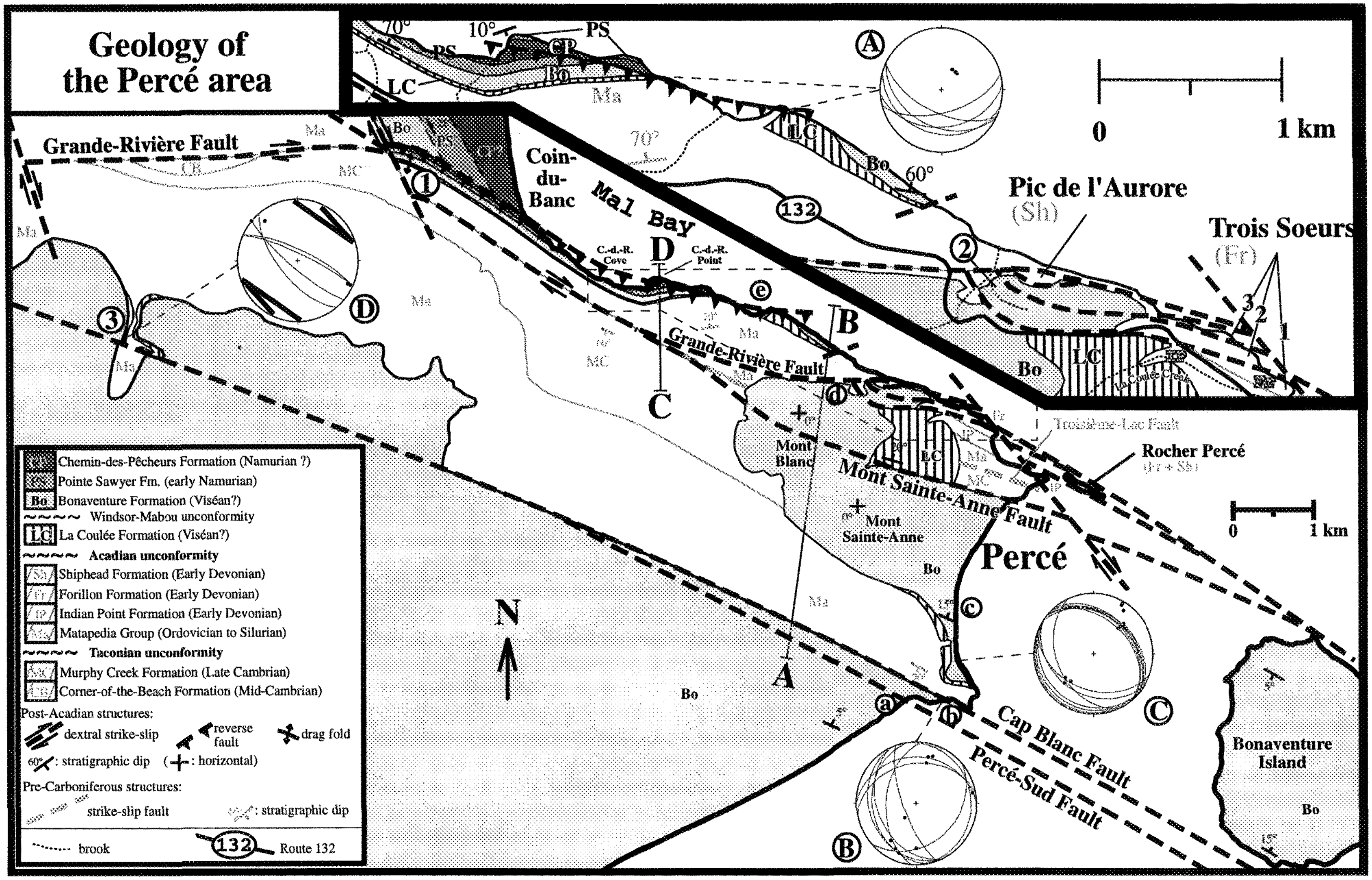


Fig. 4.3. Geology of the Percé area, with fault planes (great circles) and striae (dots) orientation in (A) the strike-slip duplex of the Grande-Rivière Fault in the Cannes-de-Roches Cove, (B) the deformation corridor at Cap Blanc, (C) the La Coulée Formation calcrete at Percé-Beach and (D) the La Coulée Formation calcrete on the side of Murphy Creek. Mapping of pre-Carboniferous units is from Kirkwood (1989). Localities: (1) Lemieux Road outcrop; (2) west-side brook of Pic de l'Aurore; (3) Murphy Creek outcrop. Composite columns of localities a-e and cross-section of Transect A-B are shown on Figure 4.4. Cross-section of Transect C-D is shown on Figure 4.6.

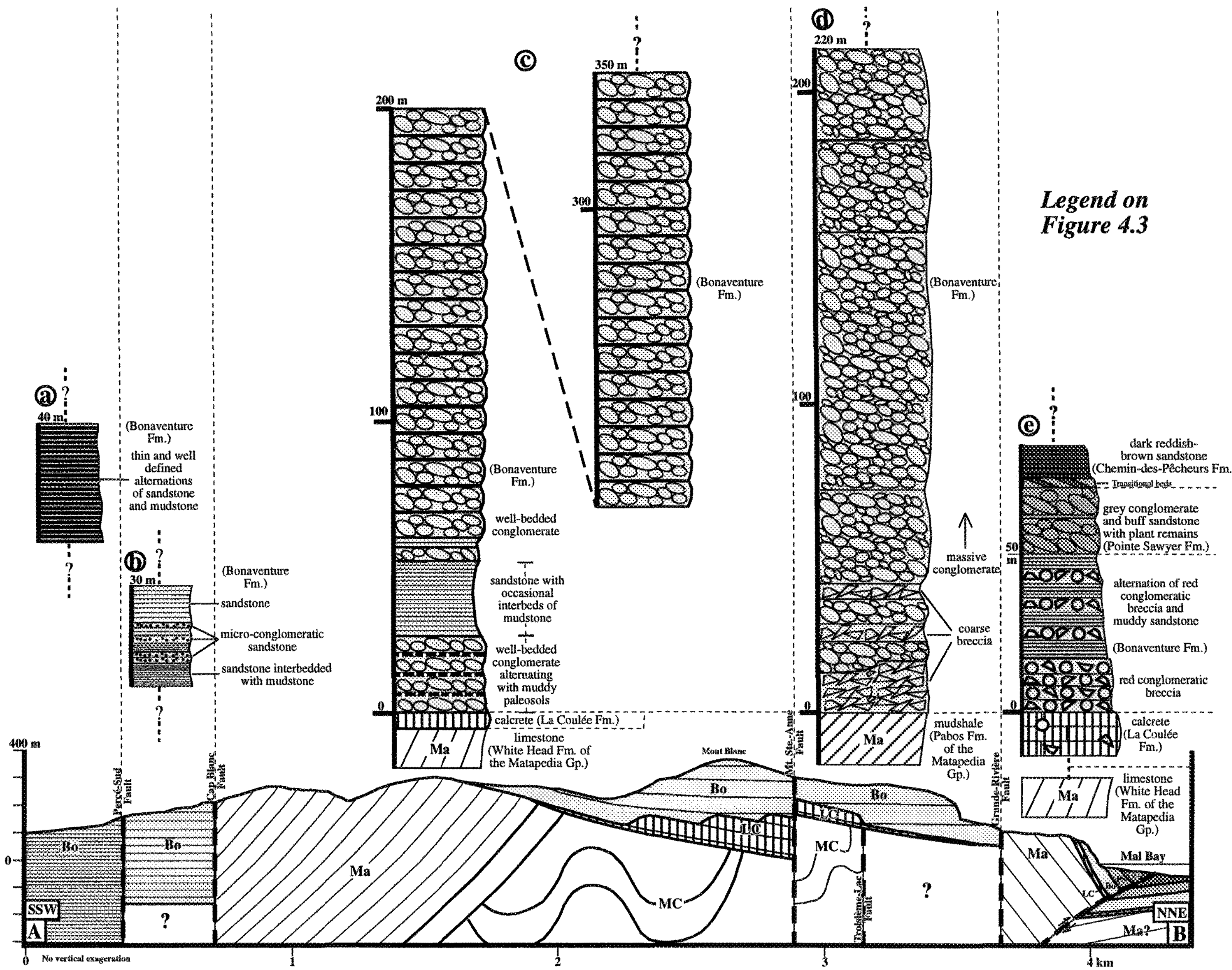


Fig. 4.4. Stratigraphic columns a to e and cross-section A-B (legend, localities and transect are shown on Figure 4.3).

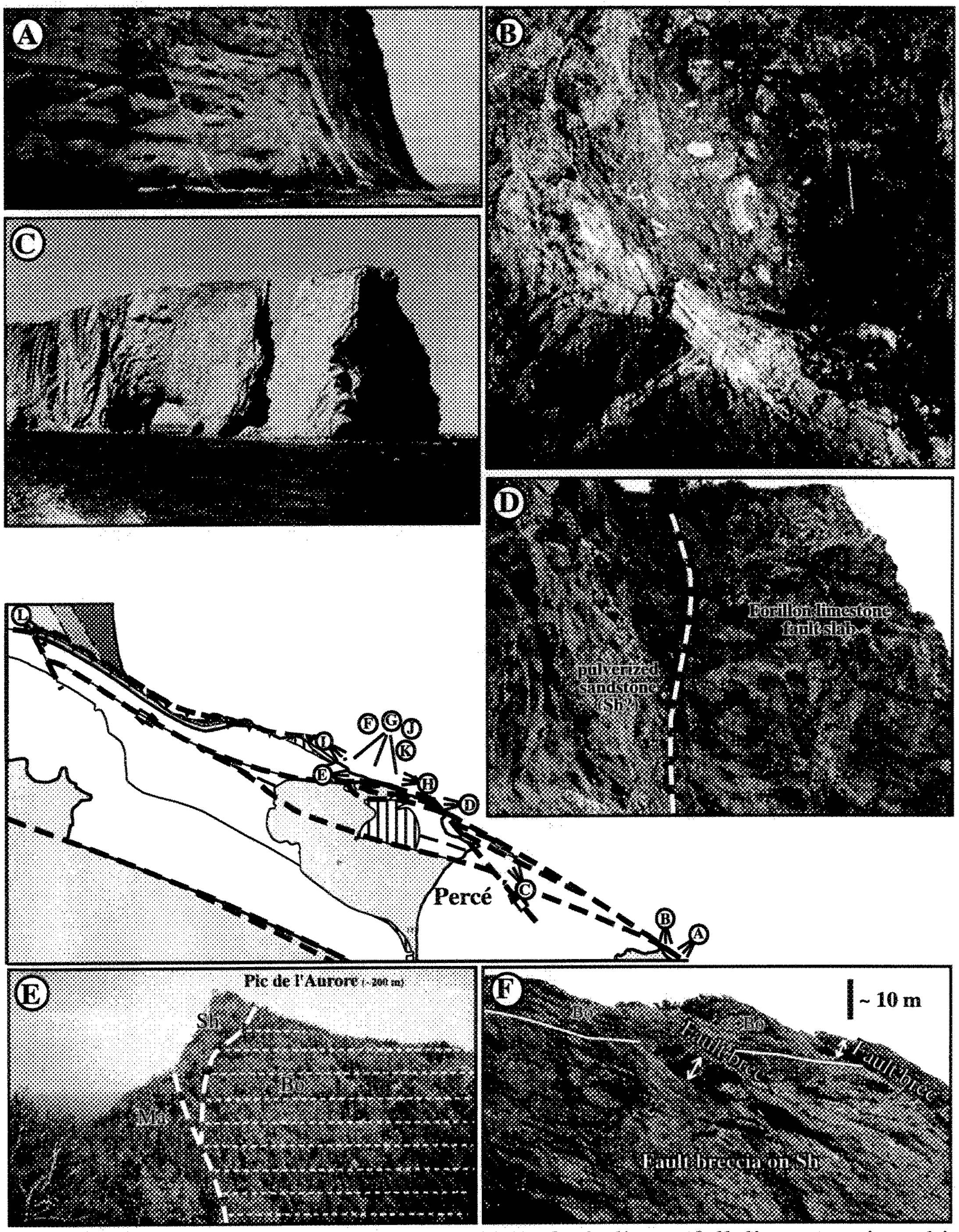
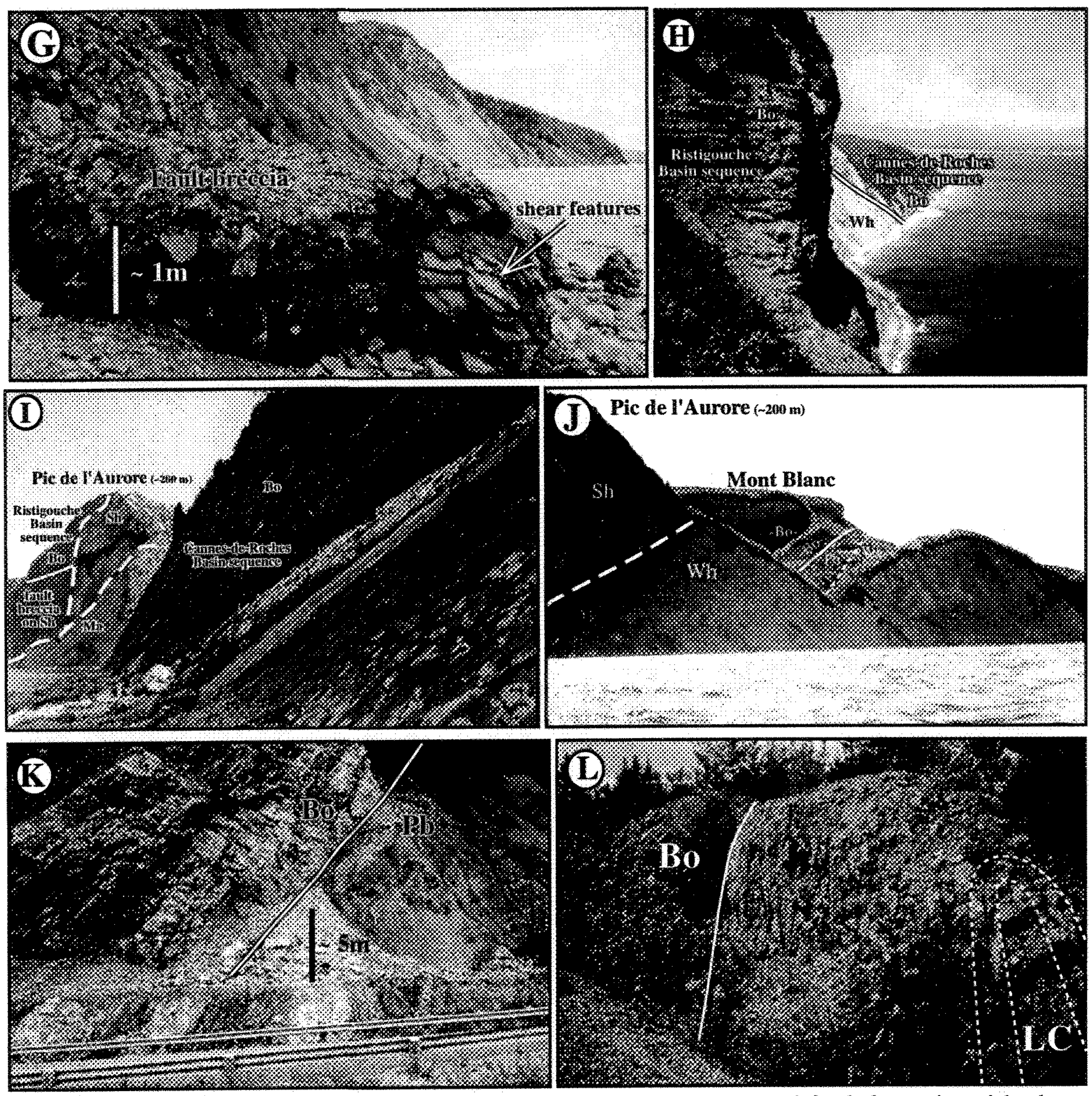


Fig. 4.5. The Grande-Rivière Fault. Dashes= fault line; full lines=stratigraphic contact; dots=bedding. (A) Laminated calcite veins affecting the northern end of Bonaventure Island. (B) Large blocks of limestone and fault breccia in multi-episodic travertine veins. (C) The Rocher Percé, interpreted as a fault slab of Forillon limestone. (D) The second "Sister", a fault slab of Forillon limestone. (E) View of Pic de l'Aurore from the west. A large fault slab of the Shiphead Formation (Sh) is caught between rocks of the Matapedia Group (Ma) and horizontal beds of the Bonaventure Formation (Bo). (F) View of a coastline section called "La Muraille", between Pic de l'Aurore and the "Trois Soeurs", where red fault breccia, up to 3 m-thick, is truncating the Shiphead Formation (Sh) and the overlying red sedimentary breccia of the Bonaventure Formation (Bo).



(...Fig. 4.5...) (G) Collapsed section of massive and compact red fault breccia with shear structures, very angular clasts and no sedimentary structures. (H) View from the east side of Pic de l'Aurore. The thick sequence of the Bonaventure Formation, within its former limits, is overlooking its thin equivalent within the Cannes-de-Roches Cove sequence. (I) Opposite view of Figure 4.5H. A major post-Acadian strike-slip fault is separating the Cannes-de-Roches Cove sequence from the Bonaventure Formation within its former limits. (J) View from the north of Pic de l'Aurore, which is cut by the Grande-Rivière Fault. Further west, the latter is siding the northern flank of Mont Blanc. (K) Detail of the background view shown on Figure 4.5J, where red sedimentary breccia beds of the Bonaventure Formation (Bo), resting unconformably on Ordovician shales of the Pabos Formation (Pa), were uplifted in response to movement of the nearby Grande-Rivière Fault. (L) Drag fold in calcretized La Coulée conglomerates (LC) at the Lemieux Road outcrop. The fold has a 60° plunge toward the ESE (110°).

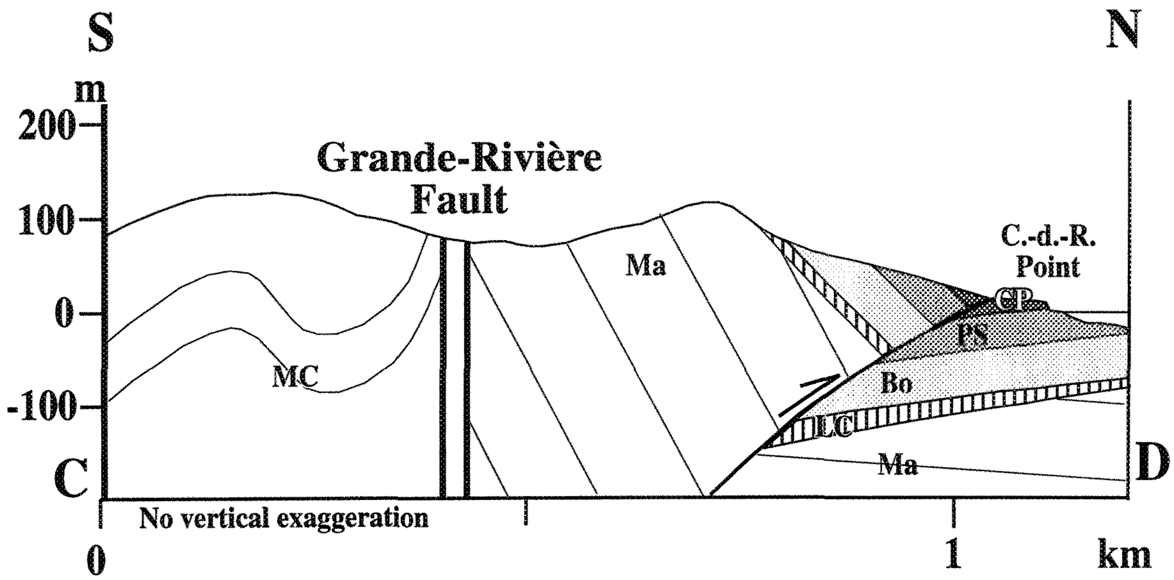


Fig. 4.6. Reverse fault affecting the Cannes-de-Roches Cove sequence (from transect C-D of Figure 4.3; the legend is also on Figure 4.3).

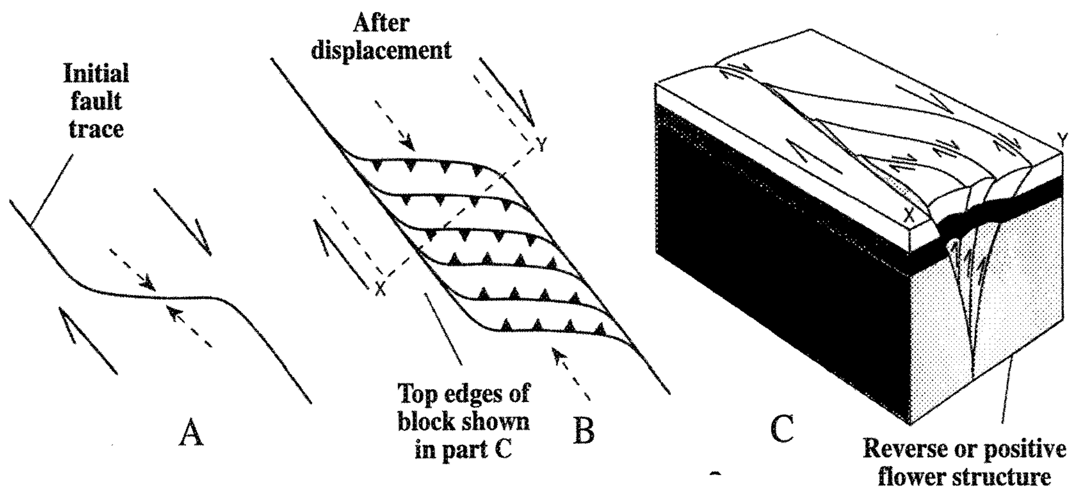


Fig. 4.7. Strike-slip duplexes associated with dextral movement in an S-shaped fault deviation. Modified from Woodcock and Fischer (1986) by Twiss and Moores (1992).

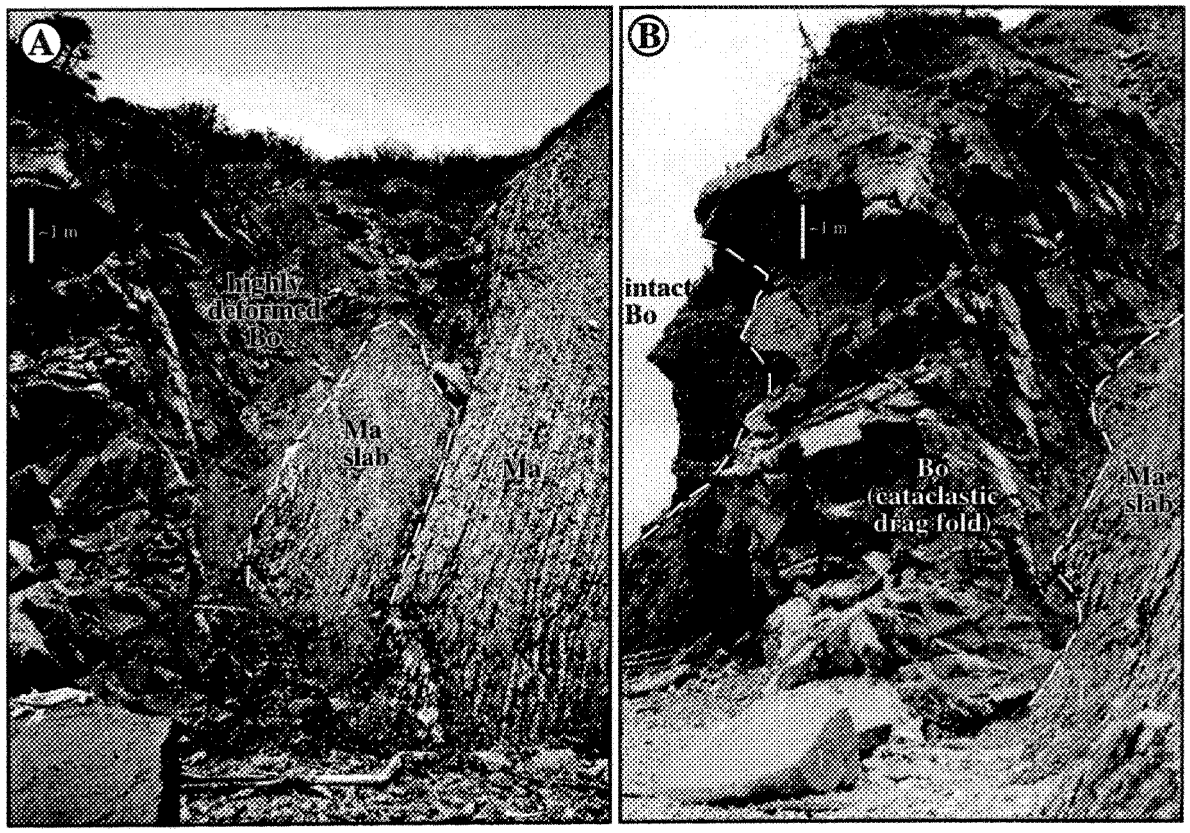


Fig. 4.8. The Cap-Blanc Fault. (A) Coastal outcrop of the fault zone, with a decametric fault slab of Matapedia limestone (Ma) and highly deformed Bonaventure Formation sandstone (Bo) within a cataclastic drag fold. (B) Contrast between the 20-25 m wide fault zone and the undeformed Bonaventure Formation beds that extend further away from the fault.

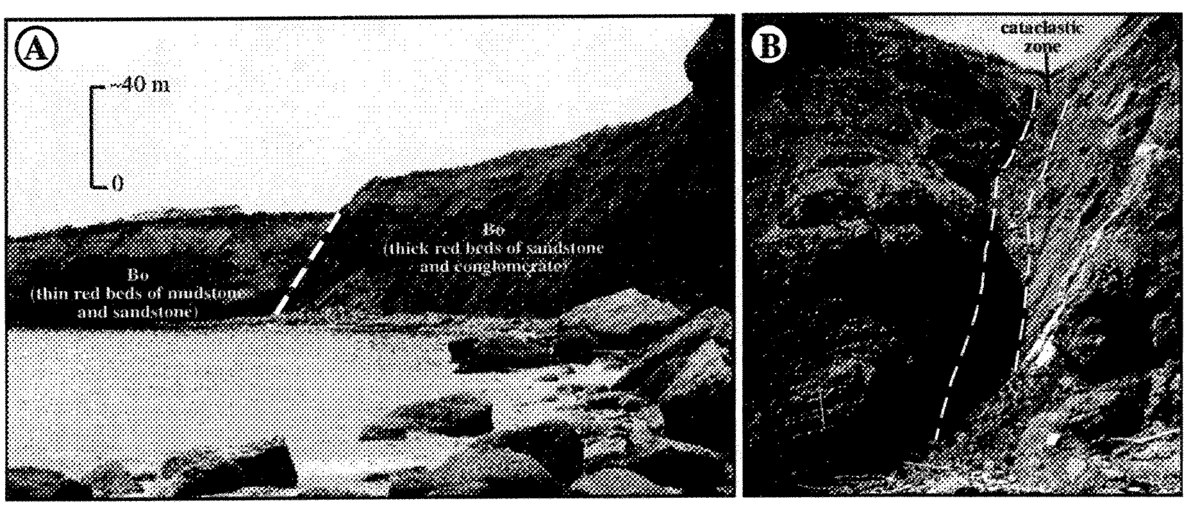


Fig. 4.9. General view (A) and detail (B) of the Percé-Sud Fault.

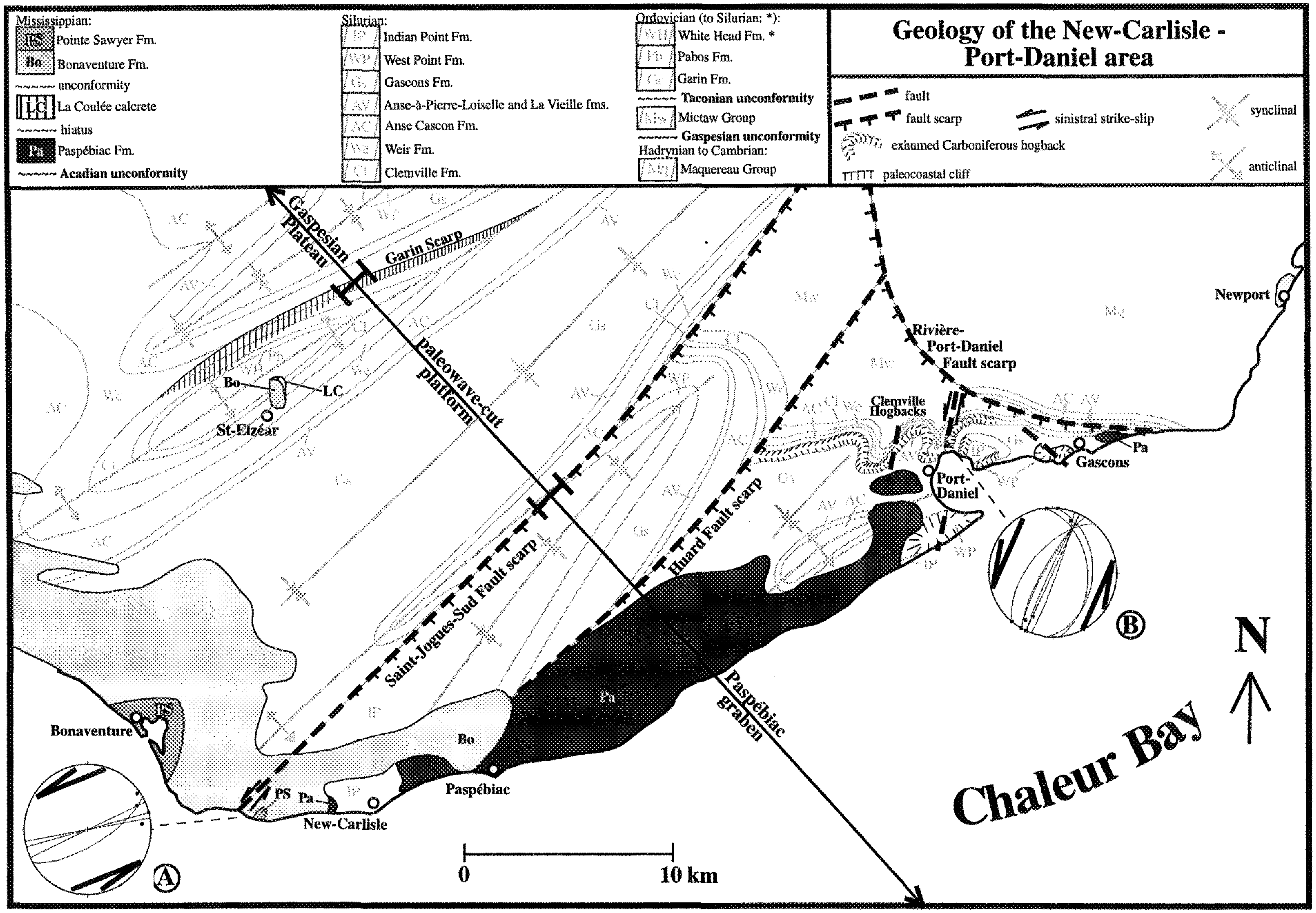


Fig. 4.10. Carboniferous geology of the New-Carlisle - Port-Daniel area, with fault planes (great circles) and slickensides (dots) orientation in (A) the Saint-Jogues-Sud Fault system and (B) the Port-Daniel Fault system. Mapping of pre-Carboniferous units is by Bourque and Lachambre (1980).

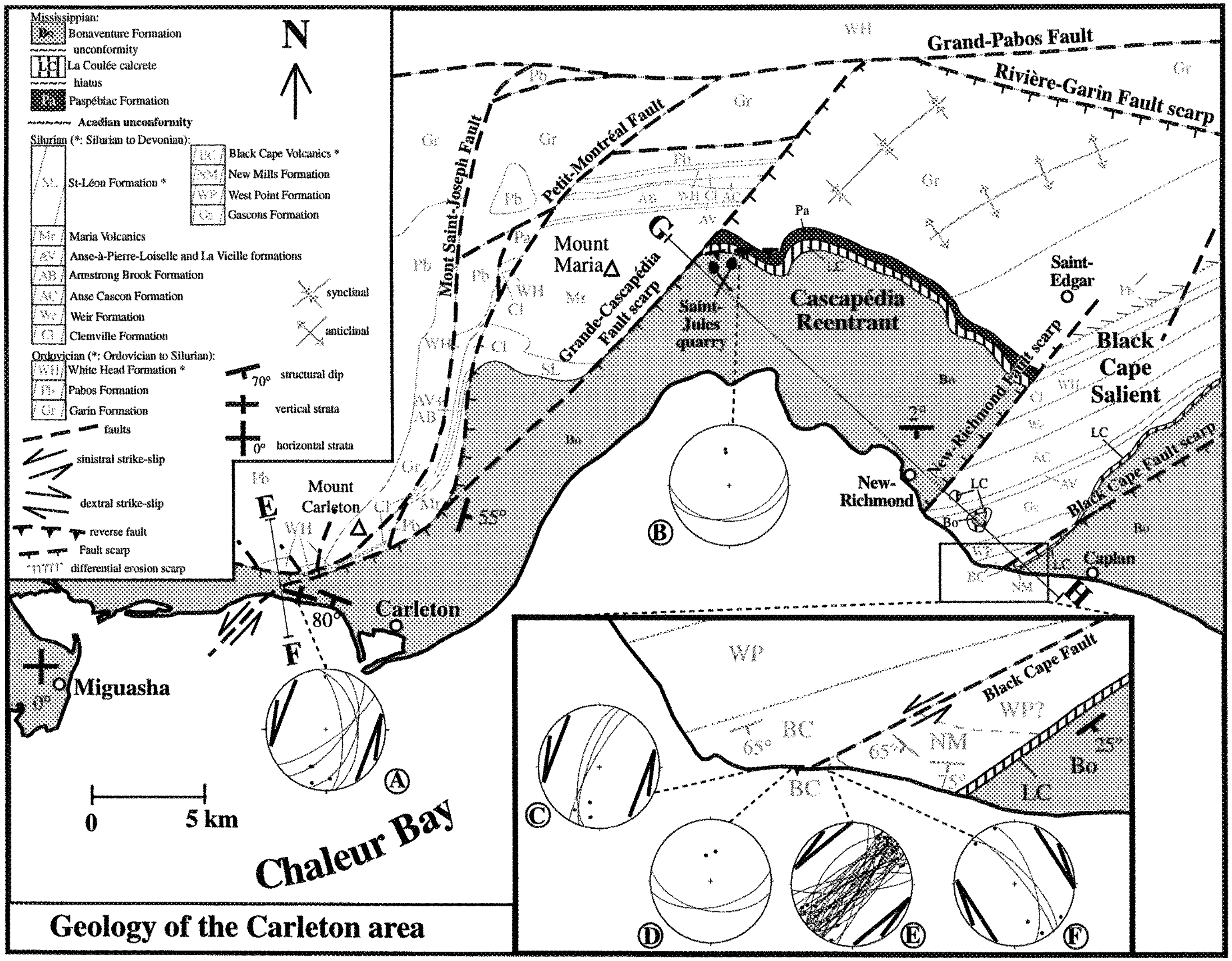


Fig. 4.11. Carboniferous geology of the Carleton area, with fault planes (great circles) and slickensides (dots) orientation in (A) the vertically uplifted Carboniferous strata near the Petit-Montréal - Mont Saint-Joseph - Grande-Cascapédia Fault system, (B) the groundwater calcrete of the Saint-Jules quarry, and (C-F) in the vicinity of the Black Cape Fault. The cross-sections of transects E-F and G-H are shown on Figure 4.12. Mapping of pre-Carboniferous units is by Bourque and Lachambre (1980) and Gosselin (1988).

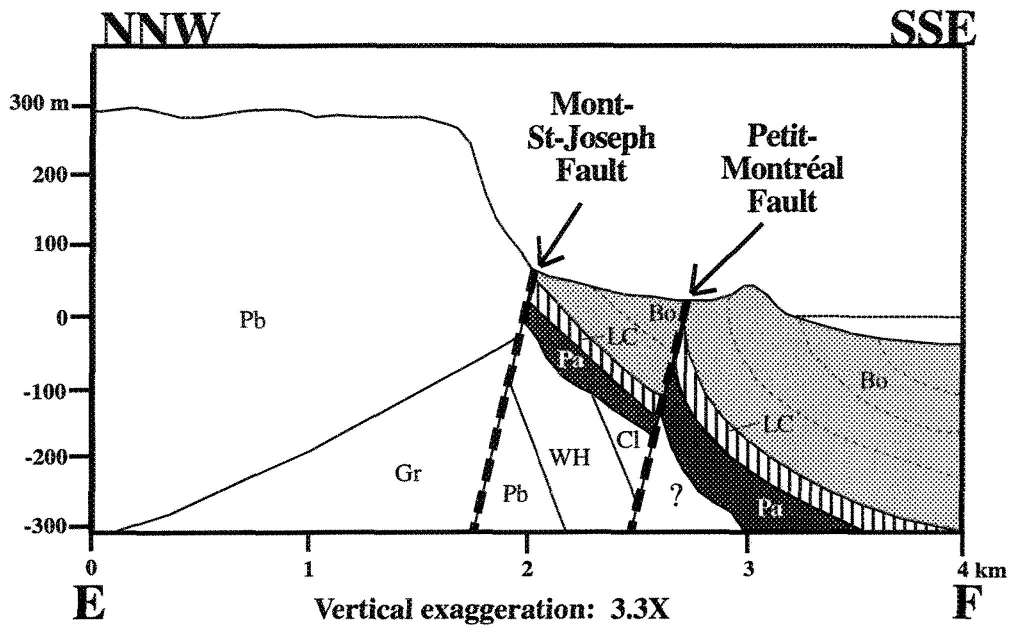


Fig. 4.12. Cross-section E-F. The transect is shown on Fig. 4.11.

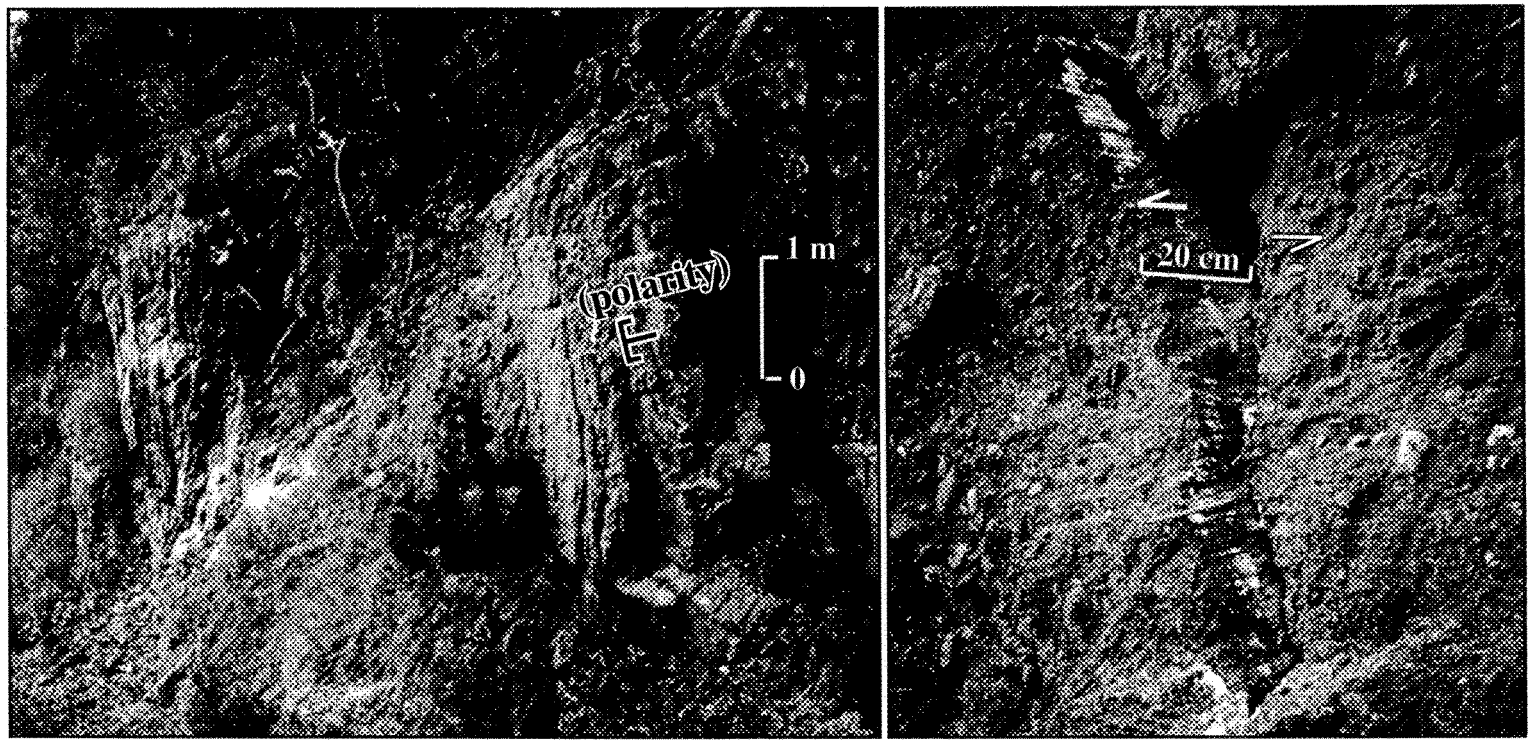


Fig. 4.13. (A) Vertical to slightly overturned strata of the Bonaventure Formation in the vicinity of the Petit-Montréal Fault. (B) Small sinistral fault affecting the tilted on edge strata.

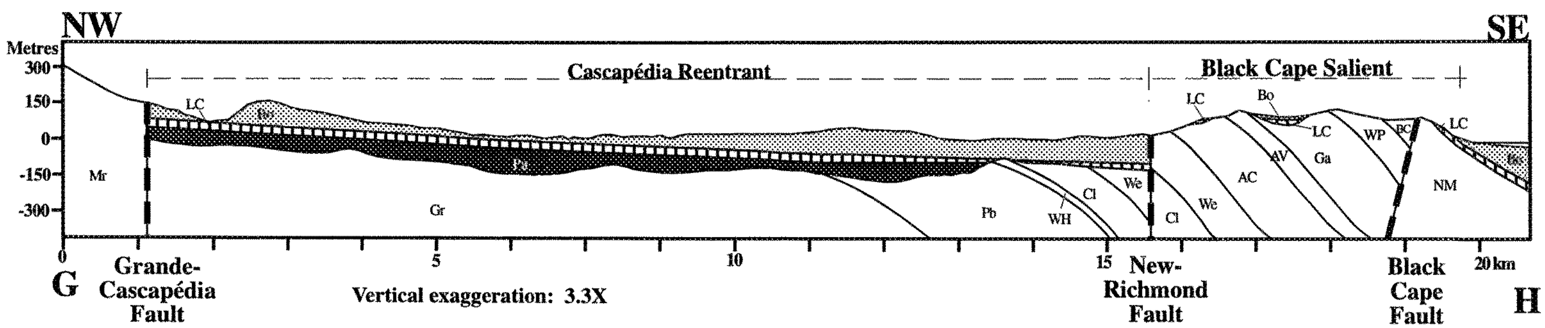


Fig. 4.14. Cross-section G-H. The transect is shown on Fig. 4.11.

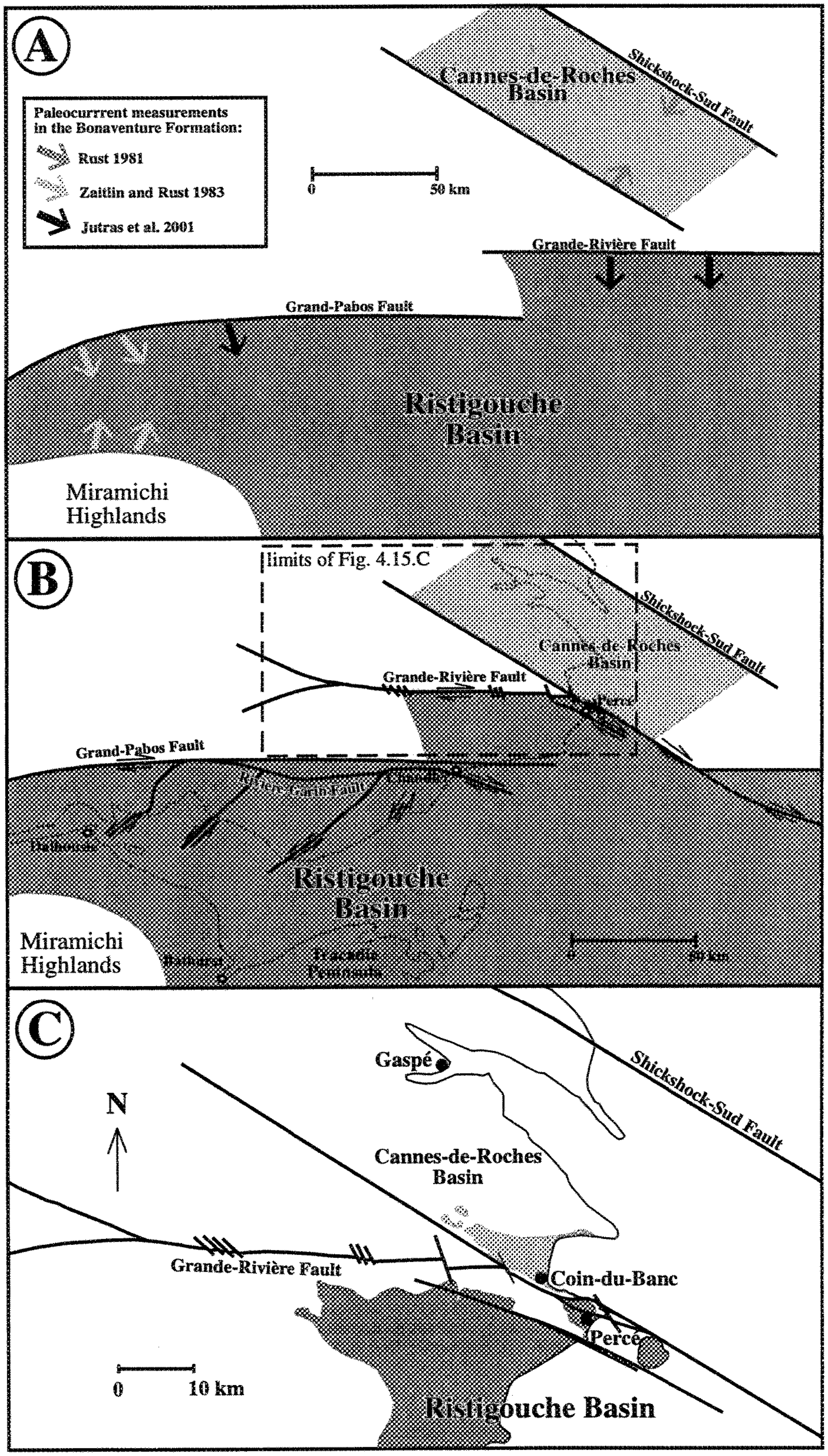


Fig. 4.15. Evolution of the Ristigouche and Cannes-de-Roches basins. (A) Proposed basin geometry during sedimentation of the Bonaventure Formation (modified from Jutras *et al.*, 2001). (B) Model for the juxtaposition of the two basins through strike-slip activity. (C) Present location of remnants of the two basins in the Percé area..

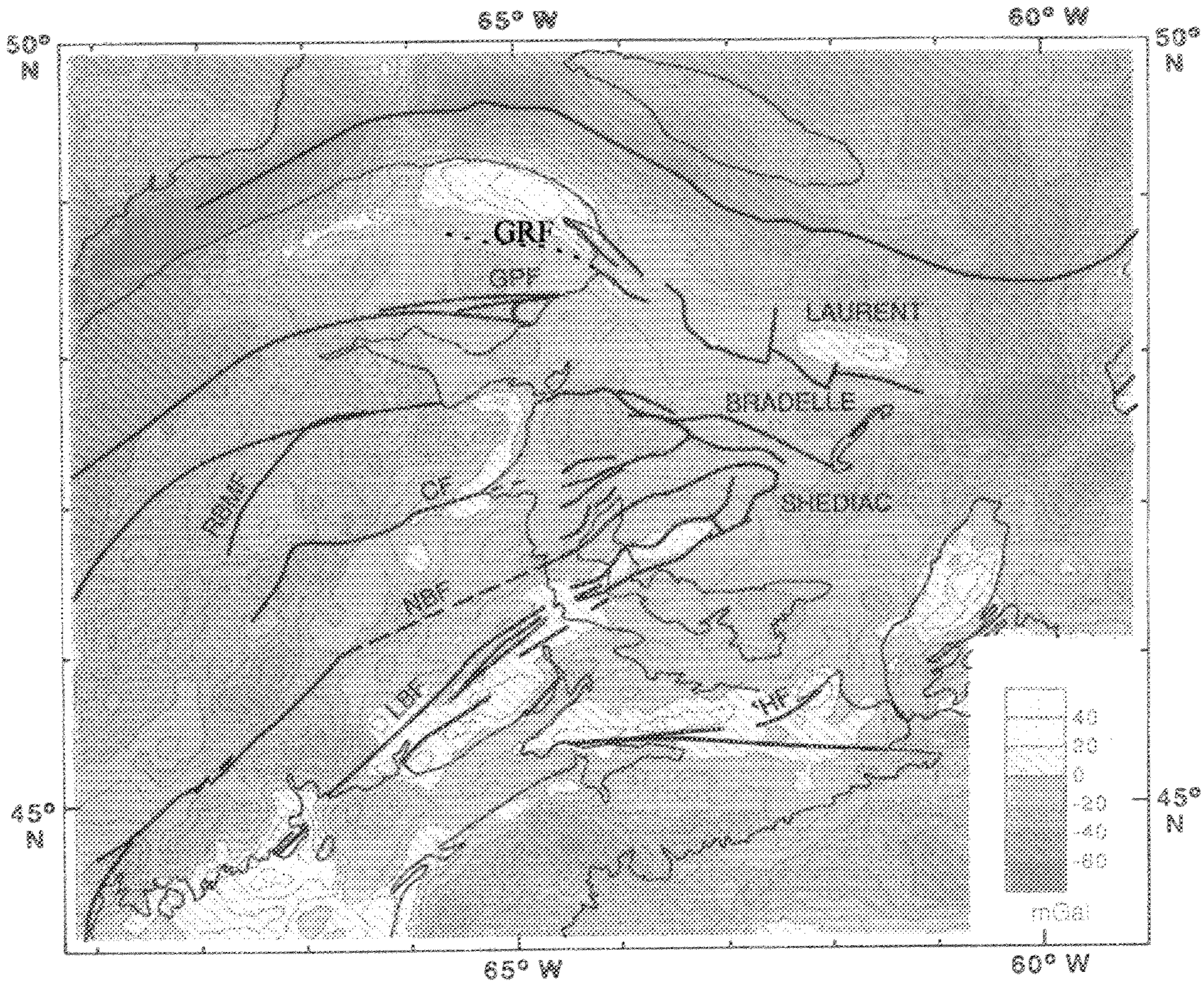


Fig. 3.16. Gravity data in the southwestern part of the Gulf of St.-Lawrence, with major structural features superimposed.: free-air anomaly offshore and Bouguer anomaly on land, with a 10 mGal contour interval. The dotted line inland corresponds to the Grande-Rivière Fault (GRF). Modified from Durling and Marillier (1990).

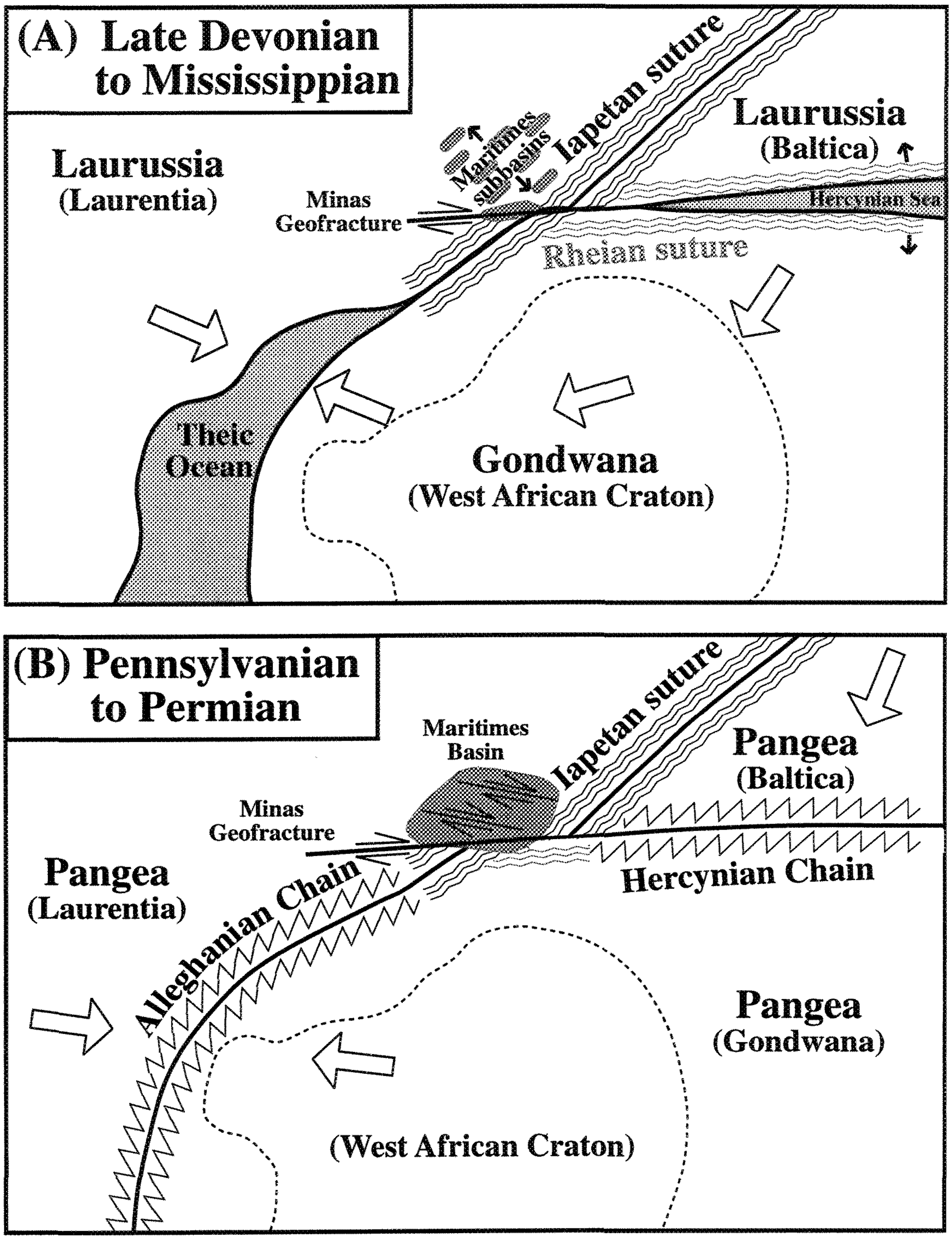


Fig. 4.17. Evolution of the Maritimes Basin in relation to the general Appalachian context. (A) Clockwise rotation of Gondwana with respect to Laurussia during gradual closing of Theic in Late Devonian to Mississippian time. The triple-junction of Laurentia, Baltica and Gondwana may have acted as a pivot for this rotation, causing extension in the areas of the Maritimes Basin and of the incomplete Rheian suture. (B) Construction of the Alleghanian Chain, resulting from final closure of Theic in Pennsylvanian to early Permian time, and construction of the Hercynian Chain in southern Europe from rejuvenated compression along the Rheian suture. The collision will change the tectonic style in the Maritimes, which is then mainly affected by transcurrent to transpressive deformation. Modified from Lefort and Van der Voo (1981), Kent and Keppie (1988), Rodgers (1988) and Condie and Sloan (1998).

CONCLUSION

L'étude des unités clastiques du Carbonifère de la Gaspésie a permis de redéfinir plusieurs aspects des contextes stratigraphique, paléoenvironnemental et tectonique de leur mise en place. L'étude des structures qui les affectent a également permis de mieux définir le contexte tectonique post-Mississippien de la Gaspésie.

NOUVEAU CADRE TECTONOSTRATIGRAPHIQUE DU CARBONIFÈRE DE LA GASPÉSIE

Les roches du Groupe de Miguasha, d'âge Frasnien (Fig. 4, dans l'Introduction), peuvent être considérées comme représentant les dernières molasses de la chaîne Acadienne en Gaspésie (Rust *et al.*, 1989). Les formations subséquentes appartiennent à un nouveau contexte tectonosédimentaire post-acadien que l'on peut dorénavant mieux rattacher au bassin des Maritimes.

La Formation de Paspébiac

La nouvelle Formation de Paspébiac, dont les roches étaient jusqu'à présent incluses dans la Formation de Bonaventure, se distingue de cette dernière par le caractère exclusivement local des clastes inclus dans sa fraction grossière et par l'aspect chaotique et mal trié de son matériel. On peut en déduire que la sédimentation s'est réalisée dans un contexte d'escarpements de failles qui devaient être très actives (Chapitre 3). Une oxydation très pénétrante, l'absence de traces de plantes et la présence de nombreuses calcrètes pédogéniques sont les témoins d'un climat tropical aride. Ce type de climat est également suggéré par la morphologie de la surface que cette formation a enfouie, laquelle est caractérisée par la présence de crêts de calcaire pur.

Les études de provenance pétrographique, de paléocourants et de distribution des faciès indiquent que des reliefs associés aux failles du Grand-Pabos, de Rivière-Port-Daniel, de Saint-Jogues-Sud et peut-être de Huard étaient la source probable des sédiments. Les roches de la Formation de Paspébiac sont confinées à l'intérieur de deux petits grabens ou demi-grabens formés par ces failles dans le sud et le sud-ouest de la Gaspésie.

Les roches de la Formation de Paspébiac n'étant pas plissées, elles seraient postérieures à la déformation compressive affectant le Groupe de Miguasha, laquelle est fort possiblement liée à un épisode tectonique du Dévonien supérieur terminal, qui, selon Howie et Barss (1975), aurait affecté la base du Groupe de Horton. Étant sous-jacentes à des formations dont la limite d'âge supérieure est le Viséen (les formations de La Coulée et de Bonaventure), ceci suggère un âge Tournaisien à Viséen pour la Formation de Paspébiac, bien que la possibilité d'un âge Dévonien supérieur ne puisse être écartée.

Les grabens ou demi-grabens du Paspébiac pourraient faire partie du Groupe de Horton (Dévonien supérieur à Tournaisien), qui forme la base du bassin des Maritimes et qui occupe de multiples petits sous-bassins d'extension limités par des failles normales (Durling et Marillier, 1993) (Chapitre 3). La Formation de Hillsborough, unité clastique à la base du Groupe de Windsor, s'est accumulée dans un environnement similaire à celui du Groupe de Horton et pourrait, elle aussi, être équivalente à la Formation de Paspébiac.

La Formation de La Coulée

Une nouvelle unité clastique a été définie comme la Formation de La Coulée, d'épaisseur inconnue, mais dont les 60 premiers mètres de brèches et conglomérats ont été reconnus dans la région de Percé (Chapitre 1). Cette unité est recouverte en discordance angulaire par la Formation de Bonaventure et se distingue de cette dernière par sa couleur grise et sa composition monolithique. Aussi, les 30 premiers mètres de la Formation de La Coulée ont partiellement ou entièrement été calcrétizés par des eaux souterraines, phénomène que l'on ne retrouve pas dans la Formation de Bonaventure.

Des structures et textures associées à la zone vadose (calcrètes laminaires et 'vadoïdes') ont été reconnues à seulement 6 m de la base de la calcrète (Chapitre 1). Puisque les calcrètes d'eau souterraine ne peuvent se développer que lorsque la nappe phréatique est située à moins de 5 m de la surface (Wright et Tucker, 1991), les 24 m de calcrétization sus-jacents et les derniers 30 m de sédiments non-calcrétizés de la succession suggèrent que sédimentation et calcrétization étaient synchrones. Ce type de calcrètes d'eau souterraine, matures, massives et épaisses de plusieurs mètres, n'est présentement documenté qu'en bordure de bassins évaporitiques, dans la zone où les eaux douces souterraines se mélangent avec les eaux souterraines salées (Mann and Horwitz 1979; Arakel and McConchie 1982; Jacobson *et al.*, 1988; Arakel *et al.*, 1989).

Les 60 m de matériel grossier associé à des coulées de débris suggèrent une sédimentation continentale à l'intérieur d'un cône de déjection situé en bordure d'un escarpement de faille (Chapitre 1). L'absence de débris de plantes, le caractère non-oxydé et pauvre en argile du matériel des coulées de débris, et la formation de calcrètes d'eau souterraine, indiquent que la Formation de La Coulée a évolué dans un environnement tropical aride, mais sous des conditions de nappe phréatique élevée, probablement en bordure d'un bassin évaporitique (Chapitre 1).

Les lits clastiques de la Formation de La Coulée n'ont pas été reconnus ailleurs que dans la région de Percé, mais des calcrètes similaires et occupant la même position stratigraphique, en discordance angulaire sous la Formation de Bonaventure, se retrouvent à plusieurs endroits dans le sud de la Gaspésie.

Selon des données géomorphologiques (Jutras et Schroeder, 1999), la mer de Windsor aurait brièvement occupé le sud de la Gaspésie lors de son extension maximale. Aucun dépôt corrélatif à cet épisode n'a été reconnu, mais une calcrète de 6 à 12 m d'épaisseur est directement installée sur une paléo-terrasse d'abrasion et occupe la base de la succession du Carbonifère. Il est possible que les dépôts à la base de la succession étaient d'origine marine, mais cette calcrète mature et massive masque complètement la nature du matériel à l'intérieur duquel elle s'est développée (Chapitre 1).

À Saint-Jules-de-Cascapédia, la calcrète d'eau souterraine s'est formée dans un régolithe développé dans les lits supérieurs de la Formation de Paspébiac (Chapitre 3). Cette observation vient souligner le fait que les calcrètes d'eau souterraine de la Gaspésie n'ont pas exclusivement les lits clastiques de la Formation de La Coulée comme sédiment encaissant. On ne peut donc postuler que la présence de la calcrète implique la présence initiale de la Formation de La Coulée, tel que proposé dans le Chapitre 1 de la thèse. L'appellation de Formation de La Coulée n'est donc pas appropriée pour les calcrètes dont le sédiment encaissant n'est pas démontré comme étant cette unité. Nous notons par-contre que les calcrètes d'eau souterraine de la Gaspésie sont toutes situées dans la même position stratigraphique relative, entre les dépôts du Bonaventure et, lorsque présents, du Paspébiac. Cette position stratigraphique correspondant à celle de la Formation de La Coulée, nous proposons de cartographier et nommer informellement ces calcrètes en tant que 'calcrète de La Coulée'.

Étant stratigraphiquement situées au-dessous de la Formation de Pointe Sawyer, correspondant à la base du Groupe de Mabou, et au-dessus de la Formation de Paspébiac, équivalente au Groupe de Horton ou à la Formation de Hillsborough, les Formation et calcrète de La Coulée sont fort probablement équivalentes chronologiquement au Groupe de Windsor. La présence sous-jacente d'une paléo-terrasse d'abrasion à Saint-Elzéar et l'association génétique des calcrètes à la proximité d'un bassin évaporitique suggèrent également une corrélation au Windsor. Un âge Viséen moyen à supérieur est ainsi indirectement attribué à la Formation et calcrète de La Coulée.

La Formation de Bonaventure

La Formation de Bonaventure, reconnue depuis Logan (1846), est constituée de puissantes unités clastiques: des conglomérats massifs et des grès et siltstones plus finement stratifiés. Dans la région de Percé, cette formation recouvre en discordance angulaire les restes de la Formation de La Coulée. Cette dernière a en effet été légèrement déformée, probablement par des failles normales, et presqu'entièrement érodée avant que ne sédimente la Formation de Bonaventure (Chapitre 1).

Les lits clastiques rouges des membres inférieur et moyen de la Formation de Cannes-de-Roches, par leur position stratigraphique sous la Formation de Pointe Sawyer et au-dessus de la Formation de La Coulée, sont maintenant considérés comme faisant partie intégrante de la Formation de Bonaventure, bien que, selon les données de paléocourants et les reconstructions paléogéographiques, ils aient sédimenté dans un bassin différent (Chapitre 2). Le bassin dans lequel a sédimenté la Formation de Bonaventure, dans ces anciennes limites, est nommé 'bassin de Ristigouche', selon l'appellation de van de Poll

(1995), alors que le bassin dans lequel ont sédimenté les anciens membres inférieur et moyen de la Formation de Cannes-de-Roches est ici nommé 'bassin de Cannes-de-Roches'.

Comme les formations de Paspébiac et de La Coulée, la Formation de Bonaventure est interprétée comme étant le fait d'une sédimentation continentale, dans le contexte d'escarpements de failles (Zaitlin et Rust, 1983). Les débris clastiques du Bonaventure sont par-contre mieux classés, plus arrondis et plus polygéniques. Alors que les formations de Paspébiac et de La Coulée ne contiennent que des débris de roches très locales, la Formation de Bonaventure contient 10 à 20% de clastes résistants (caillous arrondis de quartz ou de jaspe) et ayant possiblement voyagé sur une longue distance. Une oxydation très pénétrante, l'absence de traces de plantes et la présence de nombreuses calcrètes pédogéniques témoignent d'un climat tropical aride, sans doute très similaire à celui dans lequel ont évolué les formations de Paspébiac et de La Coulée. En discordance de ravinement sous la Formation de Pointe Sawyer, dont l'assemblage de spores correspond à la base du Groupe de Mabou, la Formation de Bonaventure est fort probablement contemporaine au Groupe de Windsor (Chapitre 3).

La Formation de Pointe Sawyer

La Formation de Pointe Sawyer se distingue visuellement du Bonaventure sous-jacent par sa couleur grise et ses abondants fragments de charbon, mais le matériel clastique qui la compose, hormis les débris de plantes, est très semblable à celui de la Formation de

Bonaventure. La Formation de Pointe Sawyer est caractérisée par des conditions climatiques suffisamment humides pour empêcher l'oxydation des matériaux meubles en surface et permettre la prolifération de plantes, bien que celles-ci correspondent à des espèces tolérantes à l'aridité (Chapitre 2).

Autrefois nommée membre supérieur de la Formation de Cannes-de-Roches, cette formation a été reconnue par-dessus la Formation de Bonaventure entre les municipalités de Bonaventure et de New-Carlisle, à plus de 100 km du bassin de Cannes-de-Roches (Chapitre 2). Étant en contact de ravinement avec les lits sommitaux du Bonaventure au niveau de la Pointe Sawyer, dont elle a pris le nom, cette unité n'est pas un équivalent latéral des faciès rouges sous-jacents, comme l'avait d'abord proposé Rust (1981), mais une formation sus-jacente ayant évolué sous un climat différent. Son assemblage de spores (Zone SM) donne un âge Viséen supérieur selon les données de Utting (1987), mais cet assemblage ne se retrouve que dans les formations sus-jacentes au Groupe de Windsor, alors que le sommet de ce dernier serait d'âge Namurien inférieur selon sa population de foraminifères (Mamet, 1970). La Zone SM est maintenant considérée comme correspondante à un âge Namurien inférieur (J. Utting, comm. pers., 2001) et la Formation de Pointe Sawyer est ainsi corrélée à la base du Groupe de Mabou (chapitres 2 et 3).

La Formation du Chemin-Des-Pêcheurs

En quatre ou cinq mètres de lits de transition, les lits clastiques calcareux de la Formation de Pointe Sawyer, gris et riches en débris de plantes, passent à des grès laminaires bourgognes foncés, libres de débris calcareux et organiques (Chapitre 2). Ces grès bourgognes foncés un retour vers des conditions oxydantes. Bien que la transition avec les lits gris de la Formation de Pointe Sawyer soit graduelle, les différences pétrographiques et le changement d'environnement sédimentaire dont témoignent les lits de grès bourgognes foncés ont été jugés suffisant pour leur octroyer le statut de formation (Formation du Chemin-des-Pêcheurs).

Les quatre premières formations du Carbonifère de la Gaspésie (Paspébiac, La Coulée, Bonaventure et Pointe Sawyer) sont toutes caractérisées par une dominance de débris calcareux provenant des successions cambro-ordovicienne et siluro-dévonienne qui leur servent également de socle. Même dans les fractions fines, les débris calcareux sont abondants, voire dominants, témoignant d'une source essentiellement locale. Par-contre, les grès de la Formation du Chemin-des-Pêcheurs sont plus matures et correspondent au début d'une sédimentation beaucoup plus distale, provenant possiblement des premières poussées orogéniques de la chaîne Alléghanienne, laquelle s'édifiera au sud tout au cours du Pennsylvanien et du Permien inférieur.

Il subsiste très peu de témoins en Gaspésie de cette formation de puissance inconnue. La possibilité est néanmoins grande de la retrouver sur une grande étendue lors d'éventuels forages au centre du graben de Ristigouche (baie des Chaleurs), là où elle aura eu plus de chance d'être préservée. Étant en continuité stratigraphique verticale avec la Formation de Pointe Sawyer, la Formation du Chemin-des-Pêcheurs est probablement d'âge Namurien et équivalente au Groupe de Mabou des Provinces Maritimes (Chapitre 2).

Déformations postérieures à la sédimentation du Mississippien

Des déformations transpressives, manifestées par trois systèmes de failles transcourantes, des failles inverses et des plis d'entraînement, ont affecté la succession sédimentaire des bassins du Paléozoïque supérieur de la Gaspésie (Chapitre 4). La plupart des failles impliquées avaient déjà été identifiées auparavant, mais leur déplacement transcourant n'ayant pas été reconnu dans les unités du Carbonifère, elles avaient ainsi été considérées comme étant liées à des phases tardives de l'orogenèse Acadienne (Kirkwood, 1989; Malo et Kirkwood, 1995; Kirkwood *et al.*, 1995). Il est proposé d'attribuer, jusqu'à preuve du contraire, toutes les déformations transcourantes cassantes en Gaspésie à la phase alléghanienne (permo-carbonifère) et de ne considérer que les déformations ductiles et ductiles-cassantes comme étant antérieures. Cette conclusion est non-seulement supportée par l'identification de structures transpressives cassantes dans les roches du Carbonifère de la Gaspésie, mais également par l'idée qu'une période d'exhumation sépare nécessairement les plissements acadiens, développés à relativement grande profondeur, des déformations cassantes subséquentes, développées à faible profondeur. La prolongation sous-marine du linéament de la Faille de Grande-Rivière, à l'intérieur de roches d'âge Pennsylvanien, suggère que les déformations post-acadiennes ont perduré au moins jusqu'à la fin du Pennsylvanien, début Permien (Chapitre 4).

PERSPECTIVES POUR L'EXPLORATION PÉTROLIÈRE

Des suintements d'huile sont communément observés en Gaspésie, dans les socles pré-carbonifères, et ont mené à plusieurs efforts d'exploitation depuis le milieu du 19ème siècle (C. Morin, de la Division du Pétrole et du Gaz du Ministère des Ressources Naturelles du Québec, comm. pers., 1999). Les principaux problèmes sont le manque de roches poreuses dans les formations reconnues entre la fin du Précambrien au Dévonien inférieur, et le manque de roches-couvertures et de failles dans les roches clastiques subséquentes.

La présence des épaisses calcrètes d'eau souterraine de La Coulée sur la bordure nord de la baie des Chaleurs, lesquelles forment une couverture résiduelle discontinue mais identifiée sur environ 150 km, suggère que le coeur du graben de la baie des Chaleurs a pu être recouvert par un ou plusieurs bassins évaporitiques à l'époque de la formation des calcrètes. Ceci laisse donc présager la possibilité de retrouver des couvertures évaporitiques scellantes au coeur de la baie des Chaleurs, une région qui n'a pas été explorée par forage jusqu'à ce jour.

La conjonction des trois orientations principales de failles (Chapitre 4) tendra à former des prismes structuraux et donc d'éventuels pièges pour confiner les roches clastiques formées par les molasses synorogéniques acadiennes et la série continentale du Carbonifère. Le large corridor de déformation de la Faille de la Grande-Rivière, qui renferme d'énormes crochons de faille (Chapitre 4), pourrait contenir des petits réservoirs coincés sous des crochons de roches imperméables. Mentionnons qu'un petit réservoir d'hydrocarbures a été identifié dans un couloir de faille voisin, la Faille du Troisième-Lac, près de la ville de Gaspé (Fig. 1) (C. Morin, de la Division du Pétrole et du Gaz du Ministère des Ressources Naturelles du Québec, comm. pers., 1999). Les plissements postérieurs au Dévonien moyen, affectant le Groupe de Miguasha, et les nombreuses discontinuités récemment identifiées à l'intérieur des roches du Carbonifère, dont principalement celle qui sépare la Formation de La Coulée de la Formation de Bonaventure, peuvent aussi contribuer à former des pièges.

Dans la perspective que les roches sus-jacentes ne laisseront pas nécessairement s'échapper les hydrocarbures, les shales de la Formation d'Escuminac (du Groupe de Miguasha), très riches en débris organiques (Hesse et Sawh, 1992) et dont l'extension sous la baie des Chaleurs est inconnue (Prichonnet *et al.*, 1996), deviennent également intéressants comme roches-mères potentielles. Enfin, grâce à l'altération des spores de la

Formation de Pointe Sawyer, correspondant à la fenêtre à l'huile (Chapitre 2), on peut déduire que les bassins de Ristigouche et de Cannes-de-Roches ont été enfouis sous les sédiments du Pennsylvanien et du Permien inférieur dans des conditions propices à la migration et à la conservation des hydrocarbures. L'histoire géologique des bassins de Ristigouche et de Cannes-de-Roches paraissant favorable au développement éventuel de réservoirs pétrolifères, l'exploration dans la baie des Chaleurs mérite, selon-nous, d'être approfondie.

PESPECTIVES POUR RECHERCHES ULTÉRIEURES

Des efforts de corrélation méritent d'être effectués sur l'ensemble du bassin des Maritimes, pour en simplifier la nomenclature stratigraphique et pour permettre l'établissement de larges reconstructions paléogéographiques. Ces reconstructions paléogéographiques seraient un atout important pour l'exploration pétrolière, surtout en ce qui concerne l'époque du Groupe de Windsor (Viséen moyen au Namurien inférieur). Une meilleure compréhension du contexte tectonique post-Acadien dans les Appalaches canadiennes serait également rendue possible par de telles reconstitutions. Ce genre de travail devrait éventuellement être étendu vers l'équivalent européen du bassin des Maritimes.

Une calcrète d'eau souterraine identique à celle qui affecte la Formation de La Coulée a récemment été identifiée dans le centre-est du Nouveau Brunswick, sous la Formation de Bathurst, un équivalent probable de la Formation de Bonaventure. La calcrétization massive de certains dépôts du Groupe de Windsor, possiblement par l'action d'eaux souterraines, est observée à plusieurs endroits dans les Provinces Maritimes (Plint *et al.,* 1983; P. Giles, comm. pers. 1998; R.J. Ryan, comm. pers. 2001). La position stratigraphique et le caractère génétique de chacune de ces calcrètes devraient être déterminés afin de vérifier si l'événement qui a marqué la Formation de La Coulée est unique dans le bassin des Maritimes. Les calcrètes d'eau souterraine étant associées génétiquement à la proximité de bassins évaporitiques, il est souhaitable de les situer dans des reconstructions paléogéographiques afin de mieux orienter la prospection pétrolière dans le bassin des Maritimes. Une étude comparative entre les calcrètes d'eau souterraine carbonifères du Bassin des Maritimes et les calcrètes d'eau souterraine récentes du centre de l'Australie mérite également d'être faite, afin de mieux comprendre l'environnement de formation de ce rare type de calcrète.

Les quelques données de forages et de lignes sismiques disponibles pour la baie des Chaleurs, aux ministères des ressources naturelles du Québec et du Nouveau Brunswick, devraient être analysées à la lumière des nouvelles données de terrain présentées ici. La géométrie des unités et structures d'âge Carbonifère au sein de la baie devrait être mieux définie afin de pouvoir estimer plus étroitement le potentiel pétrolier de cette dernière. De nouvelles données de subsurface mériteraient d'être recherchées dans le centre de la baie, là où les données actuelles sont les plus pauvres et où le potentiel pétrolier pourrait se situer.

RÉFLEXIONS SUR L'INTÉGRATION DE DONNÉES GÉOMORPHOLOGIQUES ET TECTONOSTRATIGRAPHIQUES DANS LES ÉTUDES PALÉOENVIRONNEMENTALES

Tel que mentionné dans l'introduction, la présente étude tectonostratigraphique fut précédée et orientée par une étude géomorphologique qui en a ouvert les pistes. Les nombreuses contributions de la présente étude sur le schéma tectonostratigraphique du Carbonifère de la Gaspésie, une région très accessible et étroitement étudiée par plusieurs générations de chercheurs, nous forcent à donner crédit à l'approche employée, qui a cherché à unir les données géomorphologiques, sédimentologiques et structurales. Sans être nouvelle, cette méthode est largement sous-utilisée.

Tout comme les reliefs sont importants dans l'étude de bassins actifs, ils le sont également dans l'étude de bassins reliques. Aucune donnée géomorphologique n'est généralement disponible dans le cas de bassins déformés sous des conditions ductiles, mais certaines données intéressantes et complémentaires peuvent subsister dans le cas de bassins anciens ayant évolué essentiellement en domaine cassant. Ces données se retrouvent à la fois au sein de sections de surfaces enfouies, ce type de données étant généralement pris en note par le géologue, et à l'intérieur de surfaces exhumées, qui elles ne sont que très rarement étudiées par le géologue, le schéma devenant plus compliqué dû à une ou des surimpressions morphologiques synchrones ou postérieures à l'exhumation. L'ordre des impressions morphologiques peut néanmoins être établi d'une façon très similaire à la reconstitution d'une suite d'événements géologiques selon les principes de superposition et de recoupement.

Certains bassins sédimentaires du Phanérozoïque ne sont que faiblement déformés et ne subsistent généralement que sur une partie de leur étendue originelle. La périphérie exhumée des ces bassins devrait être plus systématiquement étudiée puisqu'elle peut renfermer des informations paléoenvironnmentales complémentaires aux données structurales et stratigraphiques.

APPENDICE 1

THE LA COULÉE FORMATION

Authors: Jutras, P., Prichonnet, G. and von Bitter, P.

Age: Late Devonian or Mississippian; possibly Viséan.

History: Mapped as the Bonaventure Formation by Kirkwood (1989). Partially mapped as the Murphy Creek Formation (Cambrian) by Brisebois *et al.* (1992).

Minimum thickness: 60 m.

Lithology:
- Groundwater calcrete formed in limestone breccia (~10 m).
- Grey limestone breccia with calcrete matrix (~20 metres) topped by the same breccia with yellowish-grey matrix (~20 m).
- Grey limestone conglomerate with 100% calcareous clasts (minimum thickness: 10 m).

Distribution: The fullest succession is found on the northern side of Mont Sainte-Anne, west of the village of Percé . It can be followed upstream from the La Coulée Creek waterfall, which is located at 22A/09, 5376750m N., 406500m E . This erosional remnant covers approximately 1 km^2, a small part of which is separated by the Mont Sainte-Anne Fault. The stratigraphic level of the grey limestone conglomerate on the southern side of the fault is unknown but it corresponds to the same facies as that found in the continuous sequence on the northern side above the 50 m stratigraphic level. The calcrete base can be found underneath the Bonaventure Formation in several places around Percé. Similar calcretes, also beneath the Bonaventure Formation, can be observed at various localities in the southern Gaspé Peninsula, but their host sediment is not demonstrated to be the La Coulée Formation. These calcretes are informally referred to as 'La Coulée calcrete'.

Stratigraphic relationships:

Period	sub-	Epoch	Selected Stages	Ma	Maritimes	Gaspé Peninsula
Carboniferous	Penn.	Westphalian			Cumberland Group (or Riversdale Group)	?
		Namurian	Pendleian	323	Mabou Group (or Canso Group)	(Cannes-de-Roches Fm. ?) Bonaventure Fm.
	Mississippian	Viséan	Brigantian Asbian Holkerian	333	Windsor Group	?
						La Coulée Fm.
		Tournaisian		350	Horton Group	?
Devonian		Late	Famennian Frasnian	363 367		Miguasha Group
		Middle	Givetian Eifelian	377 381 386	Acadian orogeny	Acadian orogeny

(1): Time scale after Harland *et al.*, 1990.

APPENDICE II

COMPOSITE LIST OF PALYNOMORPHS	LOCALITIES	
	Pointe Sawyer	Cannes-de-Roches Cove
SPORES		
Acanthotriletes sp.	X	
Auroraspora macra Sullivan, 1968	X	
Auroraspora solisorta Hoffmeister, Staplin and Malloy, 1955	X	X
Calamospora parva Guennel, 1958	X	
Chomotriletes multivittatus Playford, 1978	X	
Colatisporites decorus (Bharadwaj and Venkatachala) Williams, 1973	X	X
Colatisporites denticulatus Neville, 1973	X	X
Convolutispora mellita Hoffmeister, Staplin and Malloy, 1955		X
Convolutispora sp.	X	
Convolutispora tessellata Hoffmeister, Staplin and Malloy, 1955	X	X
Crassispora trychera Neves and Ioannides, 1974	X	X
Cymbosporites sp.	X	X
Densosporites columbaris Utting, 1987	X	
Dictyotriletes odontolophos Utting, 1987	X	X
Dictyotriletes sp.		X
Discernisporites barssii Utting, 1987		X
Discernisporites micromanifestus (Hacquebard) Sabry and Neves, 1971	X	X
Granulatisporites granulatus Ibrahim, 1933	X	
Granulatisporites tuberculatus Hoffmeister, Staplin and Malloy, 1955	X	X
Ibrahimispores magnificus Neves, 1961	X	X
Knoxisporites literatus (Waltz) Playford, 1962		X
Knoxisporites probolos Utting, 1987	X	X
Knoxisporites stephanephorus Love, 1960	X	X
Knoxisporites triradiatus Hoffmeister, Staplin and Malloy, 1955	X	X
Leiotriletes inermis (Waltz) Ischenko, 1952	X	
Leiotriletes ornatus Ischenko, 1956		X
Lycospora pusilla (Ibrahim) Schopf, Wilson and Bentall, 1944		X
Microreticulatisporites hacquebardii Utting, 1987	X	X
Punctatisporites glaber (Naumova) Playford, 1962	X	X
Punctatisporites minutus Kosanke, 1950	X	
Raistrickia magdalena Utting, 1987		X
Reticulatisporites carnosus (Knox) Neves, 1964	X	X
Rugospora corporata Neves and Owens var. *verrucosa* Neville, 1968	X	
Rugospora minuta Neves and Ioannides, 1974	X	X
Rugospora polyptycha Neves and Ioannides, 1974	X	X
Schopfipollenites acadiensis Utting, 1987	X	X
Schopfites claviger Sullivan, 1968	X	X
Secarisporites remotus Neves, 1961	X	X
Spelaeotriletes arenaceus Neves and Owens, 1966	X	X
Spelaeotriletes pretiosus var. *bellii* (Playford) Utting, 1987	X	
Spelaeotriletes pretiosus var. *windsorensis* (Playford) Utting, 1987	X	X
Spelaeotriletes tuberosus Utting, 1987	X	
Vallatisporites sp.	X	
Verrucosisporites sp.	X	
ACRITARCHS		
Veryhachium sp.		X

APPENDICE III

THE POINTE SAWYER FORMATION

Authors: Jutras, P., Prichonnet, G. and Utting, J.

Age: Carboniferous. Late Viséan (Brigantian) to early Namurian (Pendleian).

Historic: This unit was identified as the Upper Member of the Cannes-de-Roches Formation by Alcock (1935). This author considered the Cannes-de-Roches Formation to be penecontemporaneous with the Bonaventure Formation. From spore analysis, Hacquebard (1972) and Barss in Hacquebard (1972) suggested an Early Namurian age (c/b zone) for this unit, whereas Barss (personnal communication in Rust 1981) proposed a Viséan age. Kirkwood (1989) and Brisebois et al. (1992) have placed the Cannes-de-Roches Formation as time-equivalent to the basal beds of the Bonaventure Formation. Globensky (1993) excluded the Cannes-de-Roches Formation from the Canadian Stratigraphic Glossary, mistakenly thinking that Rust (1976) had proposed to abandon it as a stratigraphic unit. However, Rust himself subsequently published material on the Cannes-de-Roches Formation (Rust, 1981, 1982; Rust et al., 1989). Following identification of the Cannes-de-Roches Formation Upper Member on top of the Bonaventure Formation, it is here proposed to abandon the Lower and Middle members, which are lateral equivalents of the Bonaventure Formation, and to raise the Upper Member to formation status. It is proposed to abandon the term Cannes-de-Roches Formation, to avoid later confusion regarding the limits of that formation, and to rename the unit Pointe Sawyer Formation.

Maximum observed thickness: 20 m.

Distribution: The main exposures of the Pointe Sawyer Formation are on the south shore of Mal Bay, near Percé, in the Gaspé Peninsula of Québec (Zone 22A, 5377500m. N., 405500 m. E.), where they dip subvertically. The type section of the Cannes-de-Roches Cove (Zone 22A, 5377500m. N., 405500 m. E.), which was the only exposure where the formation could be followed on its entire thickness, has collapsed into the sea in 1998 or 1999. The basal beds of that formation can also be observed at Pointe Sawyer, near the town of Bonaventure (Zone 22A, 5319500 m. N., 320500 m. E.).

Lithology: Grey calcareous continental clastics with carbonized plant remains, mainly conglomerates with some sandstones and mudstones. The type section of the Cannes-de-Roches Cove (~20 m) was showing two fining-upward grey conglomeratic units separated by 1-2 m of buff sandstone prior to destruction of the upper half.

Stratigraphic relationships: Overlying with a small erosional discontinuity the Bonaventure Formation and overlain conformably by the dark reddish-brown sandstones of the Chemin-des-Pêcheurs Formation.

APPENDICE IV

THE CHEMIN-DES-PÊCHEURS FORMATION

Authors: Jutras, P., Prichonnet, G. and Utting, J.

Age: Carboniferous (Namurian).

Historic: Mapped as the Cannes-de-Roches Formation by Alcock (1935), McGerrigle (1950), Kirkwood (1989) and Brisebois (1992), and as the Upper Member of the Cannes-de-Roches Formation by Rust (1981). None of these authors have mentioned or described the facies of this unit.

Minimum thickness: 10 m.

Distribution: The only exposures of the Chemin-des-Pêcheurs Formation are on the south shore of Mal Bay, near Percé, in the Gaspé Peninsula of Québec (Zone 22A, 5377500m. N., 405500 m. E.). The thickest and type section (10 m) is at Cannes-de-Roches Point.

Lithology: Laminar, dark reddish-brown sandstones.

Statigraphic relationships: Overlying conformably the Pointe Sawyer Formation with ~4 m of transitional pinkish-red beds, gradually taking a reddish-brown color. No overlying formation has been identified. It is the youngest sedimentary formation of the Paleozoic identified in the Gaspé Peninsula.

APPENDICE V

THE PASPÉBIAC FORMATION

Authors: Jutras, P. and Prichonnet, G.

Age: Post-Middle Devonian and pre-Namurian (probably Tournaisian).

Historic: This unit was mapped as the Bonaventure Formation, which it closely resembles, by Logan (1846), Alcock (1935), Badgley (1956), McGerrigle and Skidmore (1967), Ayrton (1967), Bourque and Lachambre (1980), De Broucker (1987), Gosselin (1988), Brisebois *et al.* (1992) and van de Poll (1995).

Maximal observed thickness: ~50 m.

Distribution: The main exposures are on the coastal cliffs between the towns of New-Carlisle (Zone 22A, 5320000 m.N., 327500 m.E.) and Port-Daniel (5335000 m.N., 352000 m.E.) in the southernmost sector of the Gaspé Peninsula of Québec, where it underlies the Bonaventure Formation. It can also be observed at the level of the Saint-Jules-de-Cascapédia quarry (Zone 22A, 5347500 m.N., 282000 m.E.), where it underlies a La Coulée calcrete. A small remnant can also be observed near the town of Gascons, with coastal cliff exposure (Zone 22A, 5340000 m.N., 365000 m.E.).

Lithology: Red continental clastics. The coarse fractions only include locally derived sedimentary clasts. The sediments are poorly sorted. Paleosol overprints are abundant. They include calcrete hardpans and buff-colour calcareous nodules.

Stratigraphic relationships: The Paspébiac Formation has only been observed overlying basement rocks of the Ordovician and the Silurian. It does not bear the foldings that have affected the Miguasha Group (Frasnian), which are also exposed within the southern Gaspé Peninsula. Hence, it probably post-dates these rocks. Its weathered upper beds are invaded by a La Coulée groundwater calcrete (Viséan?) at the Saint-Jules quarry.

APPENDICE VI

STEREONET DATA

Strike and dip of fault planes (with plunge and trend of slickensided lineations) on...

(Fig. 4.3A)...reverse fault planes affecting the Carboniferous succession of the Cannes-de-Roches Cove in a strike-slip duplex of the Grande-Rivière Fault: 075°60° (60°045°, 60°030°, 60°040°), 105°30° (no striae), 085°40° (no striae), 105°50° (no striae), 115°40° (no striae), 115°60° (no striae).

(Fig. 4.3B)... secondary thrusts affecting sandstones of the Bonaventure Formation within the main deformation corridor of the Cap Blanc Fault: 160°72° (65°220°), 260°35° (33°015°), 155°35° (27°215°), 185°48° (23°015°), 170°27° (015°200°), 050°33° (27°180°), 155°22° (19°205°), 355°10° (05°080°), 270°25° (20°020°).

(Fig. 4.3C)... secondary thrusts affecting the La Coulée Formation groundwater calcrete of Percé-Beach, adjacent to the Cap Blanc Fault: 310°36° (30°045°), 310°35° (35°045°), 310°32° (32°052°), 120°32° (32°225°), 110°40° (40°220°), 155°38° (38°230°), 120°08° (08°030°), 124°14° (14°035°), 317°37° (37°045°), 313°41° (41°044°), 120°03° (03°030°), 320°33° (33°054°), 304°32° (32°048°).

(Fig. 4.3D)... dextral R structures of the Cap Blanc Fault developed within the La Coulée Formation: 295°75° (03°115°), 130°80° (01°310°), 295°80° (06°115°), 140°65° (10°320°).

(Fig. 4.10A)... sinistral P structures of the Saint-Jogues-Sud Fault affecting sandstones of the Bonaventure Formation:
075°90° (00°075°), 060°70° (no striae), 260°90° (15°085°, 05°055°), 245°90° (15°065°).

(Fig. 4.10B)... sinistral shearing affecting Silurian limestones of the La Vieille Formation and its Carboniferous karst infill in the vicinity of Port-Daniel: 205°86° (00°205°), 220°60° (00°220°), 205°90 (25°205°), 210°78° (15°210°),
020°85° (15°020°), 210°80° (00°210°), 005°38° (00°005°), 355°45° (00°355°).

(Fig. 4.11A)... sinistral R structures affecting tilted on edge strata of the Bonaventure Formation within a drag fold associated to the Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system: 353°46° (14°360°),
018°48° (10°195°), 040°66° (34°203°), 055°75° (35°200°), 355°68° (20°175°).

(Fig. 4.11B)... reverse fault planes affecting the La Coulée Formation groundwater calcrete of the Saint-Jules quarry in the vicinity of the Petit-Montréal - Mont-Saint-Joseph - Grande-Cascapédia fault system: 085°45° (45°355°), 090°45° (45°355°).

(Fig. 4.11C)... sinistral P structures of the Black Cape Fault developed within the Black Cape Volcanics, less than 1m above the Lazy Cove sedimentary unit: 200°75° (18°190), 220°80° (20°210°), 195°65° (39°195°).

(Fig. 4.11D)... reverse fault planes associated with the Black Cape Fault and affecting the Black Cape Volcanics: 080°55° (55°350°), 100°50° (50°010°).

(Fig. 4.11E)... sinistral P structures of the Black Cape Fault developed within the Black Cape Volcanics:

040°89° (30°215°), 211°89° (30°200°), 259°81° (15°070°), 221°75° (20°220°), 058°80° (20°060°), 242°65° (30°240°), 085°80° (07°085°), 245°86° (10°245°), 051°85° (15°050°), 052°065° (10°050°). 241°84° (060°15°), 221°50° (040°15°), 035°81° (08°035°), 031°79° (05°210°), 251°80° (10°070°), 041°77° (10°040°), 060°80° (20°060°), 021°86° (20°040°), 030°78° (10°050°), 225°82° (10°045°), 031°81° (15°030°), 039°60° (18°040°), 021°69° (04°200°), 210°83° (12°030°), 219°72° (05°040°), 029°76° (02°039°), 052°84° (15°052°), 049°88° (08°050°), 041°78° (15°041°), 039°87° (12°038°), 051°72° (01°52°), 035°73° (11°215°).

(Fig. 4.11F)... dextral R' structures of the Black Cape Fault developed within the Black Cape Volcanics: 160°80° (35°160°), 315°70° (08°315°, 05°135), 340°65° (05°340°, 07°160°).

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