BULLETIN OF CANADIAN PETROLEUM GEOLOGY
VOL. 55, NO. 3 (SEPTEMBER, 2007), P. 217–236

Viséan tectonostratigraphy and basin architecture beneath the Pennsylvanian New Brunswick Platform of eastern Canada

P. JUTRAS
Department of Geology
Saint Mary's University
Halifax, NS B3H 3C3
pierre.jutras@smu.ca

R.A. MACRAE
Department of Geology
Saint Mary's University
Halifax, NS B3H 3C3
andrew.macrae@smu.ca

J. UTTING
Natural Resources Canada
Geological Survey of Canada (Calgary)
3303 - 33 Street NW
Calgary, AB T2L 2A7
jutting@nrcan.gc.ca

ABSTRACT

Available core, borehole, seismic, gravity, aeromagnetic and palynological data are combined with field data to reconstruct the Viséan tectonostratigraphy and architecture of the Central Basin of New Brunswick, which is mainly hidden below the New Brunswick Platform, an unconformable cover of Pennsylvanian rocks. The Viséan Central Basin is separated from the contemporaneous Ristigouche Basin of northern New Brunswick and eastern Quebec by the Bathurst Horst, a buried Viséan basement high. Like in the Ristigouche Basin, erosional remnants of the La Coulée Calcrete occur in the Central Basin below coarse red conglomerates of the Bonaventure Formation, which were previously not correlated with this unit. This suggests the nearby presence of an evaporitic basin at the time of phreatic calcrete hardpan formation, a period of uplift and erosion, and subsequent burial by continental clastics, which were probably controlled by active faulting at the margin of the basin. As opposed to the Ristigouche Basin, the Bonaventure Formation includes a volcanic interval in the Central Basin. The latter basin was affected by faulting, uplift, tilting and erosion during Yeadonian to Duckmantian times, which generated an angular unconformity with overlying younger rocks. Synchronous to most of this deformation, the Yeadonian to Duckmantian Red Pine Brook Formation was deposited in the Bathurst Subbasin, which partly overlaps the Central Basin, and which is composed of reworked Mississippian rocks that were sourced from both the latter basin and the Ristigouche Basin.

RÉSUMÉ

Des données sismiques, gravitaires, aéromagnétiques, palynologiques et de forage sont combinées à des données de terrain pour reconstruire la tectonostratigraphie et l'architecture du bassin Central du Nouveau Brunswick. Ce bassin d'âge Viséen est presqu'entièrement enfoui sous la Plateforme du Nouveau Brunswick, une couverture discordante de roches pennsylvaniennes. Il est séparé du bassin contemporain de Ristigouche, lequel occupe le nord du Nouveau-Brunswick et l'est du Québec, par le horst de Bathurst, une région source enfouie d'âge Viséen. Comme dans le bassin de Ristigouche, des reliques d'érosion de la calcrète de La Coulée sont observées dans le bassin Central sous les conglomérats rouges grossiers de la formation de Bonaventure, lesquels n'étaient auparavant pas assignés à cette unité. Ceci suggère qu'un bassin évaporitique était présent dans la région au temps où cette calcrète phréatique cuirassée s'est formée, suivi d'une période de soulèvement et d'érosion, et subséquemment suivi d'un enfouissement sous des dépôts clastiques continentaux, lesquels étaient probablement contrôlés par des failles actives à la marge du bassin. Contrairement au bassin de Ristigouche, la formation de Bonaventure inclue un intervalle volcanique dans le bassin Central. Ce dernier a été faillé, soulevé, incliné et partiellement érodé entre le Yéadonien et le Duckmantien, résultant en une discordance angulaire avec les unités plus jeunes sus-jacentes. Le dépôt de la formation de Red Pine Brook, d'âge Yéadonien à Duckmantien, fût synchrone à la majeure partie de cette déformation. Cette unité a été déposée dans le sous-bassin de Bathurst, lequel est en-partie sus-jacent au bassin Central et est composé de sédiments mississippiens remaniés à partir du reste de ce bassin et de celui de Ristigouche.

Introduction

The Viséan interval (middle Mississippian) in the composite upper Paleozoic Maritimes Basin of southeastern Canada (Fig. 1; inset) is of significant interest for oil and gas exploration as it encompasses nearly all marine and evaporitic rocks of the basin. The latter types of rocks mainly occur in the southwestern half of the basin and are laterally transitional to continental clastic rocks and phreatic calcrete hardpans of the Percé Group in the northwestern part of the basin (Jutras and Prichonnet, 2005). Regional exploration is handicapped by many uncertainties concerning the transition zone between these two systems, which is the principal problem addressed here as part of an ongoing project to correlate Viséan units across the Maritimes Basin.

The stratigraphy, sedimentology and architecture of the Mississippian Central Basin of New Brunswick (van de Poll, 1995) were poorly known prior to this study due to its nearly complete burial beneath Pennsylvanian strata of the New Brunswick Platform (van de Poll, 1995), and because of the scarcity of deep subsurface data for that area. Moreover, the sedimentology of exposed erosional remnants of Mississippian rocks along the western margin of the basin (Fig. 1) was never studied in detail. However, since the last general assessment of the Central Basin area (the Carboniferous Drilling Project of Ball et al., 1981), which was mostly limited to the study of 122 m deep boreholes that only rarely intercept pre-Pennsylvanian strata, the results from a seismic land survey were published (Steeves and Kingston, 1981), deeper wells were drilled by Atlantic Orebodies Inc. with 100% rock core recovery in key areas of the basin, and detailed mapping of Bouguer gravity anomalies was performed (Hassan, 1999).

Stratigraphic, palynological, geophysical, provenance, paleocurrent and sedimentary facies studies are here combined to better constrain the architecture of the Central Basin of New Brunswick, and to reconstruct the paleogeography of its Mississippian units, which are shown to be constrained to the Viséan. Comparisons are made with Viséan units of the contemporaneous Ristigouche Basin of eastern Quebec and northern New Brunswick, which was recently investigated (Jutras et al., 1999, 2001, 2005; Jutras and Prichonnet, 2002, 2004, 2005). It is shown that the Mississippian Central Basin is separated from the Mississippian Ristigouche Basin by a fault-bounded source area, and that the two basins are characterized by a similar Viséan stratigraphy, apart from the presence of volcanics in the Central Basin alone (Fig. 2). It is also shown that the Central and Ristigouche basins experienced a similar tectonic history during the Viséan interval. Finally, the pre- and syn-burial deformation of Viséan units in the Central Basin is assessed and tentatively correlated with post-Viséan structural data from the Ristigouche Basin area. As a result of this study, geological extrapolations and tentative predictions for the Viséan interval can be made into a large area of the western part of the Gulf of Saint Lawrence, which has not been drilled to date.

Methodology

The recently revised post-Acadian stratigraphy of the circum-Chaleur Bay area of eastern Quebec and northern New Brunswick (Jutras et al., 1999, 2001, 2005; Jutras and Prichonnet, 2002, 2004, 2005) was extended into the study area of central New Brunswick, starting with the nearest outcrops. Correlations are based on the petrographic criteria and stratigraphic constraints outlined in the next section. Basin analysis was done by combining newly acquired field and well data with seismic data from the New Brunswick Department of Natural Resources and Energy (Kingston and Steeves, 1979; Steeves and Kingston, 1981), and aeromagnetic (200 m grid) and gravity (2 km grid) data from the Geological Survey of Canada (Canadian Geodetic Information System, 2006a, b), plotted with Generic Mapping Tools (Wessel and Smith, 1991). Provenance is determined from the petrology of gravels combined with paleocurrent measurements. Two types of paleocurrent data are presented on Figure 3: clast imbrications (grey rose diagram) and trough channel orientations (white rose diagrams).

Carbon isotope data (δC^{13} VPDB) is used as a correlation criteria for phreatic calcrete hardpan occurrences (base of the Viséan La Coulée Formation). The samples were measured by dual inlet mass spectrometry at the GEOTOP (Université du Québec à Montréal) using a GV instruments Multicarb preparation system connected to an Isoprime Dual Inlet mass spectrometer. John Utting identified and interpreted spores from core and borehole samples, and also interpreted spore data from previous workers (Barss and Hamilton in Ball et al., 1981; G. Dolby, unpublished report, 1999) based on comparisons with studies from Great Britain, western Europe and the North Sea (e.g. Smith and Butterworth, 1967; Clayton et al., 1978; MacLean et al., 2005).

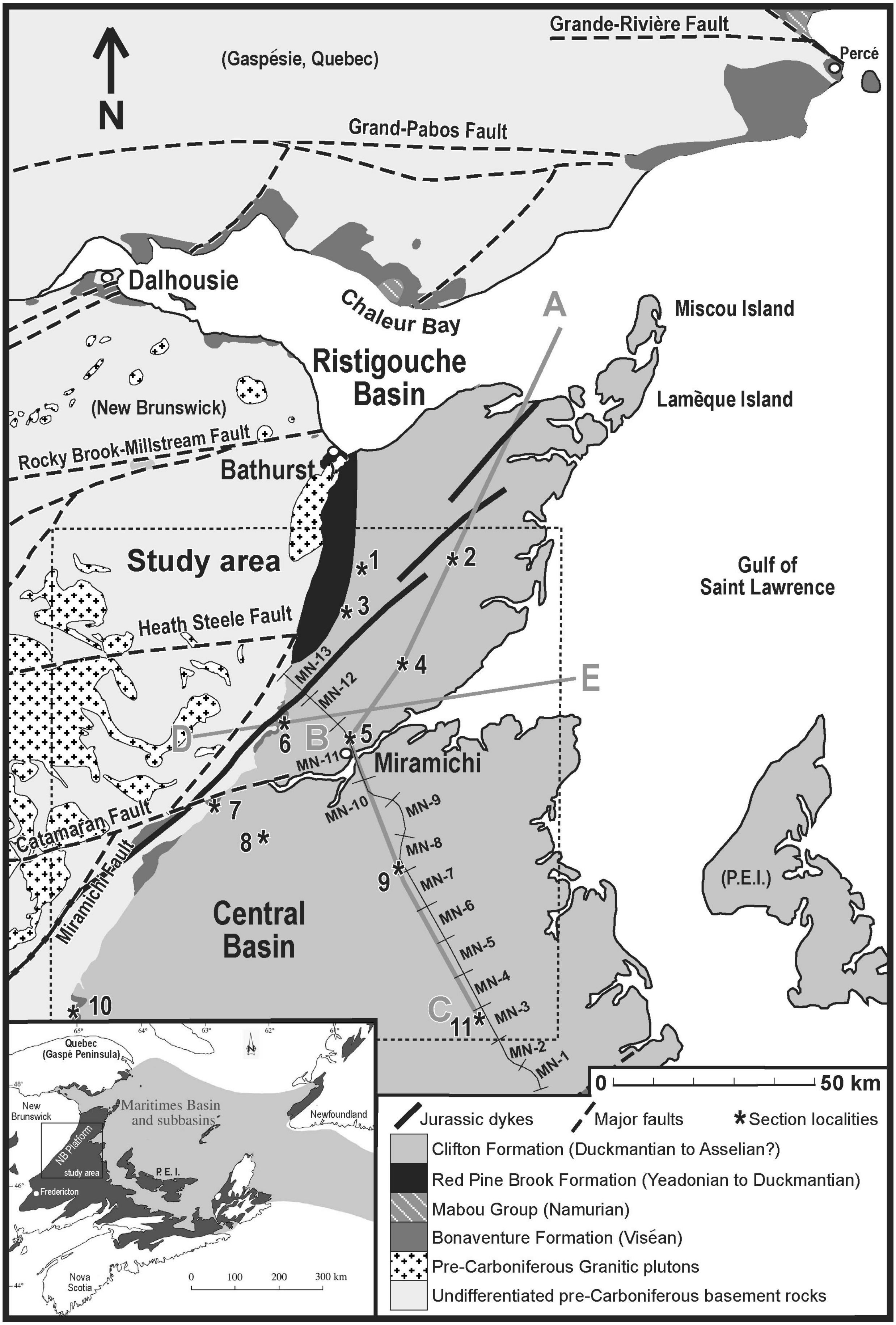
Stratigraphic Framework and Correlation Criteria in Central New Brunswick

The following Carboniferous units are recognized in central New Brunswick (Fig. 2):

La Coulée Calcrete

The La Coulée Formation was introduced by Jutras et al. (1999) for a grey alluvial fan unit affected by phreatic calcretization at the base of the Carboniferous succession in eastern Gaspésie. It

Fig. 1 (opposite). Simplified post-Acadian (post-Middle Devonian) geology of the study area and surrounding areas (modified from the New Brunswick Department of Natural Resources and Energy, 2000), with the eleven section localities described on Figure 4, the seismic transect MN-1–13 (related cross-sections are shown on figures 8 and 11), and the transects A–B–C and D–E (related cross-sections are shown on Figure 11). Inset: location of the study area within southeastern Canada (dark grey: onshore extent of upper Paleozoic rocks; light grey: offshore extent of upper Paleozoic rocks) (Modified from Gibling et al., 1992).


Grande-Rivière Fault
(Gaspésie, Quebec)
Percé
N
Grand-Pabos Fault
Dalhousie
Chaleur Bay
A
Miscou Island
Ristigouche
Basin
Lamèque Island
(New Brunswick)
Rocky Brook-Millstream Fault
Bathurst
Study area
1
2
Gulf of
Saint Lawrence
3
Heath Steele Fault
4
E
MN-13
MN-12
D
6
B
5
MN-11
Miramichi
Catamaran Fault
7
MN-10
MN-9
8
MN-8
9
MN-7
(P.E.I.)
Miramichi Fault
MN-6
Central
Basin
MN-5
MN-4
10
C
11
MN-3
MN-2
MN-1
0
50 km
Quebec
(Gaspé Peninsula)
New
Brunswick
Maritimes Basin
and subbasins
Newfoundland
NB Platform
study area
P.E.I.
Fredericton
Nova
Scotia
0
100
200
300 km
Jurassic dykes
Major faults
Section localities
Clifton Formation (Duckmantian to Asselian?)
Red Pine Brook Formation (Yeadonian to Duckmantian)
Mabou Group (Namurian)
Bonaventure Formation (Viséan)
Pre-Carboniferous Granitic plutons
Undifferentiated pre-Carboniferous basement rocks

lies unconformably below the Bonaventure Formation red-beds of Logan (1846) throughout the Ristigouche Basin (Fig. 2). Jutras and Prichonnet (2005) formally referred to this diagenetic unit as the “La Coulée Calcrete”, basal member of the La Coulée Formation, which itself forms the base of the new Percé Group (Viséan). This group also includes the Poodiac Formation (Anderle et al., 1979) and the Bonaventure Formation (Fig. 2). The Cap d’Espoir Formation of Jutras and Prichonnet (2005) was recently correlated to the Poodiac Formation and abandoned on the basis of precedence (Jutras et al., 2007).

The phreatic calcrete hardpans were recently shown to be genetically linked to Arundian to Holkerian (?) evaporites of the Lower Windsor Group (Jutras et al., 2007) (Fig. 2). They are differentiated from marine limestone by: (1) an absence of fossils; (2) a lack of bedding planes; (3) a massive or autobrecciated structure; and (4) negative carbon isotope ratios (δC^{13} VPDB), mostly lower than –2 (Jutras et al., 1999). It is differentiated from pedogenic calcretes by: (1) its stratigraphic position, lying directly on fresh basement rocks as opposed to within a soil profile; (2) its thickness, which can exceed 3 m; (3) the paucity of iron oxides, due to its position below the water table at the time of formation; and (4) its *beta* fabric (*sensu* Wright and Tucker, 1991), which is characterized by a lack of root influence.

Bonaventure Formation

The Viséan Bonaventure Formation of Logan (1846) is a red-bed unit that interdigitates at the base with Asbian limestone of the Lime-Kiln Brook Formation in southern New Brunswick (Jutras et al., 2007), and which is conformably to disconformably overlain by early Namurian (Pendleian) grey clastic rocks of the Mabou Group in eastern Quebec (Jutras et al., 2001) (Fig. 2). Intrabasinal erosion separated the La Coulée and Bonaventure formations. As a result, the latter rests on the products of this erosion (the Poodiac Formation) in basin centres, but unconformably on older rocks at basin margins (Jutras et al., 1999, 2001, 2005, 2007; Jutras and Prichonnet, 2002, 2004, 2005). Because of a faulting event that separated the Poodiac and Bonaventure formations, the contact between these two units may also be unconformable (Jutras and Prichonnet, 2005).

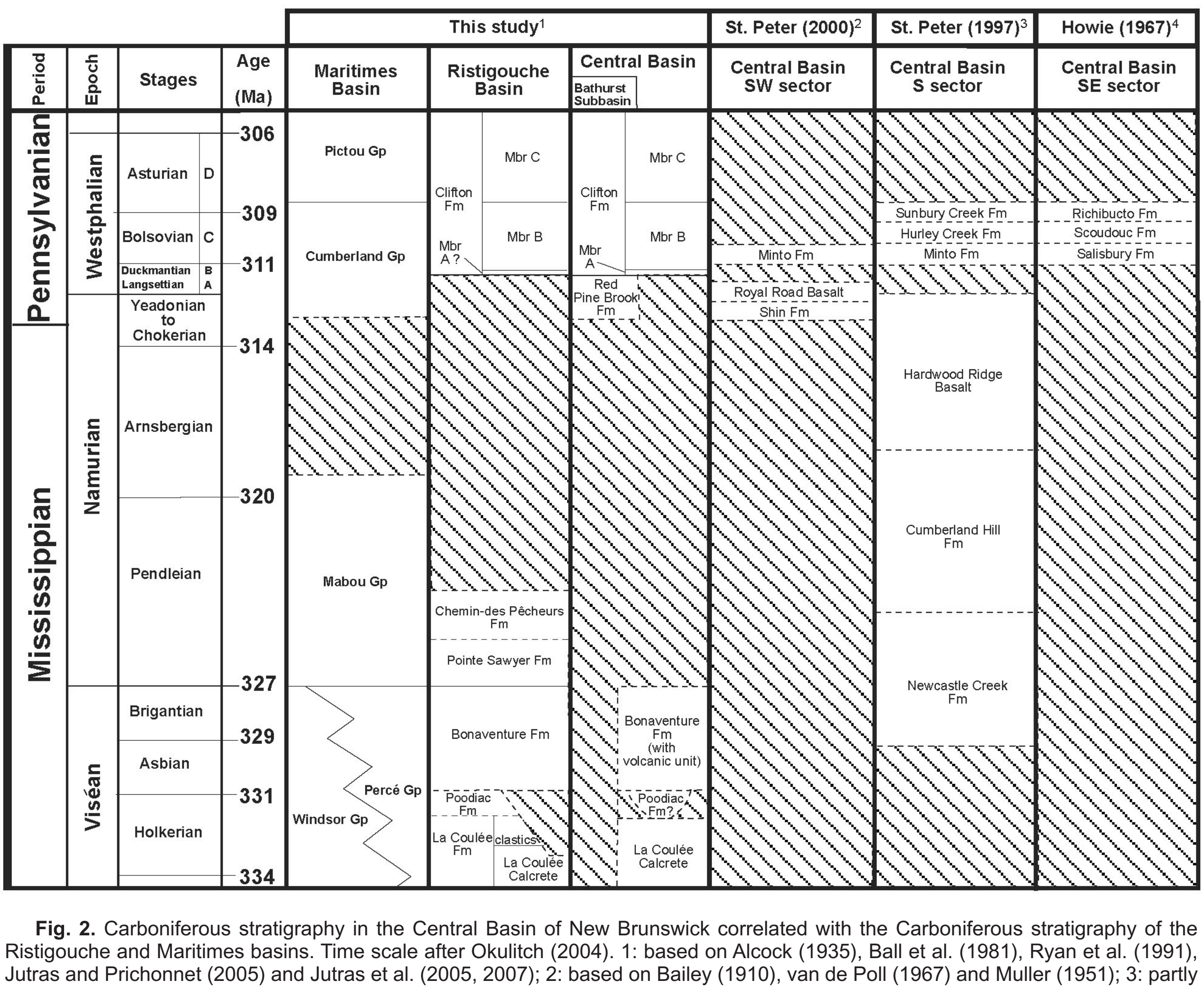


Fig. 2. Carboniferous stratigraphy in the Central Basin of New Brunswick correlated with the Carboniferous stratigraphy of the Ristigouche and Maritimes basins. Time scale after Okulitch (2004). 1: based on Alcock (1935), Ball et al. (1981), Ryan et al. (1991), Jutras and Prichonnet (2005) and Jutras et al. (2005, 2007); 2: based on Bailey (1910), van de Poll (1967) and Muller (1951); 3: partly based on Muller (1951); 4: based on Gussow (1953).

Petrographically, the Bonaventure Formation includes red conglomerate, breccia, sandstone, mudstone and pedogenic calcrete. However, it is mainly defined by its gravel fraction, which is polymictic and which includes well-rounded quartz pebbles believed to be derived from afar and distributed amongst more locally derived sedimentary, igneous and metamorphic lithic clasts (Jutras et al., 1999, 2001, 2005; Jutras and Prichonnet 2002, 2004, 2005). This is in contrast with the Upper Devonian to lower Mississippian red oligomictic conglomerate of the Saint-Jules Formation of southern Gaspé, which is mostly free of quartz pebbles (Jutras and Prichonnet, 2002, 2004), and the lower Pennsylvanian red quartzose conglomerate of the Red Pine Brook Formation (formerly Bathurst Formation of Alcock, 1935), which is almost exclusively composed of quartz and chert pebbles (Jutras et al., 2005). The Bonaventure Formation is also characterized by dessication cracks, pedogenic calcretes and an apparent absence of carbonaceous plant remains, all of which imply arid conditions.

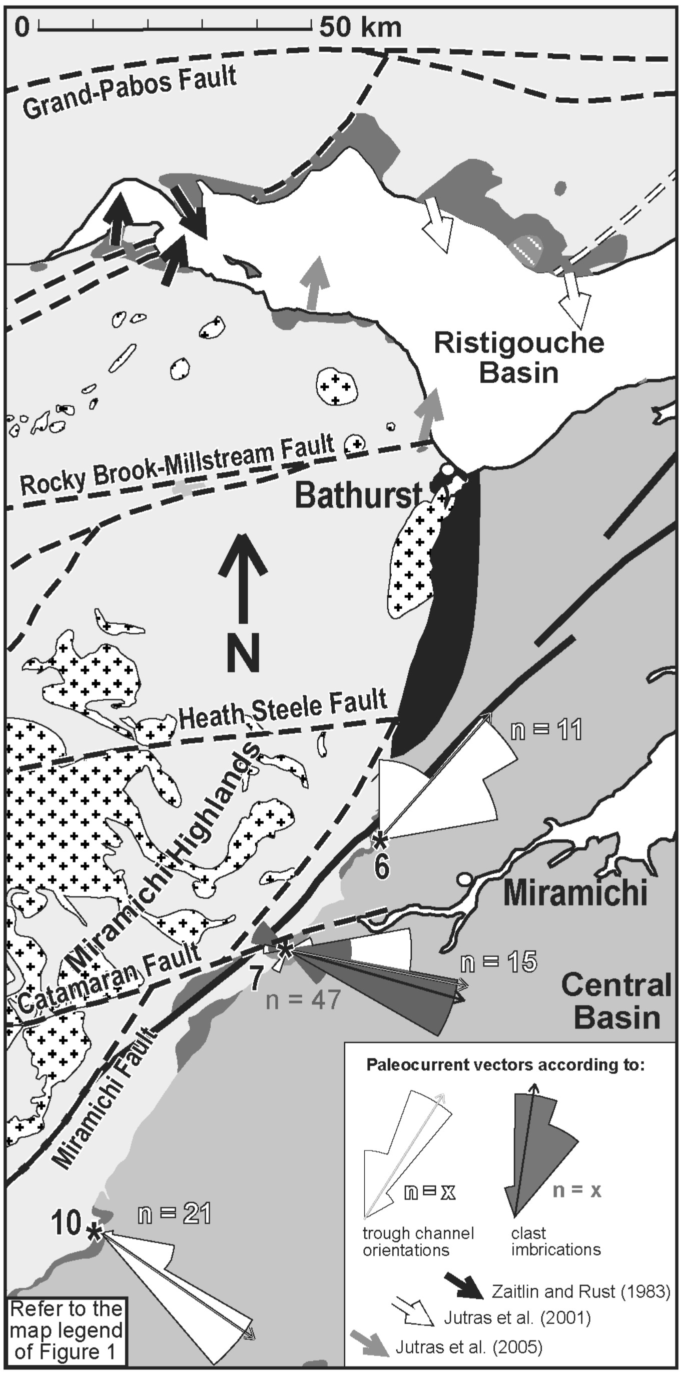


Fig. 3. Paleocurrent vectors based on trough channel orientations and clast imbrications in the Bonaventure Formation.

Based on similar petrographic criteria, Alcock (1935) and Zaitlin and Rust (1983) correlated the Bonaventure Formation of eastern Quebec with post-Acadian (post-Middle Devonian orogeny) red-beds of northern New Brunswick, which form a discontinuous belt of rocks on the south shore of Chaleur Bay (Fig. 1), and which are unconformably above thin remnants of the La Coulée Calcrete or above pre-Carboniferous basement rocks (Jutras et al., 2005). Paleocurrent trends in the Bonaventure Formation are opposite on each side of Chaleur Bay (Zaitlin and Rust, 1983; Jutras et al., 2001, 2005) (Fig. 3), suggesting that the depocentre of the Ristigouche Basin is located somewhere under the bay. Finally, based on stratigraphic and petrographic equivalence, as well as precedence, Jutras et al. (2007) correlated the Shin (van de Poll, 1967), McKinley (Anderson and Poole, 1959), Gelder (van de Poll, 1967), Wanamaker (Anderle et al., 1979), Scoodic Brook (Anderle et al., 1979) and Hopewell Cape (Ami, 1902) formations of central and southern New Brunswick with the Bonaventure Formation of Logan (1846), and formally proposed their abandonment.

Volcanic Unit

A basaltic unit with red clastic and minor tuff intervals occurs throughout the Central Basin in association with red-beds that are stratigraphically and petrographically equivalent to the Bonaventure Formation (Jutras et al., 2007) (Fig. 2). Depending on the locality, this unit is referred to as the Royal Road Basalt (Bailey, 1910), the Hardwood Ridge Basalt (Muller, 1951), the Currie Mountain Basalt (McLeod and Johnson, 1998) or the Queenstown Basalt (MacKenzie, 1964). Although existing data strongly suggest that all these volcanic occurrences occupy the same stratigraphic interval, formal correlation is beyond the scope of this paper (research in progress), and the informal term "volcanic unit" is therefore used in the present paper. South of the study area, near the City of Fredericton (Fig. 1; inset), this interval of alternating red beds and mafic flows is 252 m thick (Ball et al., 1981).

Red Pine Brook Formation

The Red Pine Brook Formation, which was formerly referred to as the Bathurst Formation (Alcock, 1935), was recently renamed by Wilson (2006) to eliminate discrepancies in the regional stratigraphic nomenclature. The unit is characterized by red quartzose conglomerate, red sandstone and red mudrock with occasional carbonaceous partings and fragments of *Calamites* (Skinner, 1974; Ball et al., 1981; Jutras et al., 2005).

A Yeadonian (late Namurian) to Langsettian (Westphalian A) spore assemblage is found near the base of this unit (Jutras et al., 2005), but upper beds of this unit are characterized by a Duckmantian (Westphalian B) assemblage (this study) (Fig. 2).

According to Jutras et al. (2005), the Red Pine Brook Formation was sourced from the Ristigouche Basin to the north and was deposited in the southern source area of this basin, which is limited by the Rocky-Brook-Millstream Fault of northern New Brunswick (Fig. 1). This mature unit is therefore the product of a reworking of Mississippian clastic rocks during a basin inversion event that occurred at the Mississippian-Pennsylvanian boundary (Jutras et al., 2005).

Clifton Formation Member A[1]

Ball et al. (1981) revised the lower contact of the Clifton Formation of Alcock (1935) and placed it at the base of a discontinuous layer of undated grey quartzose conglomerate and quartz arenite that disconformably overlies red mudrock of the Red Pine Brook Formation. These authors also subdivided the Clifton Formation into three members and referred to this mature basal unit as Member A (Fig. 2). According to Jutras et al. (2005), the Clifton Formation was sourced from farther north than the Red Pine Brook Formation.

Clifton Formation Member B[1]

The Clifton Formation Member B of Ball et al. (1981) is a thick succession of grey sandstone, minor red sandstone, grey mudrock and red mudrock, which ranges from Duckmantian (Westphalian B) at its base to at least Bolsovian (Westphalian C) and perhaps Asturian (Westphalian D) near its top (Jutras et al., 2005) (Fig. 2). The Clifton Formation Member B forms a nearly continuous cover in the eastern part of northern and central New Brunswick, and forms the bulk of what is usually referred to as the New Brunswick Platform (van de Poll, 1995).

Regional Problems of Stratigraphic Assignment at the Group Level

There is presently a lack of consensus between the upper Paleozoic stratigraphic nomenclatures of the five Canadian provinces that include rocks of the Maritimes Basin. Viséan clastic rocks of eastern Quebec were recently assigned to the new Percé Group (Jutras and Prichonnet, 2005), although equivalent rocks are included within the Mabou Group in New Brunswick (New Brunswick Department of Natural Resources and Energy, 2000). However, the latter group is restricted to early Namurian units in its type-section of Nova Scotia and does not include rocks that are facies equivalent to these Viséan clastics (Belt, 1964). Moreover, the upper Namurian to lower Westphalian Red Pine Brook Formation is also assigned to the Mabou Group in New Brunswick (Wilson, 2006), although rocks of that facies and stratigraphic position are included within the Cumberland Group in Nova Scotia (Ryan et al., 1991). A possible equivalent of the Red Pine Brook Formation is the Little River Formation of the Cumberland Group in Nova Scotia (Calder et al., 2005), which bears a similar facies and occupies the same stratigraphic position. Finally, the Clifton Formation is assigned to the Pictou Group in New Brunswick (Wilson, 2006), although rocks that occupy the same stratigraphic position and that are facies equivalent to members A and B of this unit are assigned to the Cumberland Group in Nova Scotia (Ryan et al., 1991). Based on the lithostratigraphy of type-sections and recent studies on the Ristigouche Basin in Quebec and northern New Brunswick (Jutras et al., 1999, 2001, 2005; Jutras and Prichonnet, 2002, 2005), we are here correlating the Bonaventure Formation with the Percé Group, whereas the Red Pine Brook Formation and the Clifton Formation members A and B are correlated with the Cumberland Group (Fig. 2).

Sedimentology, Petrography and Stratigraphy of Carboniferous Sections in Central New Brunswick

Eleven Carboniferous sections from cores, boreholes or outcrops were studied in central New Brunswick (Fig. 4). To better visualize lateral correlations, a depth datum of 0 is fixed at the base of the Clifton Formation contact (i.e. the base of the New Brunswick Platform; Fig. 4).

Basement Rocks

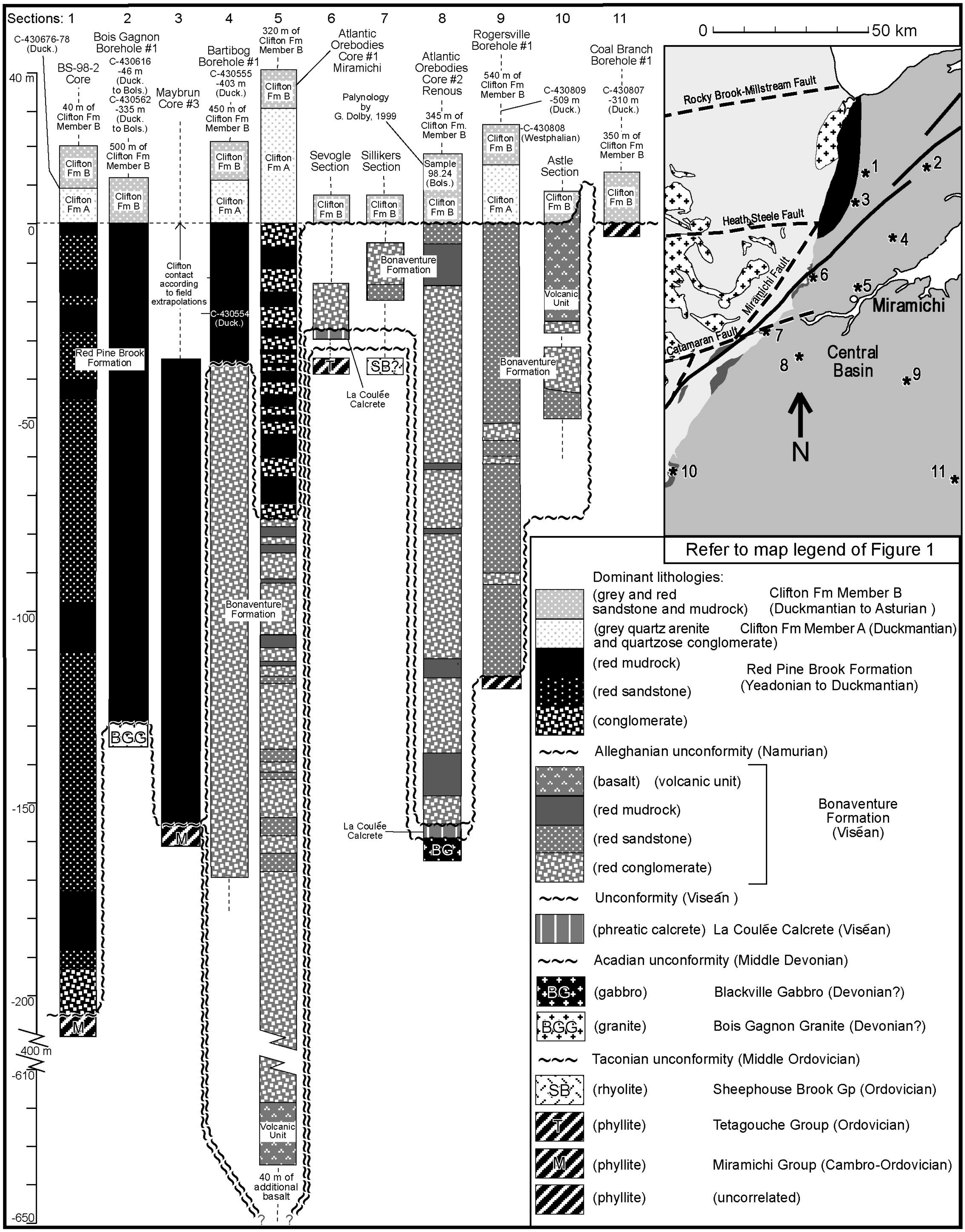
At most localities, basement rocks are characterized by Cambro-Ordovician phyllite, except at localities 1 and 8, where the Carboniferous succession rests on Devonian granite and gabbro, respectively, and possibly at locality 7, where the basement is not exposed but inferred to be Ordovician rhyolite based on the presence of rock fall boulders in Bonaventure Formation beds of that section (Fig. 4; see below).

La Coulée Calcrete

The La Coulée Calcrete was identified at the base of the Carboniferous succession on outcrop (Fig. 4, Section 6) and in the cores of one well (Fig. 4, Section 8). In Section 6, the phreatic calcrete was previously identified as Windsor Group

Fig. 4 (opposite). Stratigraphic sections of localities 1 to 11. Section 1 (BS-98-2 Well) is simplified from Jutras et al. (2005). Palynology is by J. Utting, except where indicated. Assessment numbers (A#) and Unique Identifier numbers (UI#) for the boreholes and cored wells are A# 475051 (Section 1), UI# 628 (Section 2), A# 471075 (Section 3), UI# 600 (Section 4), UI# 608 (Section 5), UI# 653 (Section 8), UI# 505 (Section 9), and UI# 472 (Section 11) at the New Brunswick Department of Natural Resources and Energy.

1 It should be noted that the study area is a transition zone in the stratigraphic nomenclatures between northern and southern New Brunswick, and that the Clifton Formation Member A of northern New Brunswick (Ball et al., 1981) is equivalent to the lower member of the Minto Formation (Muller, 1951) in southwestern areas of the New Brunswick Platform, whereas the Clifton Formation Member B is equivalent to the upper part of the Minto Formation, as well as to the Hurley Creek and Sunbury Creek formations of Muller (1951). In southeastern areas of the New Brunswick Platform, the Clifton Formation Member B is equivalent to the Salisbury, Scoudouc (abandoned and included within the Richibucto Formation by Carr, 1968) and Richibucto formations of Gussow (1953) (Fig. 2). Because the Pennsylvanian stratigraphic nomenclature of Alcock (1935) has precedence and was never formally abandoned, but rather revised by Ball et al. (1981), it is here applied to central New Brunswick (Fig. 2).


Sections: 1 2 3 4 5 6 7 8 9 10 11
C-430676-78 (Duck.)
BS-98-2 Core
40 m of Clifton Fm Member B
Bois Gagnon Borehole #1
C-430616 -46 m (Duck. to Bols.)
C-430562 -335 m (Duck. to Bols.)
500 m of Clifton Fm Member B
Maybrun Core #3
Clifton contact according to field extrapolations
Bartibog Borehole #1
C-430555 -403 m (Duck.)
450 m of Clifton Fm Member B
C-430554 (Duck.)
320 m of Clifton Fm Member B
Atlantic Orebodies Core #1 Miramichi
Sevogle Section
Sillikers Section
Palynology by G. Dolby, 1999
Atlantic Orebodies Core #2 Renous
345 m of Clifton Fm. Member B
Sample 98.24 (Bols.)
Rogersville Borehole #1
540 m of Clifton Fm Member B
C-430809 -509 m (Duck.)
C-430808 (Westphalian)
Astle Section
Coal Branch Borehole #1
C-430807 -310 m (Duck.)
350 m of Clifton Fm Member B
Clifton Fm B
Clifton Fm A
Red Pine Brook Formation
Bonaventure Formation
Volcanic Unit
La Coulée Calcrete
BGG
M
T
SB?
BG
40 m of additional basalt
40 m
0
-50
-100
-150
-200
400 m
-610
-650
0 50 km
Rocky Brook-Millstream Fault
Heath Steele Fault
Miramichi Fault
Catamaran Fault
Miramichi
Central Basin
N
1 2 3 4 5 6 7 8 9 10 11
Refer to map legend of Figure 1
Dominant lithologies:
(grey and red sandstone and mudrock) Clifton Fm Member B (Duckmantian to Asturian)
(grey quartz arenite and quartzose conglomerate) Clifton Fm Member A (Duckmantian)
(red mudrock)
(red sandstone)
(conglomerate)
Red Pine Brook Formation (Yeadonian to Duckmantian)
Alleghanian unconformity (Namurian)
(basalt) (volcanic unit)
(red mudrock)
(red sandstone)
(red conglomerate)
Bonaventure Formation (Viséan)
Unconformity (Viseán)
(phreatic calcrete) La Coulée Calcrete (Viséan)
Acadian unconformity (Middle Devonian)
(gabbro) Blackville Gabbro (Devonian?)
(granite) Bois Gagnon Granite (Devonian?)
Taconian unconformity (Middle Ordovician)
(rhyolite) Sheephouse Brook Gp (Ordovician)
(phyllite) Tetagouche Group (Ordovician)
(phyllite) Miramichi Group (Cambro-Ordovician)
(phyllite) (uncorrelated)

marine limestone (Howie and Barss, 1975). However, it lacks fossils or bedding and bears carbon isotope values that are too low (average δC^{13} VPDB = –2.98; n=3) for marine carbonates, but that correspond well with previous values obtained from the La Coulée Calcrete throughout New Brunswick and eastern Quebec (Jutras et al., 2007). In addition, the carbonate is characterized by massive micrite with irregular streaks of younger generations of calcite, similar to many other occurrences of the La Coulée Calcrete (Jutras et al., 1999, 2001, 2007; Jutras and Prichonnet, 2002).

In the cores of Section 8, a 3.25 m thick remnant of massive phreatic calcrete hardpan (average δC^{13} VPDB = –4.76) sits on gabbroic basement rocks. It contains floating angular clasts of the gabbro, suggesting that it was developed within a regolith. Beneath the contact with overlying red-beds, the phreatic calcrete hardpan is weathered and marked by red karst infills.

Bonaventure Formation

In sections 6 and 8, the La Coulée Calcrete is unconformably overlain by red polymictic conglomerate of the Bonaventure Formation (Figs. 4 and 5). In Section 9, the Bonaventure Formation sits directly on basement rocks, with no intervening phreatic calcrete hardpan, and the Bonaventure Formation is itself absent between basement and Pennsylvanian rocks in sections 1, 2, 3 and 11 (Fig. 4). Sections 4, 5, 7 and 10 include Bonaventure Formation beds, but do not reach the basement.

Bonaventure Formation occurrences in the study area were previously mapped as the Bathurst Formation at locality 6 by Davies (1977), as unnamed Mississippian red beds at locality 7 by Fyffe (1984), as the Shin Formation at locality 10 by St. Peter (2000), and as Mabou Group rocks in localities 4–10 by the New Brunswick Department of Natural Resources and Energy (2000).

Petrography

The Bonaventure Formation is dominated by granular to cobble conglomerate at all sections except in Section 9, which is dominated by red sandstone and mudstone at this stratigraphic level (Fig. 4). On outcrop, the conglomerates are trough cross-stratified and are occasionally cut by sandstone channels. Oversized boulders floating in a granular to pebbly matrix were observed in the three outcrop sections (Sections 6, 7 and 10) and in the cores of Section 5. They are interpreted as rock fall boulders that were probably scavenged from a closer source than the much finer grained sediment that forms the rest of the deposit. The boulders consist of phreatic calcrete hardpan at Section 6, rhyolite at Section 7 (Fig. 6), and basalt at sections 5 and 10.

Like in the Ristigouche Basin, the Bonaventure Formation in the Central Basin is characterized by an abundance of eodiagenetic overprints in the form of calcrete nodules and localized green reduction, especially in the sandy to muddy intervals, and the conglomerates are polymictic and immature in composition, with quartz vein fragments constituting 10–50% of the gravels. Clast composition, other than quartz, varies from one locality to the next, but typically includes a variety of fine-grained sedimentary and metasedimentary rock clasts (mainly grey phyllite), as well as mafic and felsic volcanics. Granite clasts are absent in the lower few tens of metres, but become increasingly abundant up-section.

Volcanic Unit

Basalt is not observed in any of the sections that reach the base of the Bonaventure Formation, and its precise position within this unit is therefore unknown. If the basaltic interval was originally present in the entire Central Basin at the same stratigraphic level, prior to post-Viséan deformation and erosion, it is preceded by at least 155 m of red-beds based on Section 8 (Fig. 4).

In Section 10, a 10 m gap separates the Bonaventure red-bed succession from at least 25 m of overlying basalt, which St. Peter (2000) tentatively correlated with the Royal Road Basalt of the Fredericton area (Fig. 1; inset). However, a concordant contact between the base of the basalt and 3 m of underlying conglomerate can be observed in a section nearby. The volcanic unit is unconformably overlain by grey sandstone of the Clifton Formation Member B. The contact with the underlying basalt is highly irregular and the grey sandstone wraps around an erosional pinnacle of basalt that was at least 25 m in height. As a result, the remnant thickness of the basalt varies between 25 and 50 m in the Astle area.

In Section 5, below 543 m of Bonaventure Formation red-beds, the well terminates in 55 m of weathered, vesicular basalt (Fig. 4). Previous core loggers have expressed uncertainty concerning the basalt unit at the base of this well as to whether it consists of pre-Carboniferous basement rocks or Carboniferous flows (Baldwin, 1985). The latter conclusion is here favored for the following reasons: (1) a thick basaltic interval occurs in the Viséan red-bed succession of the Central Basin in the study area (Fig. 4, Section 10) and farther south, near Fredericton (Ball et al., 1981); (2) the vesicular basalt is texturally similar to that of Section 10; (3) the basalt does not show either cleavage or metamorphic minerals; (4) red-beds near the contact with the basalt include granite clasts (Fig. 7), whereas basal Bonaventure Formation conglomerates elsewhere are devoid of such clasts, which only start appearing quite high in the succession (Jutras et al., 2005; this study). It is therefore concluded that the base of the Bonaventure Formation is not intercepted by this well, which only reaches the uppermost part of the volcanic interval.

Paleocurrents and Provenance

Based on trough channel orientation in sandstone and conglomerate, the Bonaventure Formation was sourced from the southwest at Section 6, from the WNW in Section 7 (with concurring data from clast imbrications), and from the NW at Section 10 (Fig. 3).

Red Pine Brook Formation

Mature red-beds of the Red Pine Brook Formation are only identified in sections located between the Catamaran and Rocky Brook-Millstream faults, in sections 1–5, if these faults are extrapolated beneath the New Brunswick Platform (Fig. 4).

The succession fines away from these two faults, as only sections 1 and 5 include conglomerate.

Section 1, which was logged by Jutras et al. (2005), intersects 205 m of Red Pine Brook Formation red-beds above Ordovician phyllite. At this locality, the Red Pine Brook Formation is dominated by red sandstone but includes several quartzose conglomerate and mudrock intervals. The Bois Gagnon borehole #1 of Section 2 reportedly reached granitic basement rocks below the Carboniferous succession (unpublished well log by C. St. Peter of the NBDNRE, 1999). Unfortunately, cuttings of the granitic basement are now missing, but the presence of a buried granite (the Bois Gagnon Granite) is consistent with the strong negative Bouguer gravity anomaly that characterizes the area (Hassan, 1999).

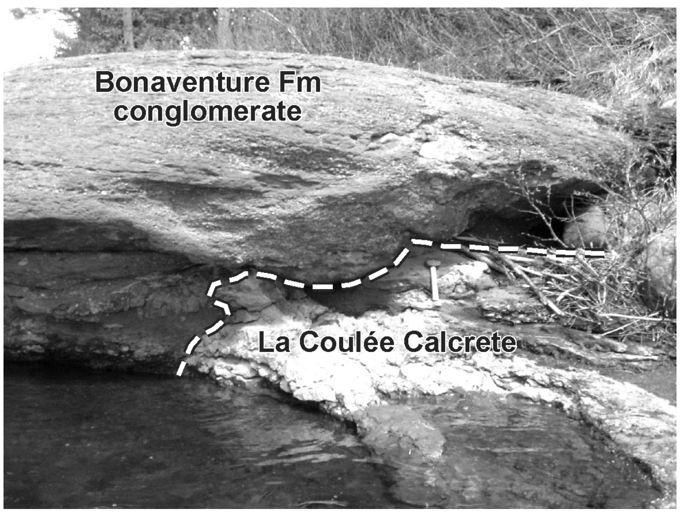


Fig. 5. Unconformable contact between the La Coulée Calcrete and the Bonaventure Formation along the Sevogle River of central New Brunswick (Fig. 4, Section 6). 30 cm hammer for scale.

Fig. 6. Rock fall boulders of Ordovician rhyolite in fluvial conglomerates of the Bonaventure Formation near Sillikers (Fig. 4, Section 7). 30 cm hammer for scale.

In his well log, St. Peter interpreted the entire succession above basement as belonging to the Clifton Formation in the Bois Gagnon borehole #1 of locality 2. However, red mudstone cuttings dominate in the basal 129 m, and this interval is correlated instead with the Red Pine Brook Formation based on extrapolations from the more reliable core data that were obtained from nearby wells at localities 1 and 3 (Fig. 4).

Cores from the Maybrun Well at locality 3 (Maybrun Mines Limited, 1954) are no longer available, but the original logs show red shale of the Red Pine Brook Formation (then called Bathurst Formation) from 104 m to a depth of 218 m, where it rests on Cambro-Ordovician phyllite. No cores were recovered above 104 m, but based on mapping (New Brunswick Department of Natural Resources and Energy, 2000), the uppermost core sample of red shale is extrapolated to occur about 155 m below the base of the Clifton Formation.

Between red polymictic conglomerate of the Bonaventure Formation and grey sandstone of the Clifton Formation Member A, a 37 m interval of Red Pine Brook Formation red shale was identified in the Bartibog #1 borehole of Section 4 (Fig. 4). Although Bonaventure and Red Pine Brook mudrock cannot be easily distinguished in rock cuttings, the presence of this interval is confirmed by palynological data (see next section).

A 76 m interval of Red Pine Brook Formation beds was identified between the Bonaventure and Clifton formations in cores of Section 5, where it is characterized by red quartzose

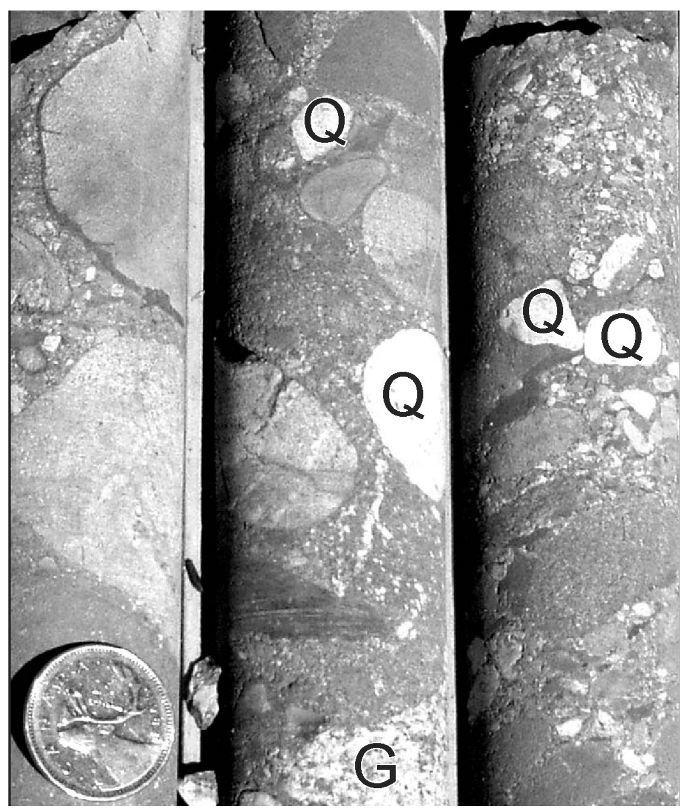


Fig. 7. Polymictic pebble conglomerate of the Bonaventure Formation near the contact with underlying basalt in the Atlantic Orebodies #1 Well near Miramichi (Fig. 4, Section 5). Q: quartz pebble; G: granite pebble.

conglomerates (granular and pebbly) and red mudrock, with minor grey shale (Fig. 4). A 10 cm thick lag of loose quartz pebbles is found at the paraconformable contact between the Bonaventure and Red Pine Brook formations. Whereas the Red Pine Brook Formation includes pervasive kaolinization in many intervals, such eodiagenetic features are absent in the Bonaventure Formation, which was deposited in a more arid environment. Moreover, the latter includes occasional reduction bands or haloes, as well as many horizons of pedogenic calcrete, both uncommon features in the overlying unit.

Palynology

A spore assemblage that is diagnostic of the Yeadonian (late Namurian) to Langsettian (Westphalian A) time period was retrieved from basal beds of the Red Pine Brook Formation near the City of Bathurst (Jutras et al., 2005), and productive samples were obtained in the present study 13 m below the basal Clifton contact in the Red Pine Brook Formation (GSC locality C-430554; –485 m) in Section 4 (Fig. 4), and 69 m above the contact in Member B (GSC locality C-430555; –403 m). In the Red Pine Brook Formation (C-430554), well preserved miospores include *Crassispora kosankei, Endosporites globiformis, Lycospora pellucida* (abundant), *Lycospora pusilla* (common to abundant), *Latosporites* sp., *Schopfipollenites ellipsoides, Florinites mediapudens, Florinites pumicosus, Florinites* spp. and *Potonieisporites elegans.* Sample C-430555, from the overlying Clifton Formation, contains a similar assemblage, including the stratigraphically diagnostic *Endosporites globiformis.* In the North Sea, this taxon has its earliest occurrence in the late Langsettian (MacLean et al., 2005). Thus, an age no older than late Langsettian or possibly younger (Duckmantian?) is proposed for both samples. This implies that no significant time gap separates the Red Pine Brook and Clifton formations, although the contact between the two units is in places disconformable (Jutras et al., 2005).

Clifton Formation

Like in northern New Brunswick (Ball et al., 1981; Jutras et al., 2005), coarse quartz arenite of the Clifton Formation Member A is laterally discontinuous in central New Brunswick, where 9 to 31 m of this unit are observed in sections 1, 4, 5 and 9 (Fig. 4). The overlying Member B, which is dominated by grey sandstone, forms the most ubiquitous unit in central New Brunswick.

Geophysical Study of Central New Brunswick

Seismic Reflection Data

A seismic survey was performed across the New Brunswick Platform by Geoterrex Ltd. for the New Brunswick Department of Natural Resources and Energy in 1978 using the Mini-Sosie method of Serres and Wiles (1978) (Transect MN-1-13 on Figure 1). The results were compiled by Kingston and Steeves (1979) and Steeves and Kingston (1981), who derived depth estimates for the top of the pre-Carboniferous basement and delineated a number of faults offsetting this contact, but the lack of marked contrasts in acoustic impedance within Carboniferous rocks prevented definition of the internal architecture of the basin fill successions. Most of the faults are interpreted by Kingston and Steeves (1979) to have a reverse component (e.g. Fig. 8 sections MN-5 and -7).

After a gradual deepening from 300 m to 900 m between the south end of MN-1 and the north end of MN-10 (Transect shown on Figure 1), the basement contact rapidly deepens to 1700 m in the middle of MN-11, at the southern limit of the City of Miramichi (Kingston and Steeves, 1979; Fig. 8). A 5 km long gap in seismic data coincides with the Miramichi River and the City of Miramichi. North of this short gap, however, the contact lies at 800 m and dips to the south (Kingston and Steeves, 1979). According to these authors, the attitude of Pennsylvanian reflectors as the line approaches this gap suggests that this area is characterized by a narrow trough or syncline (the Miramichi Trough), which pre-dates the Pennsylvanian strata. The southward-dipping basement contact gradually shallows to zero between MN-11 and the end of MN-13, near the town of Sevogle (Kingston and Steeves, 1979; Steeves and Kingston, 1981).

Aeromagnetic Data

Aeromagnetic data for the New Brunswick area were initially acquired by the Geological Survey of Canada (GSC) in 1958, and interpreted by Allan Spector and Associates Limited (1980) who recognized (but did not map) a suite of NE- to ENE-trending faults beneath the New Brunswick Platform. These and additional data are now compiled into a 200 m spacing grid housed at the Geoscience Data Repository of the GSC (Canadian Geodetic Information System, 2006a), along with the means to visualize them with the Generic Mapping Tools of Wessel and Smith (1991). Figure 9 displays (A) the first vertical derivative of the residual total magnetic field for the study area, and (B) our interpretation of the main post-orogenic brittle faults, which contrast with older structures by their more consistent linearity. Because these minor brittle faults are unlikely to have developed a strong magnetic susceptibility, their identification is based on the linear truncation of magnetic anomalies, such as those created by plutonic rocks.

Minor faults crossing Transect A–B–C (Fig. 1) are labeled from 1 to 14 (Fig. 9B). The Rocky Brook-Millstream, Heath Steele (new name) and Catamaran faults are larger structures that were mapped in basement rocks of the Miramichi Highlands (New Brunswick Department of Natural Resources and Energy, 2000) and that we are projecting into the Carboniferous basin, again based on the linear truncation of magnetic anomalies. Although the interpretation becomes increasingly difficult towards the east, as the Carboniferous cover thickens rapidly in that direction, the seismic transect MN-1 to MN-13 provides the means to test our magnetic interpretation this far to the east (Fig. 1). Of the faults that are traced from aeromagnetic data and that cut the seismic transect, only fault #1 shows no seismic signature in the interpreted section of Kingston and Steeves (1979). The aeromagnetic data therefore indicate that faults offsetting the basement contact in seismic section MN-1 to MN-13 dominantly strike NE to ENE (Fig. 9B). The southern extension of some of these faults is best observed in the higher resolution magnetic surveys that were recently performed in the Fredericton area (e.g. Kiss et al., 2004).

As a general trend, magnetic signatures are more diffused in areas that are covered by a thick cover of Carboniferous rocks than in areas where basement rocks are exposed (in reference to mapping data on Figure 1), suggesting that they are mainly controlled by the latter rocks. Within the New Brunswick Platform, the magnetic signatures are sharper between the Rocky Brook-Millstream and Heath Steele faults, suggesting a thinner cover in this area. This conclusion is supported by drill hole data, which indicate that Viséan rocks are absent in that area, whereas the thickness of Pennsylvanian strata is relatively constant along a north-south vector (Fig. 4). Finally, Jurassic mafic dykes form distinct traces on the first vertical derivative image (Fig. 9B) and suggest a wider extent than suggested by recent maps (New Brunswick Department of Natural Resources and Energy, 2000).

Gravity Data

Gravity data for New Brunswick (Fig. 10A), archived at the Geoscience Data Repository of the GSC (Canadian Geodetic Information System, 2006b) and first compiled by Hassan (1999), are superimposed on the aeromagnetic data in Figure 10B to compare the two datasets. Most post-Acadian structures have both a magnetic and a gravity signature.

Sharp negative Bouguer anomalies west of the New Brunswick Platform correspond to granitic plutons (e.g. the Antinouri Lake and Pabineau Falls granites; Fig. 10B, localities AG and PFG). Similar anomalies which occur below the Carboniferous cover are also interpreted as granitic plutons (Fig. 10B), as for example the anomaly that coincides with granite basement in the borehole at locality 1 (here referred to as the Bois Gagnon Granite) (Fig. 4, Section 1; Fig. 10B, locality BGG).

Strong positive Bouguer gravity anomalies west of the New Brunswick Platform correspond to Ordovician and Silurian mafic rocks (Fig. 10B, localities OB and SB). Similar anomalies occur beneath the Carboniferous cover and are also interpreted as corresponding to mafic rocks in the basement. In support of this conclusion, the Blackville Gabbro was intersected in the Atlantic Orebodies #2 Well in one of these areas of strong positive anomaly (Fig. 10B, locality BG; Fig. 4, Section 8). Basalt was also encountered beneath the Carboniferous cover in a drill hole near the village of Canobie (Fig. 10B, locality CAN; well drilled by Jonpol Explorations in 1985, with cores no longer available), where it coincides with a similar anomaly.

A complex cluster of relatively sharp Bouguer gravity anomalies (Fig. 10A) occurs between the Rocky Brook-Millstream and Heath Steele faults (Fig. 10B). The sharpness of the anomalies suggests that thickness of the Carboniferous cover is greatly reduced in that area, in concurrence with aeromagnetic (Fig. 9) and drill hole data (Fig. 4).

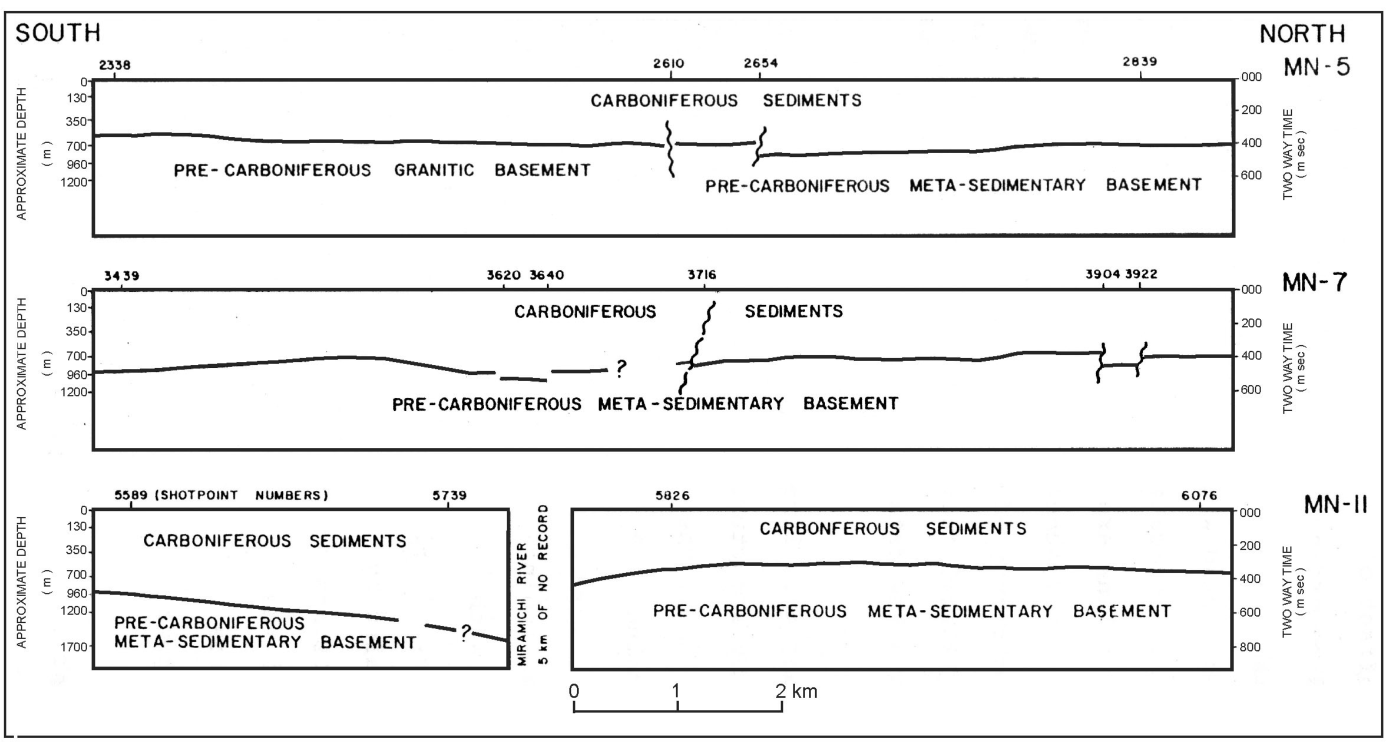


Fig. 8. Excerpts from seismic transect MN-1–13 (location shown on Figure 1). Modified from Kingston and Steeves (1979).

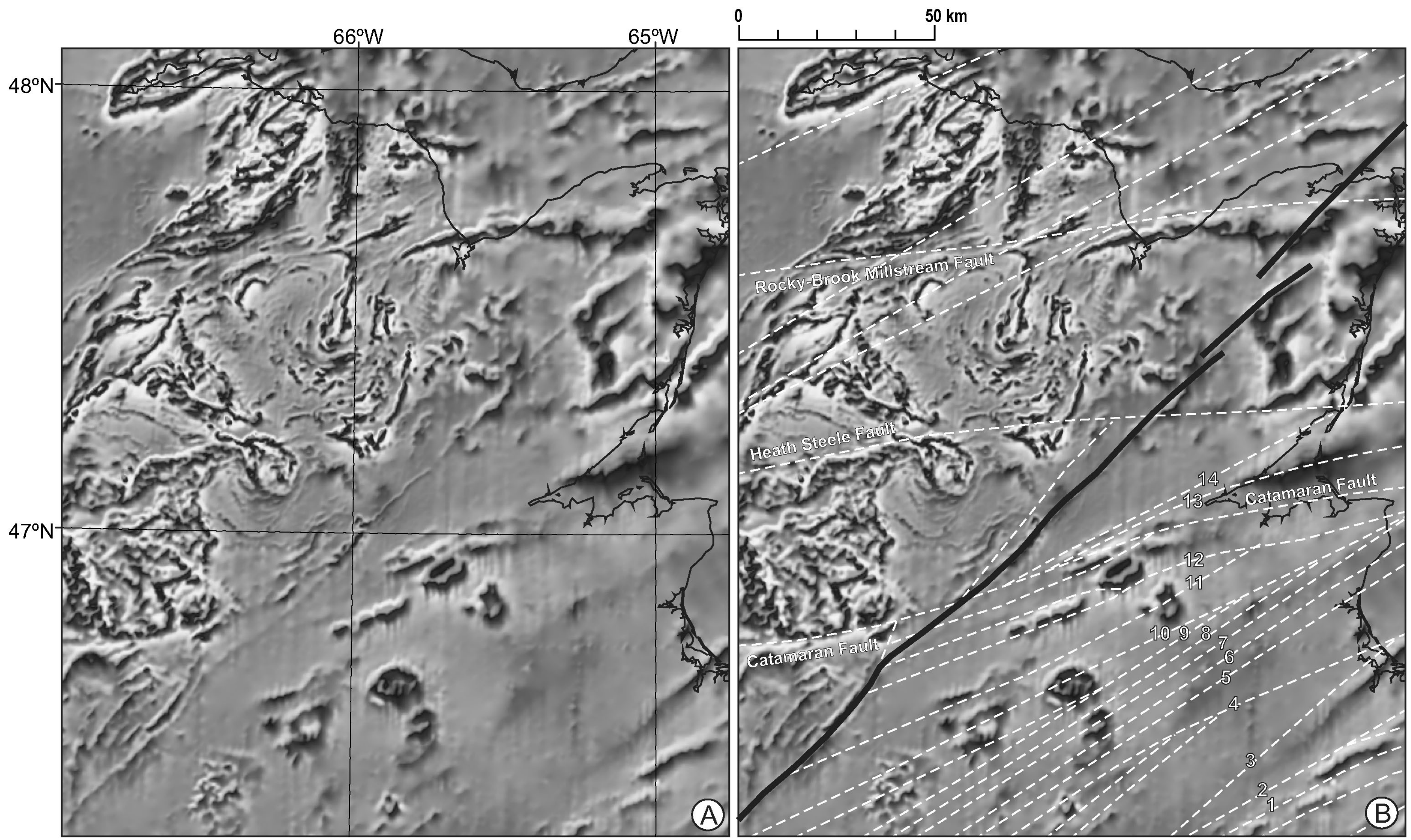


Fig. 9. A) First vertical derivative aeromagnetic data (200 m grid) for northern New Brunswick mapped as shaded relief, with illumination from the northwest (azimuth: 315º) (extracted from the Canadian Geodetic Information System, 2006a, of the Geological Survey of Canada website at http//gdr.nrcan.gc.ca). B) Delineation of the main post-Acadian structures (dotted lines) based on the truncation of magnetic anomalies. The mapping of Jurassic dykes (full lines) is based on linear magnetic anomalies cross-cutting older anomalies.

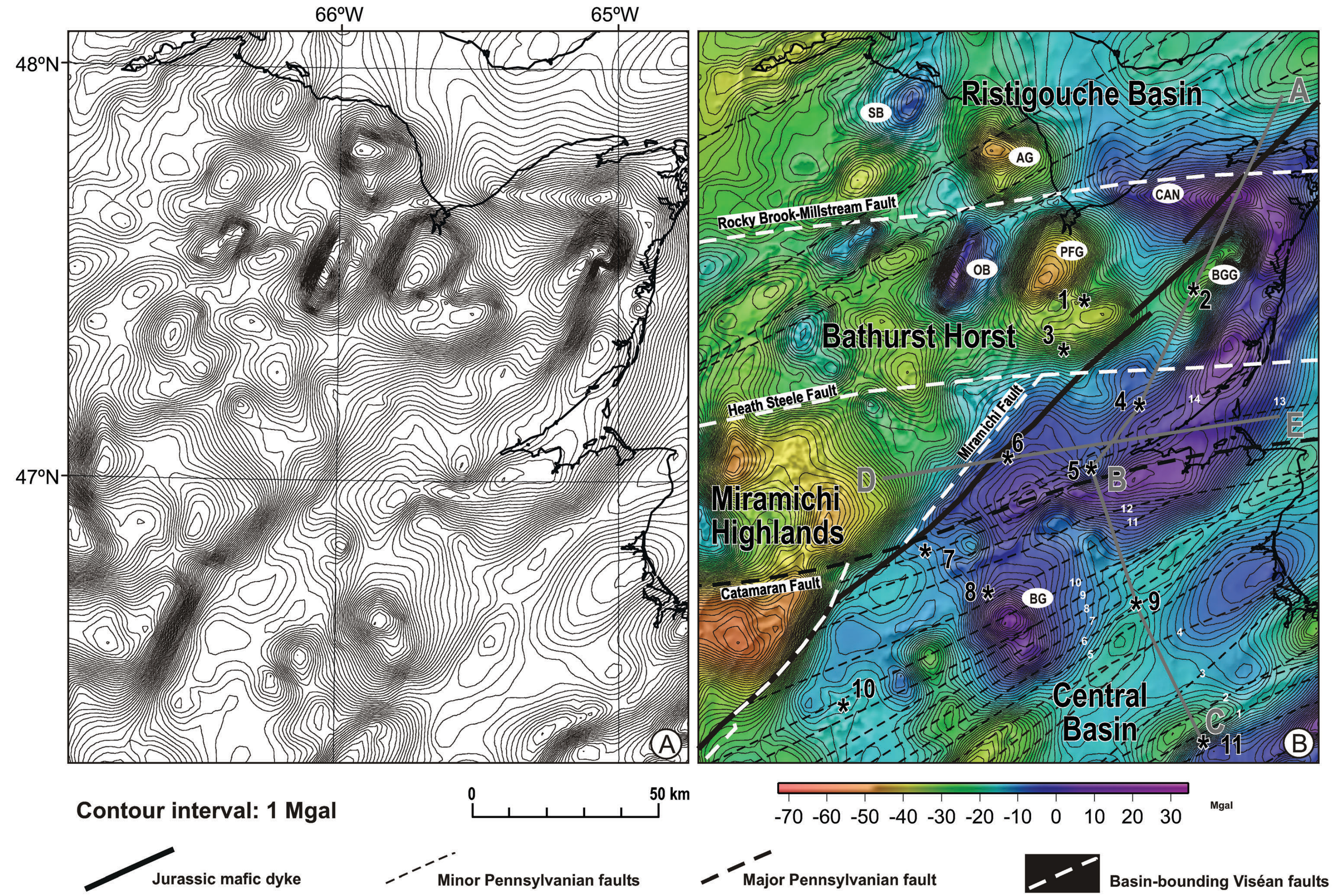


Fig. 10. A) Bouguer gravity map of New Brunswick (2 km grid; contour interval=1 mgal; extracted from the Canadian Geodetic Information System, 2006b, of the Geological Survey of Canada website at http//gdr.nrcan.gc.ca). In B), the same gravity data is presented with a colour gradient and the first vertical derivative aeromagnetic data of Figure 9 superimposed as shaded relief, along with the delineation of the main post-Acadian structures and Jurassic dykes. Localities 1–11 correspond to the sections of Figure 4. Localities AG (Antinouri Granite; Late Devonian) and PFG (Pabineau Falls Granite; Early Devonian) are strongly negative Bouguer anomalies corresponding to exposed granite plutons. Based on the Bois Gagnon Borehole (Fig. 4, Section 1), the strongly negative Bouguer anomaly of locality BGG corresponds to a buried granite pluton (Bois Gagnon Granite; undated). Localities SB (Silurian basalt) and OB (Ordovician basalt) are strongly positive Bouguer anomalies corresponding to mafic basement rocks. Based on the Canobie #4 Well (cores no longer available), the strongly positive Bouguer anomaly of locality CAN corresponds to buried mafic basement rocks. Based on the Atlantic Orebodies #2 Well (Fig. 4, Section 8), the strongly positive Bouguer anomaly of locality BG corresponds to a buried mafic pluton (Blackville Gabbro; undated). The cross-sections of transects A–B–C and D–E are shown on Figure 11.

Discussion

Viséan Tectonostratigraphy

The Bathurst Horst

Available data suggest that an over 1 km thick succession of Viséan rocks abuts the southern side of the Heath Steele Fault, whereas rocks of that age are absent between this fault and the Rocky Brook-Millstream Fault to the north (Fig. 11, Section A–B–C). Because paleocurrent and facies data in the Ristigouche Basin suggest a source area to the south of the Rocky Brook-Millstream Fault (Jutras et al., 2005), and because of the coarseness of Viséan red-beds a few kilometres south of the Heath Steele Fault in the Central Basin (Fig. 4, Section 5), it is concluded that the area between these two faults was never occupied by Viséan red-beds but was rather an intervening source area separating the two basins in Viséan times (Fig. 12). This fault-bounded terrain is here referred to as the Bathurst Horst (Fig. 10B). Although most of this structure is buried beneath Pennsylvanian strata (Fig. 11, Section A–B–C), it can be delineated by sharper magnetic and gravity anomalies than those formed by basement rocks that are buried deeper beneath Viséan strata (Figs. 9 and 10). Horst structures such as this one, occupied by granitic complexes and serving as source areas for clastic sedimentation, characterize most of the Late Devonian to Mississippian subbasin margins of the composite Maritimes Basin (St. Peter, 1993).

Hypothetical Marine Incursion in the Study Area

The presence of erosional remnants of the La Coulée Calcrete unconformably below the Bonaventure Formation in central New Brunswick suggests that, just as in the Ristigouche Basin (Jutras and Schroeder, 1999; Jutras et al., 1999, 2001; Jutras and Prichonnet, 2002), the Windsor Sea may have made a short-lived incursion into the Central Basin (Fig. 12A), thus favouring the establishment of salty groundwater conditions in the area, which are seemingly necessary for the formation of thick phreatic calcrete hardpans (Arakel and McConchie, 1982; Jutras et al., 2007). The regional marine transgression hypothesis is supported by the nearby occurrences of Lower Windsor Group carbonate (Chadian to Arundian?) in the area of Fredericton (Fig. 1; inset; Jutras et al., 2007).

In eastern Gaspésie, the entire Viséan succession, including the proposed invasion of the Windsor Sea, is interpreted to have been accommodated by the transtensional response of E-W striking structures to NW compression (Jutras and Prichonnet, 2005). Similar paleostress vectors are inferred to have influenced the Carboniferous basins during Viséan sedimentation in southern New Brunswick (Wilson and White, 2006). However, the fault geometry and kinematics expressed on Figure 12A are largely based on the better constrained paleogeography of the Bonaventure Formation in the Ristigouche and Central basins (defined below) (Fig. 12D).

Formation of the La Coulée Calrete

As the sea withdrew, evaporitic basins must have been stranded in the area, so that thick phreatic calcrete hardpans could develop around them (Fig. 12B). This genetic association between phreatic calcrete hardpans and evaporitic basins is based on the observation that modern analogs of these thick and massive calcretes develop in zones where a fresh groundwater discharge mixes with the salty groundwater that surrounds evaporitic basins in hyper-arid systems (Arakel and McConchie, 1982). It is also based on the identification of calcretized Lower Windsor Group limestone in the vicinity of thick Lower Windsor Group evaporites (Arundian to Holkerian?) in southern New Brunswick (Jutras et al., 2007). Lower Windsor Group evaporites are also found in wells of nearby Prince Edward Island (Fig. 1; inset; Jutras et al., 2007).

Pre-Bonaventure Uplift and Erosion, and Hypothetical Deposition of the Poodiac Formation in the Miramichi Trough

Like in the Ristigouche Basin, uplift and erosion (Fig. 12C) occurred in the Central Basin prior to deposition of the Bonaventure Formation to account for the regional unconformity with the underlying La Coulée Calcrete (Fig. 5). In the Ristigouche Basin, Jutras and Prichonnet (2005) showed that the product of this erosion yielded the Poodiac Formation (then referred to as the Cap d'Espoir Formation) in response to broad crustal flexure initiated by NW compression during a period of fault readjustment. The Poodiac Formation is also observed in the Marchbank Trough of southern New Brunswick, where it is stratigraphically constrained to Holkerian to Asbian times (Jutras et al., 2007). The Poodiac Formation has not yet been observed in central New Brunswick, but it may possibly occur below the Bonaventure Formation in more central regions of the Central Basin, such as below the Atlantic Orebodies #1 Well (Fig. 4, section 5) or farther to the east (Fig. 11), in the Miramichi Trough of Steeves and Kingston (1981).

Deposition of the Bonaventure Formation

The coarse, trough cross-stratified conglomerates that are found in all exposures and cores of Bonaventure Formation red-beds on the western margin of the Central Basin (Fig. 4, sections 5–8, 10) are best interpreted as fault-controlled alluvial fan and proximal gravelly-braidplain deposits. This is also the interpretation for most exposures of this unit in the Ristigouche Basin (Zaitlin and Rust, 1983; Jutras et al., 2001, 2005; Jutras and Prichonnet, 2002, 2005). Paleocurrent data (Fig. 3) and the distribution of this facies suggest that the Asbian to Brigantian Bonaventure Formation in central New Brunswick was sourced from a frequently rejuvenated upland bounded by the SW- to SSW-striking Miramichi Fault (Fig. 11D). The abundance of phyllite and mudrock clasts in the conglomerates corresponds well with the dominant lithologies of pre-Carboniferous basement rocks in the Miramichi Highlands to the northwest (New Brunswick Department of Natural Resources and Energy, 2000), apart from the absence of granitic clasts in the lower part of the Viséan succession. However, the increasing abundance of granitic clasts higher in the succession implies that the large Devonian granitoid intrusions that occur in the highlands began to be significantly

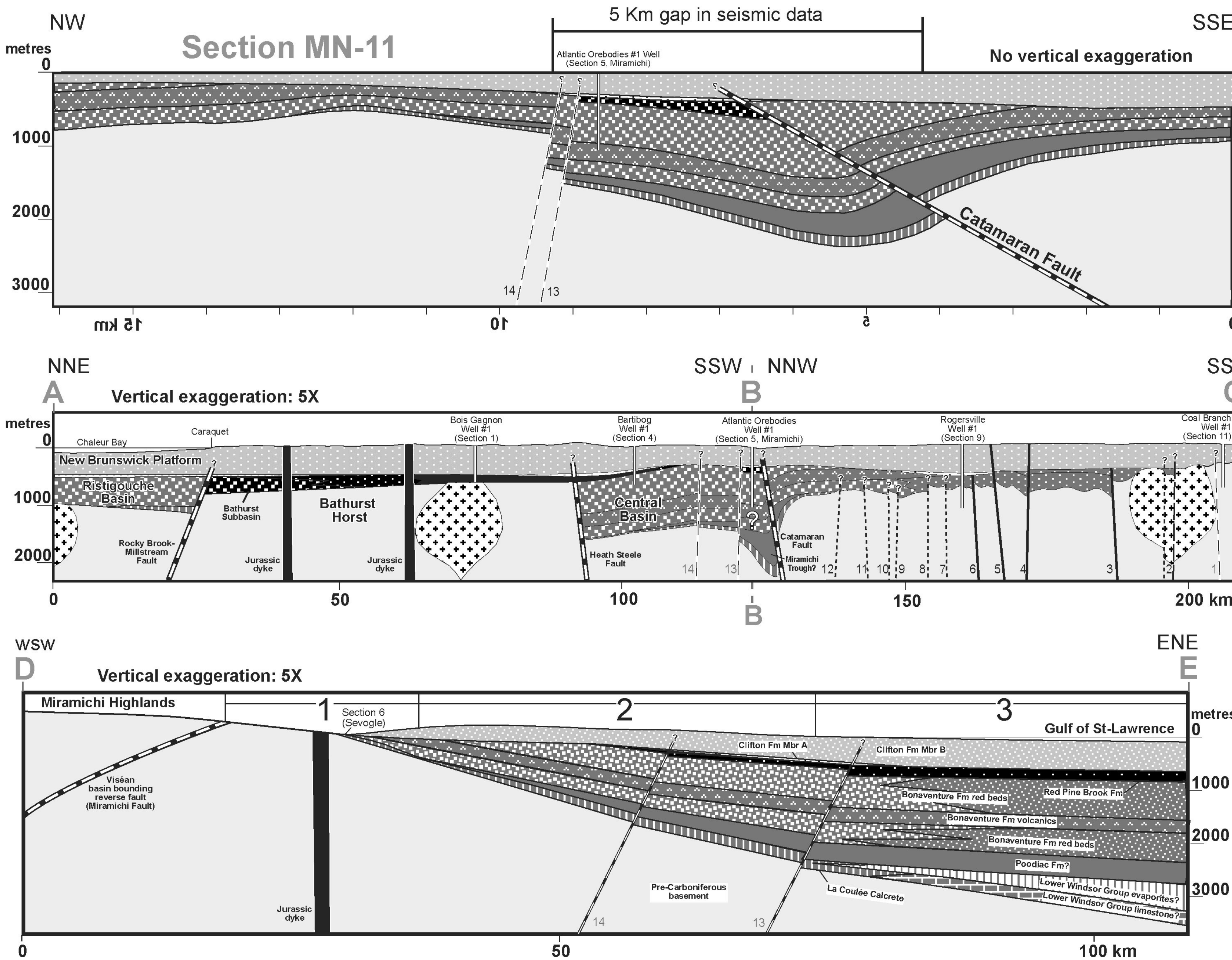


Fig. 11. Cross-sections MN-11, A–B–C and D–E (transects shown on figures 1 and 10B), interpreted from field, well, aeromagnetic, gravity and seismic data. Refer to the legend of Figure 4.

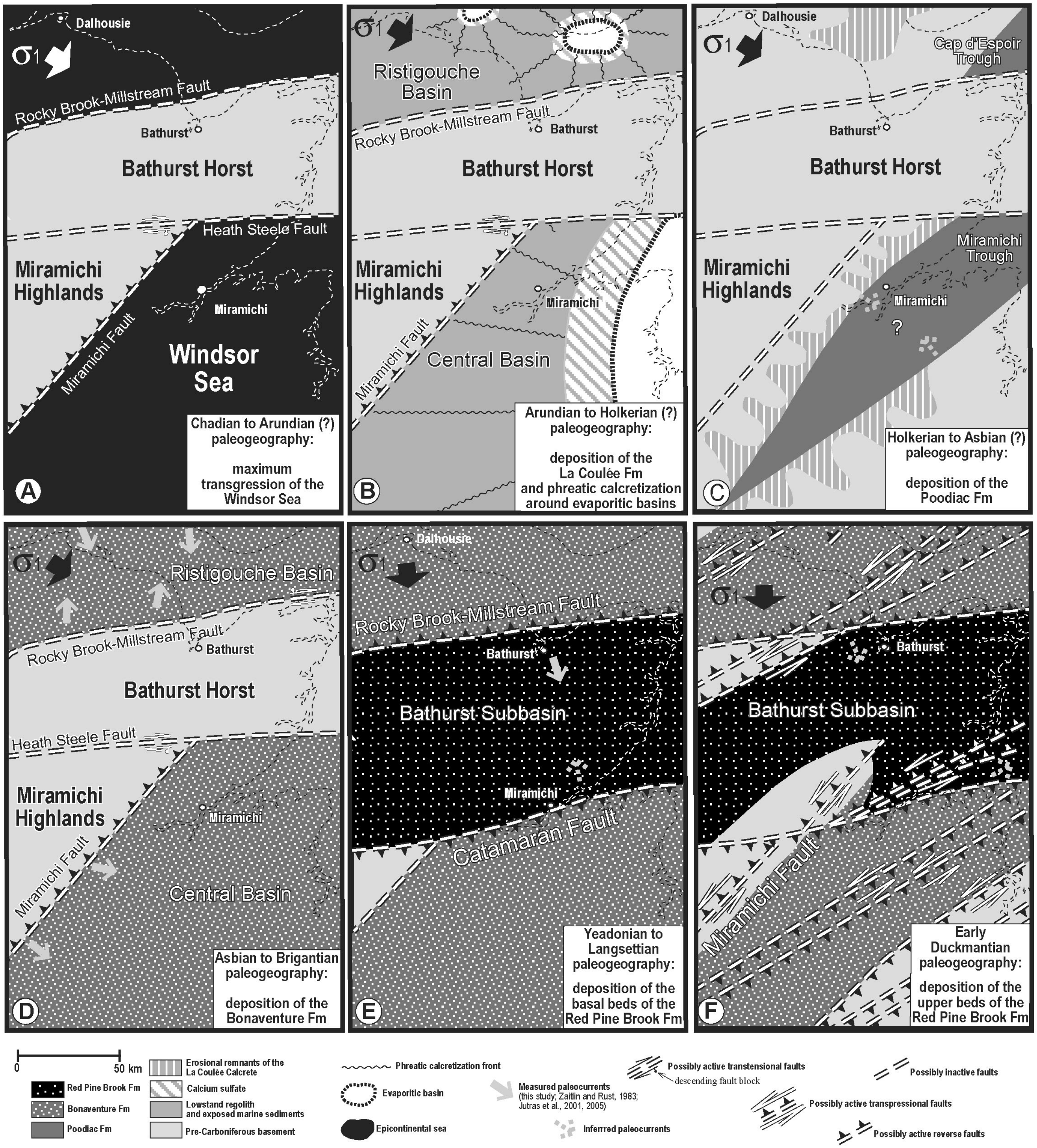


Fig. 12. A–D: Viséan tectonostratigraphy of the Ristigouche and Central basins in response to NW compression (inferred from Jutras and Prichonnet, 2005, and Wilson and White, 2006): A) Hypothetical extent of the first Windsor Sea transgression in northern New Brunswick and in the Chaleur Bay area (Jutras and Schroeder, 1999); B) Subsequent lowstand evaporitic basins in the Ristigouche and Central basins. Those of the Ristigouche Basin are hypothetical and strictly based on their genetic relationship with phreatic calcrete hardpans (Jutras et al., 1999, Jutras and Prichonnet, 2002), whereas that of the Central Basin is documented from wells in Prince Edward Island (Jutras et al., 2007); C) Pre-Bonaventure erosion of basin margins and associated deposition of the Poodiac Formation in the Miramichi (this study) and Cap d'Espoir (Jutras and Prichonnet, 2005) troughs; D) Deposition of the Bonaventure Formation in the Ristigouche (data from Zaitlin and Rust, 1983; Jutras et al., 2001, 2005) and Central basins (this study). Tentative ages are based on stratigraphic relationships in southern New Brunswick (Jutras et al., 2007). E–F: Pennsylvanian tectonostratigraphy of the Ristigouche and Central basins in response to the clockwise rotation of paleostresses from NW to N-S compression (inferred from Faure et al., 1996, and Jutras et al., 2003a, b): E) Fault-controlled deposition of the Red Pine Brook Formation in the Bathurst Subbasin in response to NNW compression in Yeadonian to Langsettian times (Jutras et al., 2005; this study); F) Deformation and partial erosion of the Bonaventure Formation by fault movement that is syn-depositional to the upper part of the Red Pine Brook Formation in response to N-S compression during the early Duckmantian.

exhumed in Viséan time. Similar observations were made for the Viséan succession in the southern part of the Ristigouche Basin (Jutras et al., 2005).

The presence of rock fall boulders in the Bonaventure Formation red-beds (Fig. 6) at the three localities that are close to the northwest margin of the Central Basin (Fig. 4, sections 6, 7 and 10), including boulders of phreatic calcrete hardpan, may imply that the floor of the fault-bounded basin had a very irregular topography at the time of burial. It therefore seems that the dissection period during which the La Coulée Calcrete was partly eroded (Fig. 12C) was interrupted by sudden initiation of Bonaventure Formation deposition (Fig. 12D), which is not unlike the scenario proposed for the Ristigouche Basin (Jutras and Prichonnet, 2005). In this context, remnants of the La Coulée Calcrete in marginal areas of the basin may only be found in interfluve areas between paleo-valleys. These inferred topographic irregularities on the basin floor may have influenced paleocurrent vectors, especially in the most basal parts of the succession. This may explain the somewhat anomalous NE-trending paleocurrents at Sevogle, parallel to the SW-striking Miramichi Fault, which may have formed a paleo-fault-scarp at the time. However, the ESE- and SE-trending paleocurrents measured at respectively Sillikers and Astle (Fig. 3, localities 7 and 10), higher in the succession, indicate that the source area of the Bonaventure Formation lay to the NW of the Miramichi Fault at the time of deposition. In the context of NW compression (inferred from Jutras and Prichonnet, 2005, and Wilson and White, 2006), this fault would have experienced reverse movement during deposition of this unit (Fig. 12D).

According to the Mini-Sosie seismic interpretation of Kingston and Steeves (1979) and Steeves and Kingston (1981), depth to basement may exceed 1700 m in the Miramichi area. This suggests that hundreds of metres of Carboniferous strata may exist below the base of the Atlantic Orebodies #1 Well (Fig. 4, Section 5), which supports the conclusion that the basalt at the base of this well is part of the Viséan succession.

Based on the successions in the Atlantic Orebodies #1 and 2 wells (Fig. 4, sections 5 and 8), and postulating that the Viséan volcanics occurred throughout the basin at the same stratigraphic level, there is at least 155 m of red-beds below them, and at least 543 m of red-beds above them. Assuming a constant total thickness of approximately 250 m for the volcanic interval (Ball et al., 1981), this gives an estimated minimal thickness of nearly 1 km for the Bonaventure Formation in the Central Basin and suggests that there is at least 400 m of additional Bonaventure Formation strata below the base of the Atlantic Orebodies #1 Well (Fig. 4, Section 5). Added to 432 m of overlying Pennsylvanian strata, this still leaves at least 250 m of Carboniferous strata unaccounted for above the basement at Miramichi, where total thickness is estimated from seismic data as possibly exceeding 1700 m. However, as noted earlier, beds of the Poodiac Formation (products of the pre-Bonaventure erosional event) may be present below the Bonaventure Formation this far deep into the basin, and the La Coulée Calcrete may be thicker (i.e. less eroded) (Figs. 11C and 12, Section D–E).

Hypothetical Lateral Variations into the Gulf of Saint Lawrence

Based on data from the Central Basin and models proposed for eastern Quebec (Jutras and Prichonnet, 2005) and southern New Brunswick (Jutras et al., 2007), it is reasonable to predict that the erosional contact between La Coulée Calcrete remnants and the Bonaventure Formation in marginal areas of the Central Basin (Fig. 11, Section D–E, sector 1) passes basinward into an increasingly complete phreatic calcrete hardpan profile overlain by increasingly thick beds of the Poodiac Formation (Fig. 11, Section D–E, sector 2), and that the phreatic calcrete hardpan in turn grades laterally into limestones and evaporites of the Windsor Group Subzone A below the Gulf of Saint Lawrence (Fig. 11, Section D–E, sector 3).

Pennsylvanian Deformation of the Viséan Central Basin

Basin Architecture

Well and seismic data indicate that the thickness of the Viséan succession beneath the Pennsylvanian cover varies from 0 at the Coal Branch #1 Well (Fig. 4, Section 11) to possibly over 1000 m in the Miramichi area (Fig. 8, Transect MN-11), whereas the thickness of the Pennsylvanian Clifton Formation is nearly the same at all localities along this transect. Northwestward thickening of Viséan strata apparently occurs in a series of steps across NE- to ENE-trending faults that only significantly affect pre-Bolsovian strata (Fig. 11, Section A–B–C). Using a combination of seismic (Fig. 8), aeromagnetic (Fig. 9) and gravity data (Fig. 10), it is interpreted that most of these faults accommodate northwest-verging reverse displacements.

The relatively fine-grained nature of Bonaventure Formation strata in the Rogersville #1 Well (Fig. 4, Section 9) suggests that these beds were deposited far from their source area, and thus that the absence of Viséan strata in the nearby Coal Branch #1 Well (Fig. 4, Section 11) is probably related to post- rather than syn-Viséan erosion associated with uplift along these NE-trending faults (Fig. 11, Section A–B–C). The lack of Viséan strata on either sides of Fault #1 may explain why this fault was not detected by the seismic survey of Kingston and Steeves (1979), although it forms a well-defined lineament on gravity and magnetic anomaly maps (Fig. 10).

It is likely that the most important structure within the Viséan Central Basin is located in the 5 km gap of seismic data beneath the City of Miramichi (Fig. 8, Section MN-11). Based on our gravity and magnetic data interpretations, it is extrapolated that the Catamaran Fault passes along the Miramichi River at the southern limit of the gap, whereas Faults #13 and 14 pass through the City of Miramichi near the northern limit of the gap (Fig. 10B). A convergence of opposite reverse offsets along the Catamaran Fault and the two other interpreted faults is necessary to connect the two ends of the gap without invoking folding to a degree that would be unrealistic in the context of brittle post-Acadian deformation (Fig. 11, Section MN-11). Because even the most conservative extrapolations between the two ends of the gap imply a depth to basement here of at least 2000 m, and because the Bonaventure Formation is unlikely to greatly exceed 1000 m in thickness below the Pennsylvanian succession in the Atlantic Orebodies #1 Well (Fig. 4, Section 5), it is postulated that part of the folding occurred before deposition of the Bonaventure Formation, when the La Coulée Calcrete was experiencing partial erosion. A synclinal structure is therefore postulated to accommodate a thick succession of Poodiac Formation beds (Fig. 12C) and to have been subsequently reworked in the drag fold of the Catamaran thrust in post-Bonaventure times (Fig. 11, Section MN-11).

Although the possible presence of mafic rocks in the pre-Carboniferous basement cannot be discarded, the elongated and pronounced positive gravity anomaly in the Miramichi area, south of the Catamaran Fault (Fig. 10), is possibly related to the doubling of the Viséan basalt succession due to reverse movement along that fault (Fig. 11, Section MN-11). In contrast, the gradual lowering of gravity anomaly values farther south, apart from the area of the Blackville Gabbro, suggests that the thickness of the Carboniferous basalt decreases in that direction, as supported by well data at localities 8 and 9 (Fig. 4), which lack basalt. However, the presence of erosional remnants of Viséan rocks just south of the Catamaran Fault (Fig. 4, Sections 7 and 8) suggests that this fault did not control Viséan sedimentation but was partly responsible for post-Viséan deformation and erosion in the study area.

Deformation of the Viséan Central Basin and Associated Deposition of the Red Pine Brook Formation

Although little is known about the geometry and kinetics of the faults that affected Viséan strata, our understanding of the regional tectonostratigraphy allows some inferences to be made. Jutras et al. (2005) suggested that deposition of the Red Pine Brook (then Bathurst) Formation was controlled by south-verging reverse movement along the WSW-striking Rocky Brook-Millstream Fault during a basin inversion event at the Mississippian/Pennsylvanian boundary. This deformation may have occurred in response to the post-Mississippian clockwise rotation of compressional stresses from a NW to a NNW trend, which is recorded in Mississippian rocks of eastern Quebec (Faure et al., 1996; Jutras et al., 2003a, b). The Viséan Bathurst Horst was buried in the process, and the Catamaran Fault, which is sub-parallel to the Rocky Brook-Millstream Fault, may have experienced reverse movement with an opposite vergence, generating erosion southeast of the fault (Fig. 12E). This is supported by the absence of Yeadonian to Duckmantian red-beds (i.e. Red Pine Brook Formation) to the south of the Catamaran Fault, and by the coarseness of the Red Pine Brook Formation in the Atlantic Orebodies #1 Well (Fig. 4, Section 5). Hence, the Red Pine Brook Formation was not deposited in a half-graben setting, as postulated by Jutras et al. (2005) based on the fining and thinning of the succession away from the Rocky Brook-Millstream Fault, but was rather deposited in a compressional graben, here referred to as the Bathurst Subbasin (Fig. 12E). The paraconformable nature of the Bonaventure-Red Pine Brook contact in the Atlantic Orebodies #1 Well suggests that early Namurian sedimentation never occurred in the Central Basin, and that this hiatus represents a period of non-deposition and weathering in the region.

In the Ristigouche Basin, Mississippian strata exposed on the north shore of Chaleur Bay experienced transpressional deformation along SW- to SSW-striking reverse-sinistral faults and SE-striking dextral faults in response to the clockwise rotation of paleostress vectors to a nearly N-S trend (Jutras et al., 2003a, b) (Fig. 12F). The SW- to SSW-striking Miramichi Fault probably responded to a similar paleostress so that the Bonaventure Formation was tilted away from it and substantially eroded along the western margin of the Central Basin prior to deposition of Clifton Formation strata (Fig. 4, sections 6–8). The apparent absence of Red Pine Brook Formation strata in the Sevogle area may suggest that lower beds of this unit could have been locally deformed and eroded as well, although other parts of the Bathurst Subbasin may have received the erosional products of this deformation (Fig. 12F). Buried SW-striking faults, interpreted by using well and geophysical data (Faults 1, 3, 6, 8, 13 and 14 on Figure 10B), may have experienced reverse-sinistral movement during this deformation, thus generating substantial erosion of Bonaventure Formation strata (Fig. 12F) prior to deposition of the unconformably overlying Clifton Formation. However, the lack of significant offset in gravity anomalies that are truncated by faults #7–11 (Fig. 10B) precludes kilometric lateral displacement to have occurred along these faults in post-Acadian times. From the available data, we tentatively consider the lower Duckmantian upper beds of the Red Pine Brook Formation as syn-depositional with the deformation of the Bonaventure Formation, whereas the Duckmantian to Asturian (?) beds of the Clifton Formation members A and B clearly postdate the bulk of this deformation, as they truncate most of these structures and show insignificant vertical displacement along faults that do cut them (Fig. 11, section A–B–C).

Conclusions

Although many uncertainties remain due to the paucity of deep wells in central New Brunswick, available data indicate that a thick (>1500 m) Viséan basin is buried below Pennsylvanian rocks in the area of Miramichi, abutting a fault-bounded basement high to the north, the Bathurst Horst, and thinning southward along a series of fault steps (Fig. 11, Section A–B–C). The succession includes erosional remnants of the Viséan La Coulée Calcrete (Arundian to Holkerian?) below red-beds of the Bonaventure Formation (Asbian to Brigantian), which is interpreted to have been sourced from the Bathurst Horst to the north and from the Miramichi Highlands to the west (Fig. 12D). The phreatic calcrete hardpan suggests the former presence of an evaporitic basin in its vicinity (Fig. 12B) (Jutras et al., 2007), and its pre-Bonaventure partial erosion (Fig. 12C) suggests a similar tectonic history to that of the Chaleur Bay area, which experienced broad crustal flexuring and associated erosion in response to NW compression (Fig. 12C) during the time interval separating the two units (Jutras and Prichonnet, 2005).

No marine or evaporitic Viséan rocks were observed in the study area, but the deeper areas of the Central Basin have not yet been drilled, and their presence below the Bonaventure Formation in the subsurface at Prince Edward Island (Jutras et al., 2007) suggests that the Viséan phreatic calcrete hardpan may be transitional to such rocks between the two areas. Marine Viséan rocks are also present in the Marysville Basin to the south (Jutras et al., 2007), and further work is therefore necessary to understand the transition between this basin and the Central Basin.

The geometry of buried faults in the Central Basin and the movement history suggested by their associated stratigraphic offsets are consistent with the regional post-Viséan tectonostratigraphy, which suggests a gradual clockwise rotation of paleostresses from NW to N-S compression in post-Mississippian times (Jutras et al., 2003a). Movement along these faults seemingly controlled early Pennsylvanian sedimentation and the deformation of Viséan basins, and preceded deposition of Duckmantian to Lower Permian strata of the Clifton Formation, which truncates most of these structures.

Acknowledgments

We wish to thank I. Knight, J. Waldron and an anonymous reviewer for providing valuable insights to improve this manuscript. We also thank S. Johnson, A. Park and C. St. Peter for fruitful discussions, and C. St. Peter and J. Allain for giving us access to cores, borehole cuttings and various documents that were necessary to complete this study. Special thanks to S. McCutcheon and J. Samson for helping us to find the remote Sevogle section. This project was supported by a research grant of the Natural Sciences and Engineering Research Council (NSERC) of Canada. We are grateful to Linda Dancey of the Geological Survey of Canada (Calgary) for processing the palynology samples.

References

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

Allan Spector and Associates Limited, Toronto, Canada. 1980. Report on aeromagnetic interpretation of New Brunswick Carboniferous basins. New Brunswick Department of Natural Resources, Open File Report 80-8, 31 p.

Ami, H.M. 1902. Notes on some of the formations belonging to the Carboniferous System of eastern Canada. Canadian Record of Science, v. 8, p. 149–163.

Anderle, J.P., Crosby, K.S. and Waugh, D.C.E. 1979. Potash at Salt Springs, New Brunswick. Economic Geology, v. 74, p. 389–396.

Anderson, F.D. and Poole, W.H. 1959. Geology, Woodstock-Frederiction; York, Carleton, Sunbury and Northumberland counties, New Brunswick. Geological Survey of Canada Map 37-1959.

Arakel, A.V. and McConchie, D. 1982. Classification and genesis of calcrete and gypsite lithofacies in paleodrainage systems of inland Australia and their relationship to carnotite mineralization. Journal of Sedimentary Petrology, v. 52, p. 1149–1170.

Bailey, L.W. 1910. The history of Currie Mountain – an old New Brunswick volcano. Bulletin of the Natural History Society of New Brunswick, v. 6, p. 189–197.

Baldwin, A.B. 1985. Diamond Drill Log, Atlantic Orebodies No. 1. New Brunswick Department of Natural Resources and Energy, U.I. 608.

Ball, F.D., Sullivan, R.M. and Peach, A.R. 1981. Carboniferous Drilling Project. New Brunswick, Mineral Resources Branch, Report of Investigations No. 18, 109 p.

Belt, E.S. 1964. Revision of Nova Scotia middle Carboniferous units. American Journal of Science, v. 262, p. 653–673.

Calder, J.H., Rygel, M.C., Falcon-Lang, H.J. and Hebert, B.R. 2005. Stratigraphy and sedimentology of early Pennsylvanian red-beds at Lower Cove, Nova Scotia, Canada: the Little River Formation with redefinition of the Joggins Formation. Atlantic Geology, v. 41, p. 143–168.

Canadian Geodetic Information System, 2006a. 200 m Canada grid: First Vertical Derivative Aeromagnetic Anomalies. Geoscience Data Repository, Geodetic Survey Division, Natural Resources Canada, Geological Survey of Canada. http//gdr.nrcan.gc.ca.

________ 2006b. 2 km Canada grid: Bouguer Gravity Anomalies. Geoscience Data Repository, Geodetic Survey Division, Natural Resources Canada, Geological Survey of Canada. http//gdr.nrcan.gc.ca.

Carr, P.A. 1968. Stratigraphy and spore assemblages, Moncton map-area, New Brunswick. Geological Survey of Canada, Paper 67–29, 47 p.

Clayton, G., Higgs, K.T. and Keegan, J.B. 1978. The Dinantian palynostratigraphy of the British Isles. Palynology, v. 2, p. 215–216.

Davies, J.L. 1977. Geological Map of Northern New Brunswick. New Brunswick Department of Natural Resources, Map NR-3.

Faure, S., Tremblay, A. and Angelier, J. 1996. Alleghanian paleostress reconstruction in the northern Appalachians: Intraplate deformation between Laurentia and Gondwana. Geological Society of America Bulletin, v. 108, p. 1467–1480.

Fyffe, L.R. 1984. Geological Compilation; McKendrick Lake. New Brunswick Department of Natural Resources and Energy, Map Plate 84–317.

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

Gussow, W.C. 1953. Carboniferous stratigraphy and structural geology of New Brunswick, Canada. American Association of Petroleum Geologists Bulletin, v. 37, p. 1713–1816.

Hassan, H.H. 1999. Compilation of Bouguer gravity data for New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 99-33A.

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

Jutras, P. and Prichonnet, G. 2002. Stratigraphy, depositional setting and diagenetic history of the Saint-Jules Formation (Upper Devonian or Mississippian), a newly identified post-Acadian red clastic unit in the southern Gaspé Peninsula, Québec. Canadian Journal of Earth Sciences, v. 39, p. 1541–1551.

________ and ________ 2004. Significance of paleosurfaces in interpreting the paleogeographic and stratigraphic evolution of the upper Paleozoic Paspébiac Graben, a recently identified basin in the southern Gaspé Peninsula of Quebec, Canada. Geological Society of America Bulletin, v. 116, p. 1074–1086.

________ and ________ 2005. Record of late Mississippian tectonics in the new Percé Group (Viséan) of eastern Gaspésie, Quebec. Canadian Journal of Earth Sciences, v. 42, p. 815–832.

________ and Schroeder, J. 1999. Geomorphology of an exhumed Carboniferous paleosurface in the southern Gaspé Peninsula, Québec; paleoenvironmental and tectonic implications. Géographie Physique et Quaternaire, v. 53, p. 249–263.

________, Prichonnet, G. and von Bitter, P. 1999. The La Coulée Formation, a new post-Acadian stratigraphic unit bearing groundwater calcretes, Gaspé Peninsula, Québec. Atlantic Geology, v. 35, p. 139–156.

________, ________ and Utting, J. 2001. Newly identified Carboniferous units (The Pointe Sawyer and Chemin-des-Pêcheurs formations) in the Gaspé Peninsula, Quebec; implications regarding the evolution of the northwestern sector of the Maritimes Basin. Canadian Journal of Earth Sciences, v. 38, p. 1–19.

________, ________ and McCutcheon, S. 2003a. Alleghanian deformation in the eastern Gaspé Peninsula of Quebec. Geological Society of America Bulletin, v. 115, p. 1538–1551.

________. ________ and ________ 2003b. Alleghanian faulting in the southern Gaspé Peninsula of Quebec. Atlantic Geology, v. 39, p. 201–211.

________, Utting, J. and McCutcheon, S. 2005. Basin inversion at the Mississippian-Pennsylvanian boundary in northern New Brunswick. Bulletin of Canadian Petroleum Geology, v. 53, p. 390–404.

________, ________ and McLeod, J. 2007. Link between long-lasting evaporitic basins and the development of thick and massive phreatic calcrete hardpans in the Mississippian Windsor and Percé groups of eastern Canada. Sedimentary Geology, v. 201, p. 75–92.

Kingston, P.W.E. and Steeves, B.A. 1979. Shallow seismic data from the eastern part of the New Brunswick Platform: stratigraphic and structural implications. New Brunswick Department of Natural Resources, Mineral Resources Branch, Open File Report 79-14, 31 p.

Kiss, F., Potvin, J. and Coyle, M. 2004. Shaded magnetic first vertical derivative, Chipman, New Brunswick (NTS 21 I/04). Geological Survey of Canada, Open File 4651, Scale: 1:50 000.

Logan, W.E. 1846. Sections on Chaleur Bay and coast of Gaspe. Geological Survey of Canada, Progress in Report, p. 78–110.

MacKenzie, G.S. 1964. Geology of Hampstead, New Brunswick. Geological Survey of Canada, Map 1114A.

McLean, D., Owens, B. and Neves, R. 2005. Carboniferous miospore biostratigraphy of the North Sea. In: Carboniferous hydrocarbon resource: the southern North Sea and surrounding onshore areas. J.D. Collinson, D.J. Evans, D.W. Holliday and N.S. Jones (eds.). Occasional Publications Series of the Yorkshire Geological Society, v. 7, p. 13–24.

McLeod, M.J. and Johnson, S.C. 1998. Bedrock geological compilation of the Fredericton area (NTS 21 G/15), York and Sunbury counties, New Brunswick. New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 98-33.

Muller, J.E. 1951. Geology and coal deposits of the Minto and Chipman map-areas, New Brunswick. Geological Survey of Canada, Memoir 260, 40 p.

New Brunswick Department of Natural Resources and Energy 2000. Bedrock geology of New Brunswick. Minerals and Energy Division, Map NR-1 (2000 Edition). Scale 1:500 000.

Okulitch, A.V. 2004. Geological Time Chart, 2004. Geological Survey of Canada Open-File 3040 (National Earth Science Series, Geological Atlas)-Revision.

Ryan, R.J., Boehner, R.C. and Calder, J.H. 1991. Lithostratigraphic Revisions of the upper Carboniferous to lower Permian strata in the Cumberland Basin, Nova Scotia and their regional implications for the Maritimes Basin in Atlantic Canada. Bulletin of Canadian Petroleum Geology, v. 39, p. 289–314.

Serres, Y. and Wiles, C. 1978. Mini-Sosie – New high-resolution seismic reflection system. Canadian Institute of Mining and Metallurgy Bulletin, v. 71, p. 96–102.

Skinner, R. 1974. Geology of Tetagouche Lakes, Bathurst, and Nepisiguit Falls map-areas, New Brunswick with emphasis on the Tetagouche Group. Geological Survey of Canada, Memoir 371, 133 p.

Smith, A.H.V. and Butterworth, M.A. 1967. Miospores in the coal seams of the Carboniferous of Great Britain. Special Papers in Palaeontology, v. 1, 324 p.

Steeves, B. and Kingston, P.W. 1981. Carboniferous Seismic Survey. New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Open-File 81-1, 145 p.

St. Peter, C.J. 1993. Maritimes Basin evolution: key geologic and seismic evidence from the Moncton Subbasin of New Brunswick. Atlantic Geology, v. 29, p. 233–270.

________ 2000. Carboniferous geology of the southwestern New Brunswick Platform (Marysville Subbasin). New Brunswick Department of Natural Resources and Energy, Minerals and Energy Division, Plate 2000-16.

van de Poll, H. W. 1967. Carboniferous volcanic and sedimentary rocks of the Mount Pleasant area, New Brunswick. New Brunswick Department of Natural Resources and Energy, Mineral Resources Branch, Report of Investigations 3. 52 p.

________ 1995. Upper Paleozoic rocks; New Brunswick, Prince Edward Island and Îles-de-la-Madeleine. In: Geology of the Appalachian/Caledonian Orogen in Canada and Greenland. H. Williams (ed.). Geological Survey of Canada, Geology of Canada, no. 6, p. 455–492.

Wessel, P. and Smith, W.H.F. 1991. Free software helps map and display data. EOS, Transactions of the American Geophysical Union, v. 441, p. 445–446.

Wilson, R.A. 2006. Geological map of northern New Brunswick (NTS 21 O, parts of 21 P and 22 B). New Brunswick Department of Natural Resources; Minerals, Policy and Planning Division, Plate NR-3 (second edition).

Wilson, P. and White, J.C., 2006. Tectonic evolution of the Moncton Basin, New Brunswick, eastern Canada: New evidence from field and subsurface data. Bulletin of Canadian Petroleum Geology, v. 54, p. 319–336.

Wright, V.P. and Tucker, M.E. 1991. Calcretes: an introduction. In: Calcretes. V.P. Wright and M.E. Tucker (eds.). Reprint Series Volume 2 of the International Association of Sedimentologists, Blackwell Scientific Publications, p. 1–22.

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

Manuscript received: October 12, 2006

Date accepted: August 20, 2007

Associate Editor: John Waldron