Relationships between lithofacies belts and conodont faunas, Gun River Formation (Lower Silurian), Anticosti Island, Quebec: a statistical approach

Shunxin Zhang, Christopher R. Barnes, and Susanne M.L. Pohler

Abstract: Discriminant analysis of 80 samples from the Western Carbonate Platform Facies and the Eastern Transitional Carbonate–Siliciclastic Platform Facies of the Gun River Formation (Lower Silurian) on Anticosti Island, Quebec, indicates the degree to which different conodont communities were related to particular lithofacies. The statistical analysis reveals that during most of the Gun River Formation deposition, the conodont distributional pattern of the Western Carbonate Platform Facies and the Eastern Transitional Carbonate–Siliciclastic Platform Facies of the formation remained stable, and that the boundary of the two facies oscillated eastward and westward. The analysis indicates quantitatively that *Icriodella deflecta* had a nearshore environmental preference, whereas *Rexroadus kentuckyensis* tended to reside in offshore environments. These two species play the most important role in differentiating conodont communities and determining the relationship between conodont communities and lithofacies among all of the 22 species known from the Gun River Formation.

Résumé : Une analyse discriminante de 80 échantillons du faciès occidental de la plate-forme carbonatée et du faciès oriental de la plate-forme de transition carbonate–siliclastique de la Formation de Gun River (Silurien inférieur) sur l'île d'Anticosti, au Québec, indique le degré de relation entre les diverses communautés de conodontes et des lithofaciès particuliers. L'analyse statistique révèle que, lors de la déposition de la plus grande part de la Formation de Gun River, le patron de distribution des conodontes du faciès occidental de la plate-forme carbonatée et celui du faciès oriental de la plate-forme de transition carbonate–siliclastique de la formation sont demeurés stables et que la limite entre les deux faciès oscillait vers l'est et vers l'ouest. Les résultats quantitatifs de l'analyse indiquent que *Icriodella deflecta* préférait les environnements littoraux alors que *Rexroadus kentuckyensis* avait plus tendance à rester dans des environnements au large. Ces deux espèces sont les plus significatives pour différencier les communautés de conodontes et déterminer la relation entre les communautés de conodontes et les lithofaciès parmi toutes les 22 espèces connues dans la Formation de Gun River.

[Traduit par la Rédaction]

Introduction

Conodonts are common marine phosphatic microfossils of Late Cambrian – Triassic age (Sweet 1988). They have demonstrated exceptional value as biostratigraphical tools and as geochemical and thermal maturation indicators. Much of the earlier work on conodonts had a taxonomic and biostratigraphic emphasis. The initial surge of work on the stratigraphic distribution of diagnostic conodonts was summarized by Sweet and Bergström (1974) and Higgins and Austin (1985). As more data accumulated on conodont distribution through biostratigraphic studies, attention turned to paleoecologic studies. Earlier work is represented by two contrasting models of conodont paleoecology, i.e., the depth-stratified pelagic habit (Seddon and Sweet 1971) and the nektobenthic habit with a minority of truly pelagic forms (Barnes and Fåhraeus 1975; Fåhraeus and Barnes 1975). The latter research outlined the complex patterns of conodont paleoecology. The close correlation of conodont distribution with various sedimentologic criteria was recognized, for example, in Late Ordovician and Early Silurian conodont faunas from Hudson Bay by Le Fèvre et al. (1976) and in

Received 28 February 2002. Accepted 11 October 2002. Published on the NRC Research Press Web site at http://cjes.nrc.ca on 20 December 2002.

Paper handled by Associate Editor B. Chatterton.

S. Zhang and C.R. Barnes.[1] School of Earth and Ocean Sciences, University of Victoria, P.O. Box 3055, Victoria, BC V8W 3P6, Canada.
S.M.L. Pohler.[2] Geological Survey of Austria, Rasumofskygasse 23, A-1031 Vienna, Austria.

[1]Corresponding author (e-mail: crbarnes@uvic.ca).
[2]Present address: Marine Studies Programme, University of the South Pacific, Suva, Fiji.

 DOI: 10.1139/E02-087

Triassic conodonts from Utah and Nevada by Clark and Rosser (1976). In the latter, both descriptive methods and quantitative analyses were adopted, based on known ecological factors of associated fossils and treated conodont faunas as variables to be manipulated with a number of mathematical techniques. Carr et al. (1984) successfully used the χ^2 test, discriminant analysis, and factor analysis to document that the distribution of some Early Triassic conodonts was controlled by a depth-related environmental gradient, whereas others were not.

Other studies on Silurian conodont paleoecology (Aldridge and Mabillard 1981; Aldridge and Jeppsson 1984; Idris 1984) identified the different conodont specialists in the nearshore and offshore environments based on the conodont distribution in Norway and Britain. Analytical studies of Late Ordovician and early Early Silurian conodonts from Anticosti Island, Quebec (Nowlan and Barnes 1981; McCracken and Barnes 1981), outlined the pattern of conodont communities and the impact of the latest Ordovician mass extinction. Zhang and Barnes (2002*b*) conducted cluster analysis, using both earlier and new collections, to identify 11 conodont communities through the Llandovery sequence on Anticosti Island and documented that development and replacement of the different conodont communities were related to eustatic sea level changes. Zhang and Barnes (2002*c*) also used cluster analysis to detail the relationship between lithofacies and conodont communities through this interval.

Anticosti Island lies in the Gulf of St. Lawrence, Quebec (Fig. 1). In the Late Ordovician and Early Silurian it was located about 20° south of the equator on the eastern margin of Laurentia, bordering the Iapetus Ocean. The stratigraphic sequence through this interval is continuous, undeformed, approximately 1100 m thick, and richly fossiliferous, consisting of limestone with minor shale and sandstone. The sequence is subdivided into the Upper Ordovician Vauréal and Ellis Bay formations and the Lower Silurian Becscie, Merrimack, Gun River, Jupiter, and Chicotte formations (Fig. 1). These sediments were deposited in a broad, 40–100 km wide, storm-influenced ramp to shelf, subjected to a series of marine regressions and transgressions of differing magnitudes (Petryk 1981; Long and Copper 1994; Copper and Long 1998).

In general, two northwest–southeast-trending carbonate and siliciclastic rock facies were identified (Petryk 1981): the Western Carbonate Platform Facies (abbreviated as the western facies in the following text) and the Eastern Transitional Carbonate–Siliciclastic Platform Facies (abbreviated as the eastern facies in the following text) (Fig. 2). The western facies was developed through most of the sequence and was widely distributed geographically on Anticosti Island, whereas the eastern facies was developed most extensively during the deposition of the uppermost Vauréal and Ellis Bay formations, and reappeared in the upper Becscie, upper Gun River, and upper Jupiter formations, and is restricted mainly to the eastern end of the island.

McCracken and Barnes (1981) measured three sections of Ellis Bay Formation from the west to the east of the island (Bay Ellis, Rivière Vauréal, and Rivière aux Saumons) and documented the presence of three laterally segregated conodont communities corresponding to the offshore subtidal, intermediates, and nearshore environment from the west to the east. This supported the observation of northwest–southeast-trending carbonate and siliciclastic rock facies partitioning made by Petryk (1981).

Further observations on stratigraphy and sedimentology (Long 1997) revealed that siliciclastic sand and mud were transported into the eastern end of the Anticosti Basin by sustained longshore currents that swept the coast of Laurentia along the west coast of the Strait of Belle Isle. It appears that the siliciclastic input was related to a period of lowered sea level.

New conodont data from collections of the Gun River Formation from the eastern end of Anticosti Island by S.M.L. Pohler and P. Copper are compared with earlier conodont data from the western and central part by C.R. Barnes and colleagues. The Gun River Formation comprises most of the coastal outcrops on the eastern end of Anticosti Island and hence provided the best opportunity of all the stratigraphic units to examine west–east facies and conodont community changes.

All previous Anticosti Island Silurian conodont fauna and conodont paleoecology studies, however, were restricted to the western carbonate platform belt. The present study documents the differences in conodont faunas between the western and eastern facies during the deposition of the Gun River Formation (mid-Llandovery), based on new collections from eastern Anticosti Island.

Materials and methodology

The Gun River Formation spans the *Oulodus jeannae* Subzone of the *Ozarkodina strena* Zone and lower *Ozarkodina clavula* Zone of lower Aeronian, Llandovery (Zhang and Barnes 2002*a*). The formation is superbly exposed along the coast and major rivers of Anticosti Island. Both carbonate and transitional carbonate–siliciclastic lithofacies are well developed within the formation, which enables this study of the relationships between lithofacies and conodont faunas.

Based on the type section on the south-central coast, Petryk (1981) divided the Gun River Formation into five informal members: member 1, 5 m thick, is composed of graptolite-bearing lime mudstone with lenses of grainstone and packstone with minor shale partings; member 2 consists of approximately 7 m of lime mudstone and calcisiltite with lenses and partings of coarser carbonate and shale; member 3, 105 m thick, consists mainly of lime mudstone, grainstone, and intrarudstone; member 4, 28 m thick, shows an increase in grainstone content; member 5 is a 4 m thick biohermal unit.

In a study of the Gun River sections along the northeast coast, Copper and Long (1990) included Petryk's (1981) members 4 and 5 of Gun River Formation in the Jupiter Formation, then Long and Copper (1994) divided the formation into four members: Lachute Member, 14 m thick, consists of thinly bedded (2–5 cm), irregular to nodular lime mudstone with abundant mudstone partings and minor bioclastic lags; Innimmée Member, 17–25 m thick, consists of laminated calcareous mudstone and massive to planar cross stratified calcarenites of very fine to very coarse sand grade, with minor mudstones and lime mudstone; Sandtop Member, 35–40 m thick, is dominated by massive to weakly plane to wavy laminated lime mudstone, which occur in sharp-based sets 2–10 cm thick, separated by the thin sets of calcareous

Fig. 1. Geological map of Anticosti Island, Quebec, showing section localities (sections 6–12, A, and B) of the Gun River Formation (see Figs. 3 and 4 for detail).

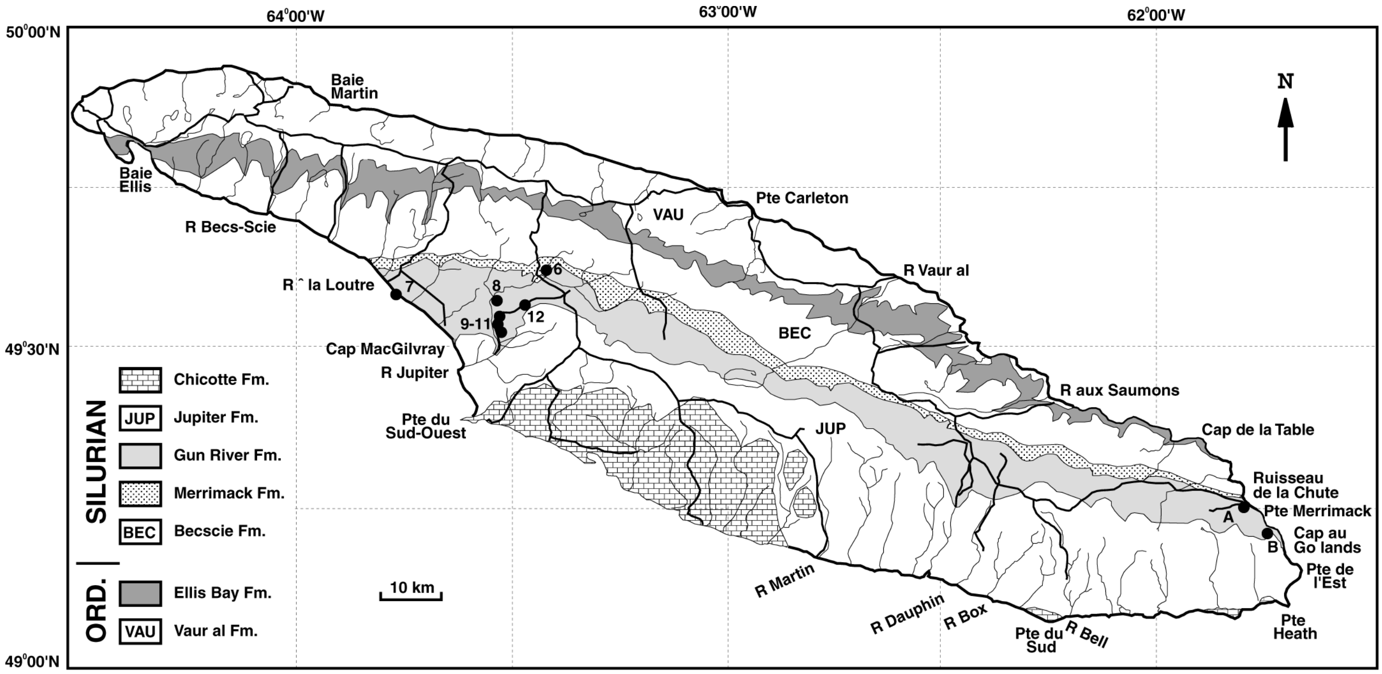
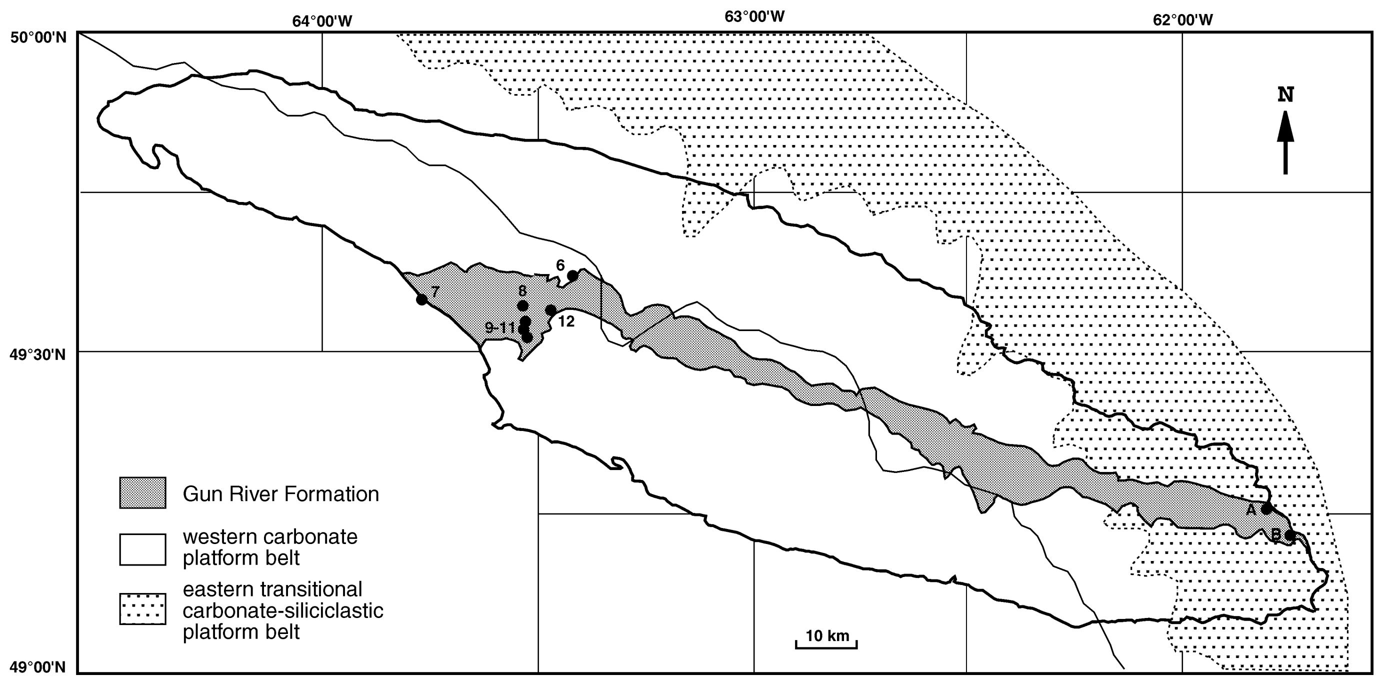


Fig. 2. Paleogeography, paleoenvironments, and major lithofacies belts of the Upper Ordovician – Lower Silurian of Anticosti Island, Quebec, showing the distribution and section localities of the Gun River Formation (see Figs. 3 and 4 for detail) (modified from Petryk 1981).



mudstone; Macgilvray Member, 23–24 m thick, is characterized by massive, nodular to subnodular lime mudstone, planer and wavy laminated lime mudstone, grainstone, abundant intraformational conglomerate, and minor calcareous mudstone.

Thus, the Lachute Member (Long and Copper 1994) corresponds to the lower two members of Petryk (1981), and the Innimmée, Sandtop, and Macgilvray members (Long and Copper 1994) to member 3 of Petryk. To compare the conodont fauna from the western and eastern facies within the same stratigraphical interval, the analysis in this paper does not include the samples from members 4 and 5 from the western facies (Zhang and Barnes 2002*a*, 2002*b*), assigned by Copper and Long (1990) to the Jupiter Formation.

For the western facies, the collections were made from the

Fig. 3. Conodont distribution in the Gun River Formation of the western facies at roadcut 3.2 km southeast of 24-Mile Camp, Rivière Jupiter (6); Baie Lafayette, southeast of mouth of Rivière à la Loutre (7); Rivière Jupiter, 16-mile pool (8); Rivière Jupiter, 8-mile, 9-mile, and 10-mile pools (9–11); and roadcut on Fire Tower Road, 13.6 km southeast of 24-Mile Camp, Rivière Jupiter (12). ^, conodont barren; *, misclassified. Samples from sections 9–12 are not included in the analysis.

lowest Gun River Formation at the road cut south of the Rivière Jupiter 24 mile camp (section 6, Figs. 1, 3). The collections were made from the remaining part of the Gun River Formation along the coast from Rivière à la Loutre west to Rivière au Fusil (section 7, Figs. 1, 3) and along Rivière Jupiter (16-mile, 10-mile, 9-mile, and 8-mile pools; sections 8–12, Figs. 1, 3; sections 9–12 are not included in this paper). In these localities, the Gun River Formation is about 80–90 m thick and is dominated by fine-grained lime mudstone and wackestone units alternating with intraclastic rudstone and grainstone. Details of sample localities and stratigraphy are provided by Zhang and Barnes (2002*a*).

For the eastern facies, the Gun River Formation was measured and sampled for conodonts between Ruisseau de la Chute in the north (section A, Figs. 1, 4) and Cap Sandtop to Cap au Goélands in the south (section B, Figs. 1, 4) by S.M.L. Pohler and P. Copper. The formation here is 80–85 m thick, being dominated by fine-grained, thin-bedded limestone interbedded with fine-grained siliciclastics that alternate with medium- to thick-bedded grainstone. Overall, there is a distinctive decrease in grain size and an increase in siliciclastic influx in these eastern sections compared to those in the west.

Figure 3 shows the 61 sample locations from a composite section of Gun River Formation sensu Copper and Long (1990) from the western facies. Seventeen of 37 A samples produced 2544 specimens, and 22 of 24 C samples produced 11 321 specimens, which are assigned to 22 species (A and C samples shown in Fig. 3 are from two different collections). Figure 4 shows the sample locations from a composite section of the eastern facies, from which 49 samples yielded 5851 specimens with eight barren conodont samples (Cu1-7, Cu3-A, Cu3-C, Cu5-1, Cu5-3, Cu5-5, Cu7-A, Cu9-3). Only 16 species are recognized in the eastern facies, all of which are present in the western facies.

The database for this study consists of 80 cases that are conodont-bearing samples yielding 19 716 conodont specimens and 22 variables that are the species identified among these specimens. For each sample, the number of conodonts per species included all the different element types, and the counted numbers are converted to relative abundance (percentage) (Table 1).

These samples are representative of both different lithofacies belts, so the variable (species) data are the values of the variables for cases (samples) whose group membership is known. It is uncertain whether all samples have proven to be predefined in the natural groups. If so, the question arises as to which species are more important than others for distinguishing between the groups. Discriminant analysis is the statistical technique most commonly used to investigate this kind of problem and to determine a mathematical combination of variables that provides the maximum separation between groups. Carr et al. (1984) performed a series of discriminant analyses to define successfully the relationships between six Early Triassic conodont taxa and three lithofacies belts.

The goal of this study is to establish statistically the relationship between lithofacies belts and conodont faunas in the Gun River Formation. A series of discriminant analyses are performed using SPSS version 6.1 for the Macintosh (SPSS Inc. 1994). Both complete and stepwise models are used to distinguish the sample groups and to identify useful species for group separation.

Discriminant analysis provides the following useful tools for data interpretation: (*i*) group means and group standard deviations are helpful to analyze the differences between groups; (*ii*) the value of Wilks' lambda (sometimes called the *U* statistic) indicates if the group means appear to be different; (*iii*) a pooled, within-groups correlation matrix examines the correlation between variables; (*iv*) classification output lists classification information for each case for a group of cases whose membership is known and which cases are misclassified; (*v*) classification summary (sometimes called confusion matrix) displays the numbers of correct and incorrect classifications; and (*vi*) histograms of discriminant scores illustrate the result.

Relationships between lithofacies and conodont faunas in the Gun River Formation

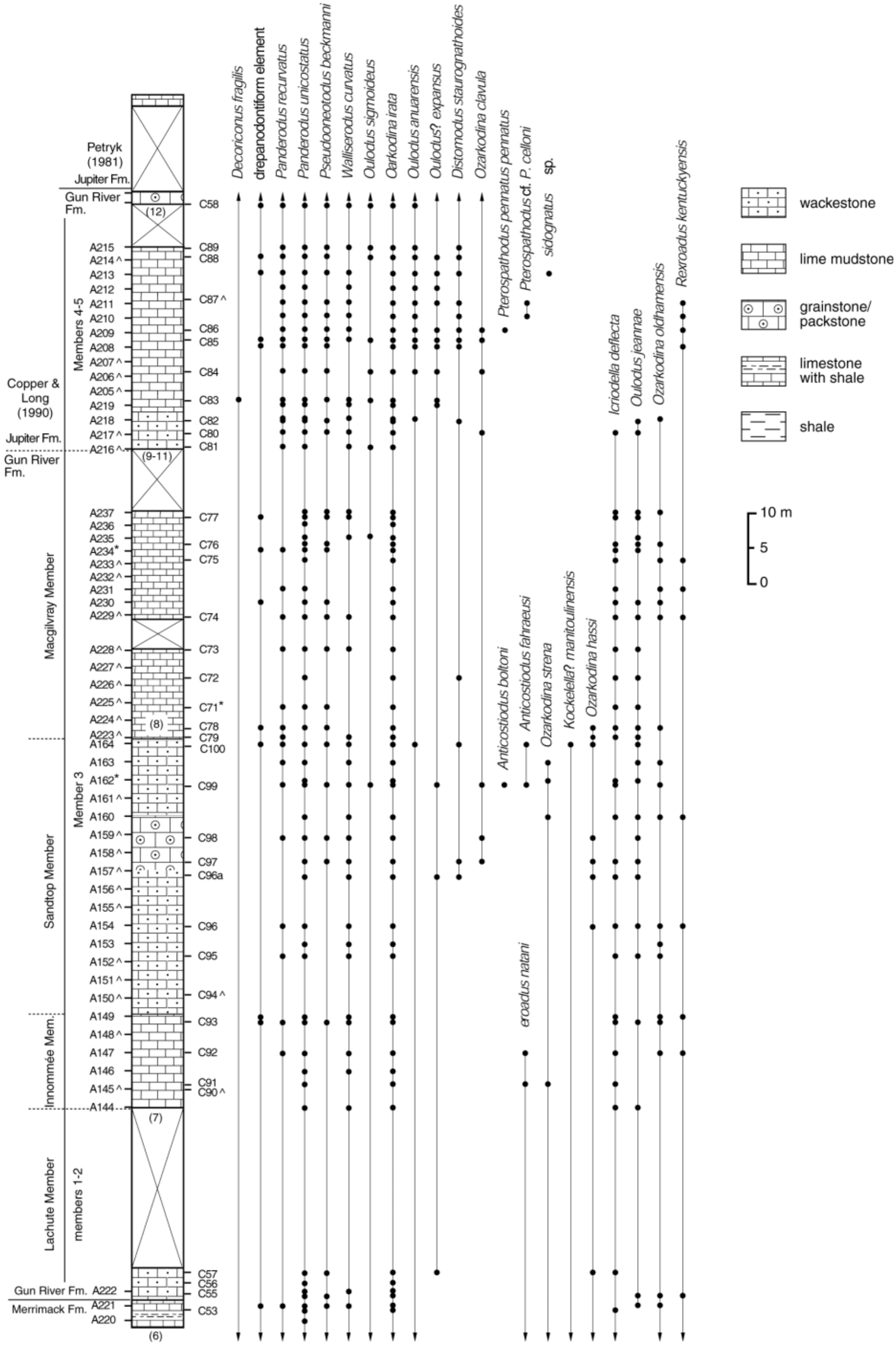
Sample selection

All 22 conodont species were selected as potential discriminating variables, which were entered together in the model as independents. Samples containing identified conodont elements assigned to one or more of the 22 species were selected as classified cases, and the species proportion in the samples comprised the database. This resulting database consisted of 80 samples assigned to either the western or the eastern facies (coded 1 for samples from the western facies and coded 2 for samples from the eastern facies). Table 2 shows the SPSS output produced after processing all the data.

Analyzing group differences

Figures 3 and 4 show the species distribution through the Gun River Formation. Table 1 gives the detailed abundance for each species in each sample. Examination of presence, absence, and abundance data for 22 conodont species shows the distribution of 16 species that are common to both lithofacies, but it also shows some obvious differences between the conodont faunas from the western and eastern facies. In the eastern facies, no specimens of *Anticostiodus boltoni* Zhang and Barnes, *Anticostiodus fahraeusi* Zhang and Barnes, *Kockelella*? *manitolinensis* Pollock, Rexroad and Nicoll, *Oulodus*? *expansus* (Armstrong), *Ozarkodina clavula* Uyeno, and *Rexroadus nathani* (McCracken and Barnes) were found. These are also rare and only found in a low abundance in several samples in the western facies. The question arises, however, whether these rare species can differentiate adequately the conodont faunas from the different lithofacies.

Initial examination of the data indicated the value of undertaking discriminant analysis. Table 3 summarizes the group means and group standard deviations and shows that


Petryk (1981)
Jupiter Fm.
Gun River Fm.
Copper & Long (1990)
Jupiter Fm.
Gun River Fm.
Members 4-5
Macgilvray Member
Member 3
Sandtop Member
Innommée Mem.
Lachute Member
members 1-2
Gun River Fm.
Merrimack Fm.
(12)
(9-11)
(8)
(7)
(6)
A215
A214 ^
A213
A212
A211
A210
A209
A208
A207 ^
A206 ^
A205 ^
A219
A218
A217 ^
A216 ^
A237
A236
A235
A234*
A233 ^
A232 ^
A231
A230
A229 ^
A228 ^
A227 ^
A226 ^
A225 ^
A224 ^
A223 ^
A164
A163
A162*
A161 ^
A160
A159 ^
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A156 ^
A155 ^
A154
A153
A152 ^
A151 ^
A150 ^
A149
A148 ^
A147
A146
A145 ^
A144
A222
A221
A220
C58
C89
C88
C87 ^
C86
C85
C84
C83
C82
C80
C81
C77
C76
C75
C74
C73
C72
C71*
C78
C79
C100
C99
C98
C97
C96a
C96
C95
C94 ^
C93
C92
C91
C90 ^
C57
C56
C55
C53
Decoriconus fragilis
drepanodontiform element
Panderodus recurvatus
Panderodus unicostatus
Pseudooneotodus beckmanni
Walliserodus curvatus
Oulodus sigmoideus
Oarkodina irata
Oulodus anuarensis
Oulodus? expansus
Distomodus staurognathoides
Ozarkodina clavula
Pterospathodus pennatus pennatus
Pterospathodus cf. P. celloni
sidognatus sp.
Icriodella deflecta
Oulodus jeannae
Ozarkodina oldhamensis
Rexroadus kentuckyensis
Anticostiodus boltoni
Anticostiodus fahraeusi
Ozarkodina strena
Kockelella? manitoulinensis
Ozarkodina hassi
eroadus natani
wackestone
lime mudstone
grainstone/ packstone
limestone with shale
shale
10 m
5
0

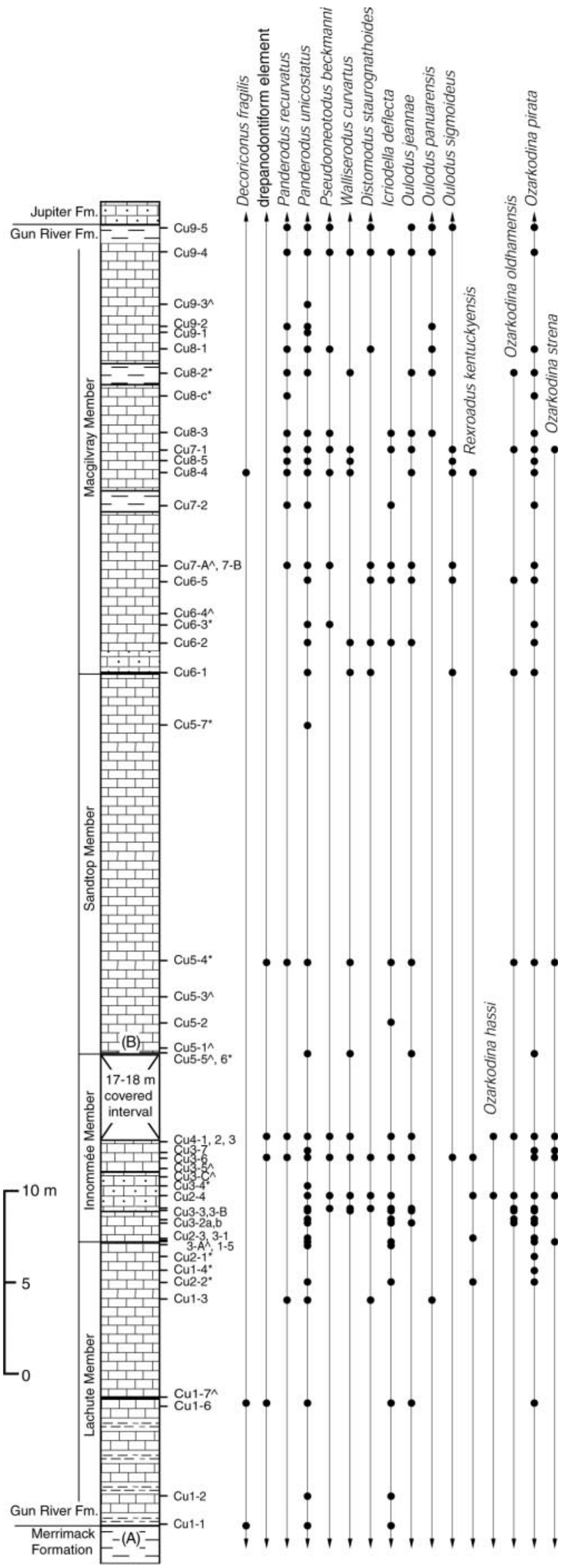


Fig. 4. Conodont distribution in the Gun River Formation of the eastern facies at Ruisseau de la Chute (A), and Cap Sandtop to Cap au Goélands (B). ^, conodont barren; *, misclassified. Legend as in Fig. 3.

both group means and group deviations of the aforementioned six species are zero in group 2 for the eastern facies, which is evident even without the analysis. The analysis, however, reveals some important differences between conodont faunas from the different lithofacies belts. The samples from the eastern facies contain 20.32% of *Icriodella deflecta* Aldridge, which is a sharp contrast to those from the western facies which yield only 4.97% of this species. Other species such as *Distomodus staurognathoides* (Walliser), *Oulodus sigmoideus* Zhang and Barnes, and *Panderodus recurvatus* (Rhodes) have a higher proportion in the eastern facies than in the western facies, and their group means and group deviations in the eastern facies range from 0.89 to 3.82% and from 2.07 to 5.03, in contrast with those from the western facies that range from 0.004 to 1.09% and from 0.02 to 2.79, respectively. These species are characterized typically by their robust elements. Samples from the western facies yield minor proportions of the following species: *Oulodus jeannae* Schönlaub, *Ozarkodina hassi* (Pollock, Rexroad, and Nicoll), *Ozarkodina oldhamensis* (Rexroad), and *Rexroadus kentuckyensis* (Branson and Branson), which have relatively slender elements, and each of these four species has a higher group mean and group deviation in the western facies than in the eastern facies. Their group means and group deviations in the western facies range from 0.35 to 5.29% and from 1.49 to 6.93, in contrast with those from the eastern facies that range from 0.02 to 2.46% and from 0.06 to 4.48, respectively.

With the exception of *Panderodus unicostatus* (Branson and Mehl) and *Ozarkodina pirata* Uyeno, all species from both facies have a higher or lower group means related to higher or lower group standard deviations, respectively. Only *P. unicostatus* and *Oz. pirata* from both facies show that their higher or lower group means are related to lower or higher group standard deviations, respectively. This indicates their ubiquitous characteristics, thus they are not useful to differentiate the conodont faunas, although *Oz. pirata* shows a closer relationship to some species from the western facies (Table 4).

Table 5 shows significance test results for the equality of group means for each variable, and the *F* values and their significance are shown in the third and fourth columns. The *F* value for *I. deflecta* is 10.82, and the significance level is almost zero. If the observed significance level is small (less than 0.05), the hypothesis that all group means are equal is rejected. The significance levels of *I. deflecta* (0.002), *P. recurvatus* (0.015), *Ou. sigmoideus* (0.016), *D. staurognathoides* (0.017), *R. kentuckyensis* (0.018), and *Ou. jeannae* (0.032) are less than 0.05, indicating that these are more important than the other species in separating the groups. The second column in Table 5 gives the values of Wilks' lambda, with the small values indicating that group means are different. The smaller lambda values are also those for *I. deflecta* (0.89), *P. recurvatus* (0.93), *Ou. sigmoideus* (0.93), *D. staurognathoides* (0.93), *R. kentuckyensis* (0.93), and *Ou. jeannae* (0.94).

Although the significance level (0.02) and lambda (0.94) of *Oz. pirata* are similar to those of *Ou. jeannae,* this species is less important in differentiating conodont faunas than *Ou. jeannae* (Table 3).

Another way to assess the contribution of a species to the separation of the groups is to examine the correlations between the values of the discriminant function and the values of the variables. Table 6 indicates that *I. deflecta* has the largest correlation, with the discriminant function having an absolute value (–0.35). The negative sign indicates that a small function value is associated with the presence of *I. deflecta* in the western facies (coded 1). This result supports quantitatively the observations made by Walliser (1971), Aldridge (1976), Aldridge and Mabillard (1981), Aldridge and Jeppsson (1984), and Idris (1984) from European collections that Silurian *Icriodella* had a nearshore, shallow-water preference. Table 6 also shows that species *P. recurvatus* (–0.26), *Ou. sigmoideus* (–0.26), *D. staurognathoides* (–0.26), *R. kentuckyensis* (0.25), and *Ou. jeannae* (0.23) have a larger correlation with the discriminant function than other species. The negative signs indicate that larger function values are associated with the presence of *P. recurvatus*, *Ou. sigmoideus*, and *D. staurognathoides* in the eastern facies together with *I. deflecta* (coded 2), and the positive signs suggest that the large function values are associated with the presence of *R. kentuckyensis* and *Ou. jeannae* in the western facies (coded 1). This output also supports quantitatively the interpretation that *R. kentuckyensis* had an offshore environmental preference (Zhang and Barnes 2002*b*, 2002*c*).

Correlations among species

Ubiquitous species such as *P. unicostatus*, *Oz. pirata*, and very rare species are not included in the following discussion. Based on analyzing group differences, it is evident that *I. deflecta* and *R. kentuckyensis* played the most important role in differentiating groups. This does not reveal which other species had a close relationship with them; however, examination of the correlation matrix of the predictor variables provides additional information.

Table 4 displays the pooled within-groups correlation matrix, which shows that *I. deflecta* has larger coefficients with several different species such as *P. recurvatus* (0.34), *D. staurognathoides* (0.28), *Ou. panuarensis* (0.23), and *Ou. sigmoideus* (0.23). This is to be expected, as all these species have higher group means and group standard deviations for the eastern facies. *Rexroadus kentuckyensis* displays the largest coefficient with *Oz. oldhamensis* (0.28); this supports the results of a cluster analysis that revealed a close relationship between them and a close relationship between them and tempestites (Zhang and Barnes 2002*c*).

Classification output

Table 7 lists the classification information for each sample for a group of samples whose natural group is known and for which samples are misclassified. The first column, case number, is the sequence number of the case in the file, which is same as the case number in Table 1. All samples are labeled from 1 to 80 in the file. There were two columns between case number and actual group in the original classification output, one column (Mis Val) indicating the number of variables with missing values (if any) for that case and one column (Sel) indicating whether a case has been excluded from the computations using selection variables, if any. These two columns have been deleted to save space in Table 7 because there were no variables with missing values and no cases being excluded from the analysis.

The group to which a sample actually belongs is listed in the column labeled actual group (column 2). The samples that are misclassified using discriminant function are marked with asterisks next to the actual group number, and the most likely group for a sample based on discriminant analysis (the group with the largest posterior probability) is listed in the column labeled “Highest group”. It is evident that three samples are misgrouped out of 39 from the western facies group, and nine samples out of 41 from the eastern facies group (Tables 7, 8). Table 8 reveals a successful discrimination of the previously defined groups: 36 of 39 samples from the western facies were predicted correctly to the members of group 1 (92.3%), and 32 of 41 samples from the eastern facies were identified correctly to the members of group 2 (78.0%). The overall percentage of samples classified correctly is 85.0% (68 out of 80 samples).

Histogram of discriminant scores

On average, samples from the western facies belt have slightly larger discriminant function scores than those from the eastern facies belt. The average value for group 1 samples from the western facies is 1.09, whereas the average value for group 2 samples from the eastern facies is 1.03 in absolute value (summarized in Table 9).

These discriminant functions can be used as axes to arrange the samples in two-dimensional space, a histogram of discriminant scores. The spatial pattern of samples in two dimensions can provide insight into underlying factors that are responsible for ecological closeness or separation. Figures 5*a* and 5*b* display the histograms of the discriminant scores for each group separately. The average score for each group is indicated in each plot, which is the same as the summary in Table 9. Two group 1 samples fall clearly into the group 2 classification area, and eight group 2 samples fall into the group 1 classification area. Both are slightly different from the summary in Table 8 which shows that three and nine samples from the western and the eastern facies are misclassified, respectively.

The combined histogram of discriminant scores for the two groups is shown in Fig. 5*c*. The amount of overlap between the two groups is clearly evident, such that the interval with midpoint 0.2 has four samples, two from group 1 and two from group 2.

Analyzing misclassified samples and facies changes

The misclassified samples always show a closer relationship to the group that is not their natural group. The significant aspect of the misclassified samples in the particular case of the Gun River Formation is that they are useful in interpreting the brief shift from the western facies to the eastern facies, or from the eastern facies to the western facies.

Table 1 shows that the common feature with the three misclassified samples from the western facies is yielding the relative abundance of *I. deflecta.* Samples A162, C71, and A234 produce 4.26–15.48% *I. deflecta*, which averages 9.20%, higher than the group mean of the species for the western facies

Table 1. Distribution of conodont species in the western and eastern facies of the Gun River Formation.

Natural group	Case number	Samples	*D. fragilis*	drepanodontiform el.	*P. recurvatus*	*P. unicostatus*	*P. beckmanni*	*W. curvatus*	*A. boltoni*	*A. fahraeusi*	*D. staurognathoides*	*I. deflecta*	*Ou. ? expansus*	*Ou. Jeannae*	*R. kentuckyensis*	*R. nathani*	*Ou. Panuarensis*	*Ou. sigmoides*	*Oz. clavula*	*Oz. hassi*	*Oz. oldhamensis*	*Oz. pirata*	*Oz. strena*	*K. ? manitoulinensis*
west	1	C55				**121** 74.69	**7** 4.23							**2** 1.24	**19** 11.73						**1** 0.62	**12** 7.41		
west	2	A222				**2** 66.67		**1** 33.33																
west	3	C56				**5** 55.56																**4** 44.44		
west	4	C57				**29** 12.78	**1** 0.44					**2** 0.88	**15** 6.61							**21** 9.25		**159** 7.4		
west	5	A144				**5** 11.9		**2** 4.76				**5** 11.9		**14** 33.33								**16** 38.1		
west	6	C91				**36** 45						**13** 16.25				**18** 22.5						**12** 15	**1** 1.25	
west	7	A146				**9** 50		**1** 5.56						**3** 16.67								**5** 27.78		
west	8	A147				**22** 64.71									**5** 14.71							**7** 20.59		
west	9	C92			**1** 0.71	**91** 64.54		**1** 0.71				**12** 8.51				**14** 9.93					**1** 0.71	**21** 14.89		
west	10	C93		**4** 0.34	**4** 0.34	**672** 57.63	**11** 0.94	**2** 0.17				**45** 3.86		**65** 5.58							**63** 5.4	**300** 25.73		
west	11	A149		**3** 0.93		**169** 52.17		**7** 2.16				**22** 6.79			**41** 12.65						**15** 4.63	**67** 20.68		
west	12	C95			**4** 1.8	**105** 47.3		**1** 0.45				**14** 6.31		**26** 11.71							**4** 1.8	**68** 30.63		
west	13	A153				**5** 100																		
west	14	A154			**1** 4	**19** 76									**2** 8							**3** 12		
west	15	C96				**70** 31.11						**43** 19.11		**46** 20.44							**5** 2.22	**61** 27.11		
west	16	C96a				**149** 59.84		**5** 2.01			**1** 0.4	**4** 1.61	**3** 1.21	**9** 3.61						**2** 0.8		**76** 30.52		
west	17	C97				**184** 36.95	**4** 0.8	**4** 0.8				**6** 1.21		**11** 2.21					**1** 0.2	**3** 0.6		**285** 57.23		
west	18	C98			**37** 6.8	**306** 56.25	**2** 0.37	**6** 1.1						**4** 7.35					**3** 0.55	**6** 1.1		**144** 26.47		
west	19	A160			**1** 0.44	**15** 6.55						**7** 3.06		**11** 4.8	**2** 0.87						**1** 0.44	**185** 80.79	**7** 3.06	
west	20*	A162*				**38** 40.43						**4** 4.26		**11** 11.7								**36** 38.3	**5** 5.32	
west	21	C99			**12** 0.26	**2813** 61.11	**178** 3.87	**67** 1.46	**14** 0.3	**14** 0.3		**9** 0.2	**31** 0.67					**7** 0.15	**14** 0.3		**119** 2.59	**1325** 28.79		
west	22	A163			**2** 1.75	**82** 71.93		**2** 1.75						**9** 7.9							**2** 1.75	**15** 13.16	**2** 1.75	
west	23	A164		**1** 0.13		**52** 6.74	**6** 0.78				**1** 0.13			**34** 4.4						**6** 0.78		**670** 86.79		**2** 0.26
west	24	C100			**48** 13.68	**154** 43.87				**2** 0.57	**2** 0.57			**17** 4.84			**12** 3.42					**116** 33.05		
west	25	C79			**5** 0.75	**584** 87.29	**2** 0.3	**5** 0.75				**23** 3.44		**11** 1.64						**4** 0.6		**35** 5.23		
west	26	C78		**2** 0.22	**5** 0.56	**698** 78.34	**2** 0.22	**11** 1.24				**4** 0.45		**31** 3.48						**5** 0.56	**25** 2.81	**108** 12.12		
west	27*	C71*			**10** 7.81	**66** 51.56	**1** 0.78					**10** 7.81		**7** 5.47								**34** 26.56		
west	28	C72				**30** 60					**1** 2	**7** 14		**7** 14								**5** 10		
west	29	C73			**1** 0.67	**89** 59.33	**1** 0.67	**4** 2.67				**17** 11.33		**16** 10.67								**22** 14.67		
west	30	C74			**2** 0.37	**412** 75.74	**1** 0.18	**5** 0.92				**13** 2.39		**5** 0.92	**20** 3.68						**7** 1.29	**79** 14.52		
west	31	A230		**1** 1.21		**49** 59.04	**6** 7.23					**6** 7.23		**5** 6.02							**1** 1.21	**15** 18.07		
west	32	A231			**1** 0.83	**84** 69.42						**7** 5.79			**16** 13.22						**1** 0.83	**12** 9.92		

Table 1 (*continued*).

Natural group	Case number	Samples	*D. fragilis*	drepanodontiform el.	*P. recurvatus*	*P. unicostatus*	*P. beckmanni*	*W. curvatus*	*A. boltoni*	*A. fahraeusi*	*D. staurognathoides*	*I. deflecta*	*Ou. ? expansus*	*Ou. Jeannae*	*R. kentuckyensis*	*R. nathani*	*Ou. Panuarensis*	*Ou. sigmoides*	*Oz. clavula*	*Oz. hassi*	*Oz. oldhamensis*	*Oz. pirata*	*Oz. strena*	*K. ? manitoulinensis*
west	33	C75				**10** 23.81						**12** 28.57			**10** 23.81						**2** 4.76	**8** 19.05		
west	34*	A234*		**1** 0.4	**5** 1.98	**156** 61.9	**1** 0.4					**39** 15.48		**7** 2.78								**43** 17.06		
west	35	C76				**131** 53.25	**1** 0.41					**22** 8.94		**11** 4.47							**1** 0.41	**80** 32.52		
west	36	A235				**38** 84.44		**2** 4.44						**1** 2.22								**4** 8.89		
west	37	A236				**1** 33.33																**2** 66.67		
west	38	C77		**1** 0.63		**61** 38.13	**5** 3.13	**3** 1.88				**3** 1.88		**16** 10								**71** 44.38		
west	39	A237				**197** 51.84	**5** 1.32	**7** 1.84				**10** 2.63		**33** 8.68							**13** 3.42	**115** 30.26		
east	40	Cu1-1	**1** 8.3			**8** 66.7	**1** 8.3					**2** 16.7												
east	41	Cu1-2				**2** 40						**3** 60												
east	42	Cu1-3			**7** 15.2	**25** 54.3					**2** 4.3						**8** 17.4					**4** 8.7		
east	43*	Cu1-4*																				**1** 100		
east	44	Cu1-5				**1** 50						**1** 50												
east	45	Cu1-6	**2** 3.6	**2** 3.6		**8** 14.5						**40** 72.7		**1** 1.8								**2** 3.6		
east	46*	Cu2-1*																				**1** 100		
east	47*	Cu2-2*				**1** 11.1						**1** 11.1			**1** 11.1							**6** 66.7		
east	48	Cu2-3				**37** 35.2						**56** 53.3			**4**							**12** 11.4		
east	49	Cu2-4				**396** 49.7	**8** 1	**3** 0.4			**6** 0.8	**44** 5.5			**8** 1					**2** 0.3	**1** 0.1	**257** 32.2	**72** 9	
east	50	Cu3-1				**14** 51.9						**9** 33.3										**3** 11.1	**1** 3.7	
east	51	Cu3-2a				**51** 17.2						**225** 75.8			**9** 3						**4** 1.3	**9** 3		
east	52	Cu3-2b				**13** 6.2						**194** 91.9									**1** 0.5	**3** 1.4		
east	53	Cu3-3				**52** 50		**1** 1				**41** 39.4		**5** 4.8							**2** 1.9	**3** 2.9		
east	54*	Cu3-4*				**4** 100																		
east	55	Cu3-6		**14** 2	**26** 3.7	**334** 47.9	**6** 0.9	**2** 0.3			**2** 0.3	**220** 31.5		**8** 1.1	**3** 0.4			**2** 0.3				**79** 11.3	**4** 0.6	
east	56	Cu3-7				**3** 33.3						**4** 44.4										**2** 22.2		
east	57	Cu3B				**366** 44.1	**3** 0.4	**9** 1.1			**1** 0.1	**330** 39.8		**19** 2.3							**53** 6.4	**49** 5.9		
east	58	Cu4-1		**1** 0.3		**107** 32	**1** 0.3					**6** 1.8		**4** 1.2						**1** 0.3	**6** 1.8	**195** 58.4	**13** 3.9	
east	59	Cu4-2				**1** 50						**1** 50												
east	60	Cu4-3			**25** 10.4	**186** 77.2	**1** 0.4	**2** 0.8				**6** 2.5									**3** 1.2	**10** 4.1	**8** 3.3	
east	61	Cu5-2										**1** 100												
east	62*	Cu5-4*		**1** 0.8	**10** 7.5	**85** 63.9		**5** 3.8				**3** 2.3		**13** 9.8							**2** 1.5	**12** 9	**2** 1.5	
east	63*	Cu5-6*				**14** 63.6		**1** 4.5						**3** 13.6								**4** 18.2		
east	64*	Cu5-7*				**1** 100																		

Table 1 (*concluded*).

Natural group	Case number	Samples	*D. fragilis*	drepanodontiform el.	*P. recurvatus*	*P. unicostatus*	*P. beckmanni*	*W. curvatus*	*A. boltoni*	*A. fahraeusi*	*D. staurognathoides*	*I. deflecta*	*Ou. ? expansus*	*Ou. Jeannae*	*R. kentuckyensis*	*R. nathani*	*Ou. Panuarensis*	*Ou. sigmoides*	*Oz. clavula*	*Oz. hassi*	*Oz. oldhamensis*	*Oz. pirata*	*Oz. strena*	*K. ? manitoulinensis*
east	65	Cu6-1				**14** 56		**1** 4			**2** 8							**4** 16			**1** 4	**3** 12		
east	66	Cu6-2				**76** 77.6		**2** 2			**5** 5.1	**2** 2		**5** 5.1								**8** 8.2		
east	67*	Cu6-3*				**8** 66.7	**1** 8.3															**3** 25		
east	68	Cu6-5				**64** 66					**1** 1	**5** 5.2		**1** 1				**8** 8.2			**1** 1	**17** 17.5		
east	69	Cu7-1			**8** 3.1	**140** 54.7	**1** 0.4	**2** 0.8				**45** 17.6		**1** 0.4				**27** 10.5			**1** 0.4	**24** 9.4	**7** 2.7	
east	70	Cu7-2			**1** 16.7	**3** 50						**1** 16.7										**1** 16.7		
east	71	Cu7-B			**6** 4.3	**84** 60.4	**8** 5.8				**5** 3.6	**3** 2.2		**12** 8.6				**6** 4.3				**15** 10.8		
east	72	Cu8-1			**10** 16.1	**33** 53.2	**1** 1.6				**5** 8.1						**6** 9.7					**7** 11.3		
east	73*	Cu8-2*			**5** 3.8	**94** 71.2		**2** 1.5						**22** 16.7			**4** 3				**2** 1.5	**3** 2.3		
east	74	Cu8-3			**23** 13.8	**96** 57.5	**1** 0.6					**10** 6		**21** 12.6			**1** 0.6					**15** 9		
east	75*	Cu8-c*				**6** 85.7																**1** 14.3		
east	76	Cu8-4	**3** 0.8		**31** 8.1	**247** 64.8	**2** 0.5	**9** 2.4						**32** 8.4	**14** 3.7			**16** 4.2				**34** 8.9		
east	77	Cu8-5			**1** 12.5	**3** 37.5		**1** 12.5										**1** 12.5				**2** 25		
east	78	Cu9-2			**1** 25	**2** 50											**1** 25							
east	79	Cu9-4			**31** 10.5	**204** 69.4	**1** 0.3				**10** 3.4			**2** 0.7			**9** 3.1	**13** 4.4				**24** 8.2		
east	80	Cu9-5			**12** 5.9	**123** 60.9	**3** 1.5	**15** 7.4			**4** 2	**3** 1.5		**3** 1.5			**13** 6.4					**26** 12.9		

Note: The absolute abundances are shown in bold, and the relative abundances are shown immediately below each absolute abundance. *, Misclassified in the analysis.

Table 2. Sample summary from discriminant analysis.

	No. of cases by group		
Facies	Unweighted	Weighted	Label
1	39	39.0	West
2	41	41.0	East
Total	80	80.0	

Note: Eighty (unweighted) cases were processed, and none of these cases were excluded from the analysis.

(4.97%) (Table 3) and lower than that for the eastern facies (20.32%). Although these samples are misclassified with most samples from the eastern facies, they do not have conodont fauna characteristics of the eastern facies or the western facies, i.e., the conodont fauna has transitional characteristics. Besides the lower abundance of *I. deflecta*, all three samples do not have the characteristic species in the eastern facies, such as *Ou. sigmoideus* and *D. staurognathoides*, and the characteristic species from the western facies, such as *R. kentuckyensis* and *Oz. oldhamensis.* Sample C71 was once grouped in the *I. deflecta – Ou. jeannae – Oz. pirata* community by a cluster analysis based on the samples from the western facies (Zhang and Barnes 2002*b*). It was interpreted as representing a moderately high sea level. When the samples from both the western and eastern facies are combined, sample C71 tends to be grouped with samples from the eastern facies. It probably represented a lower sea level than the *I. deflecta – Ou. jeannae – Oz. pirata* community, which is the dominant community in the Gun River Formation in the western facies, or a lower sea level than that of most of the samples from the western facies. If most of the samples from the western facies represented a pattern of facies distribution illustrated by Petryk (1981) (Figs. 2, 6*b*), then the presence of a sample such as C71 probably represented a shift of the eastern facies westwards for a brief interval (Fig. 6*a*).

Examining nine misclassified samples from the eastern facies reveals an interesting pattern of their distribution through the section. Three are found out of eight conodont-bearing samples (38%) in the Lachute Member, one out of 13 (8%) in the Innommée Member, three out of four (75%) in the Sandtop Member, and three out of 17 (18%) in the Macgilvray Member. Overall, the proportions of misclassified samples from the Lachute and Sandtop members (38–75%) are higher than those from the Innommée and Macgilvray members (8–18%).

Based on the sedimentary structures and brachiopods, a water depth history within the Gun River Formation was

Table 3. Group means and standard deviations for 22 species.

Species[a]	Group means Facies 1	Facies 2	Total	Group standard deviations Facies 1	Facies 2	Total
BECKMANN	0.66818	0.73902	0.70449	1.47985	1.98064	1.74384
BOLTONI	0.00779	0.00000	0.00380	0.04868	0.00000	0.03399
CLAVULA	0.02708	0.00000	0.01320	0.10360	0.00000	0.07313
CURVATUS	1.74328	1.03659	1.38110	5.37799	2.41555	4.12225
DEFLECTA	**4.97072**	**20.32195**	12.83823	**6.58526**	**28.41830**	22.12226
EXPANSUS	0.21759	0.00000	0.10608	1.07268	0.00000	0.75196
FAHRAEUS	0.02241	0.00000	0.01093	0.10231	0.00000	0.07184
FRAGILIS	0.00000	0.30976	0.15875	0.00000	1.40139	1.00929
HASSI	***0.35115***	***0.01463***	0.17869	***1.48919***	***0.06543***	1.04764
JEANNAE	***5.28569***	***2.45610***	3.83553	***6.92746***	***4.48102***	5.93938
MANITOLI	0.00664	0.00000	0.00324	0.04147	0.00000	0.02896
NATHANI	0.83151	0.00000	0.40536	3.89963	0.00000	2.73674
OLDHAMEN	***0.89418***	***0.52683***	0.70591	***1.49274***	***1.23976***	1.37266
PANUAREN	**0.08767**	**1.59024**	0.85774	**0.54748**	**4.94494**	3.61889
PIRATA	27.67731	16.13659	21.76269	20.86319	23.79528	23.01653
R.KENTUC	***2.27356***	***0.19756***	1.20961	***5.45885***	***0.74582***	3.96305
RECURVAT	**1.09623**	**3.81951**	2.49191	**2.69915**	**6.27297**	5.03039
SIGMOIDE	**0.00390**	**1.47317**	0.75690	**0.02434**	**3.72941**	2.75477
STAUROGN	**0.07954**	**0.89512**	0.49753	**0.33469**	**2.07074**	1.54703
STRENA	0.29179	0.60244	0.45100	1.01249	1.70154	1.40836
SUBERECT	0.09872	0.16341	0.13188	0.26469	0.64411	0.49480
UNICOSTA	53.36272	49.76585	51.51933	21.83703	24.88449	23.37060

Note: Significant values for the eastern and western facies are shown in bold and bold italic, respectively.
[a]BECKMANN, *Pseudooneotodus beckmanni*; BOLTONI, *Anticostiodus boltoni*; CLAVULA, *Ozarkodina clavula*; CURVATUS, *Walliserodus curvatus*; DEFLECTA, *Icriodella deflecta*; EXPANSUS, *Oulodus*? *expansus*; FAHRAEUS, *Anticostiodus fahraeusi*; FRAGILIS, *Distomodus fragilis*; HASSI, *Ozarkodina hassi*; JEANNAE, *Oulodus jeannae*; MANITOLI, *Kockelella*? *manitolinensis*; NATHANI, *Rexroadus nathani*; OLDHAMEN, *Ozarkodina oldhamensis*; PANUAREN, *Oulodus panuarensis*; PIRATA, *Ozarkodina pirata*; R.KENTUC, *Rexroadus kentuckyensis*; RECURVAT, *Panderodus recurvatus*; SIGMOIDE, *Oulodus sigmoideus*; STAUROGN, *Distomodus staurognathoides*; STRENA, *Ozarkodina strena*; SUBERECT, drepanodontiform element; UNICOSTA, *Panderodus unicostatus*.

depicted based on the section along the northeastern coast (Long and Copper 1994), i.e., the intervals of Lachute and Sandtop members may reflect a water depth of BA5 (BA, benthic assemblage of Boucot 1975), and the intervals of Innimmée and Macgilvray members may represent a water depth of BA4. It is interesting that the members with a higher proportion of misclassified samples are related to a higher sea level, and those with a lower proportion of misclassified samples are related to a lower sea level.

In the nine misclassified samples from the eastern facies, *I. deflecta* is absent from seven of the samples (Cu1-4, Cu2-1, Cu3-4, Cu5-6, Cu5-7, Cu8-2, Cu8-c) and rare in the other two (Cu2-2 (11.1%) and Cu5-4 (2.3%)). The absence or lower proportion of *I. deflecta* is characteristic of the western facies, which is expected to be more related to higher sea level than the eastern facies. Thus, these misclassified samples from the eastern facies are interpreted to be the result of the western facies expanding eastwards (Fig. 6*c*).

Comparisons between the two methods of discriminant analysis

The foregoing discussion focuses on the relationships between lithofacies and conodont faunas of the Gun River Formation and is based on the complete model. Discriminant analysis also offers another method, the stepwise model.

From the previous analysis, *I. deflecta* and *R. kentuckyensis* are the two most important species and *D. staurognathoides*, *Ou. jeannae*, *Ou. sigmoideus*, and *P. recurvatus* are less important species among the total fauna of 22 species in differentiating conodont faunas; this was not known in advance. The stepwise method identifies the useful predictor variables. The method enters the variables into the analysis step by step, and the first variable entered into the model has the largest acceptable value for the selection criterion. The analysis performed five steps to enter *I. deflecta*, *P. recurvatus*, *Ou. sigmoideus*, *R. kentuckyensis*, and *A. fahraeusi*. The first three species entered into the model coincide with the selection by the complete model. *Rexroadus kentuckyensis*, however, was placed in the fifth most important position in differentiating conodont faunas by the complete model, but here it is placed in the fourth step. *Anticostiodus fahraeusi* and *D. staurognathoides* were placed in the eleventh and fourth positions with selection by the complete model, respectively, but here the former is placed in the first fifth steps, and the latter is not even chosen by the first five steps.

The complete model gave an overall percentage of correct classification, which is 85%, but the stepwise model decreased the percentage to 80%. The two methods are in agreement on the main aspects of interpretation of conodont faunas and relationships between conodont faunas and environments. The disagreements in the minor aspects were

Table 4. Pooled within-groups correlation matrix for 22 species.

	BECKMANN	BOLTONI	CLAVULA	CURVATUS	**DEFLECTA**	EXPANSUS	FAHRAEUS	FRAGILIS	HASSI	***JEANNAE***	MANITOLI
BECKMANN	1.00000										
BOLTONI	0.20912	1.00000									
CLAVULA	0.08429	0.43930	1.00000								
CURVATUS	–0.07993	–0.00797	–0.02699	1.00000							
DEFLECTA	–0.15318	–0.02625	–0.04204	–0.13940	1.00000						
EXPANSUS	–0.00150	0.06977	–0.00596	–0.04720	–0.02815	1.00000					
FAHRAEUS	0.06053	0.45234	0.17071	–0.04696	–0.03687	0.00346	1.00000				
FRAGILIS	0.43615	0.00000	0.00000	–0.03476	0.08710	0.00000	0.00000	1.00000			
HASSI	–0.02336	–0.03871	0.06099	–0.05940	–0.03875	0.97293	–0.05296	–0.00228	1.00000		
JEANNAE	–0.03182	–0.10448	–0.03319	0.04125	–0.09161	–0.11950	–0.05752	–0.03961	–0.11636	1.00000	
MANITOLI	0.00711	–0.02632	–0.04295	–0.04838	–0.02733	–0.03334	–0.03600	0.00000	0.04695	–0.01743	1.00000
NATHANI	–0.05817	–0.03504	–0.05720	–0.05640	0.06523	–0.04439	–0.04794	0.00000	–0.05155	–0.13913	–0.03504
OLDHAMEN	–0.01857	0.14169	–0.02052	–0.04292	0.07396	–0.07316	0.00057	–0.06244	–0.09377	–0.01192	–0.07493
PANUAREN	–0.04936	–0.00282	–0.00461	–0.01889	–0.22925	–0.00358	0.09437	–0.07244	–0.00745	–0.05720	–0.00282
PIRATA	–0.04403	0.00569	0.04440	–0.14633	–0.25853	0.21704	0.02724	–0.10536	0.24843	0.05083	0.30251
R.KENTUC	–0.02225	–0.06778	–0.11064	–0.09906	0.07894	–0.08587	–0.09273	0.00150	–0.09914	***–0.24978***	–0.06778
RECURVAT	–0.07343	–0.01967	0.09715	0.02821	**–0.33715**	–0.03208	0.25501	–0.11022	–0.02287	0.01853	–0.02581
SIGMOIDE	–0.03097	0.00636	0.00279	0.20461	**–0.22590**	0.00044	0.00288	–0.07342	–0.00432	–0.05053	–0.00017
STAUROGN	0.04807	–0.00608	–0.00992	0.03074	**–0.28181**	–0.00217	0.03054	–0.09674	–0.00790	–0.01448	0.00386
STRENA	–0.06613	–0.02376	–0.03879	–0.06185	–0.10835	–0.03010	–0.03251	–0.06939	–0.00427	–0.01401	–0.02376
SUBERECT	0.08327	–0.02279	–0.03720	–0.04063	0.24183	–0.02887	–0.03118	0.27985	–0.02810	–0.00911	0.00722
UNICOSTA	0.14390	0.03790	0.00489	0.09128	–0.46022	–0.18632	–0.02340	0.01396	–0.20188	–0.13688	–0.22809

Note: The matrix is for 22 species (abbreviations as in Table 3). A number of significant species show a close relationship, whose correlation coefficients

Table 5. Tests for univariate equality of group means for 22 species (Wilks' lambda (*U*-statistic) and univariate *F*-ratio with 1 and 78 degrees of freedom).

Variable	Wilks' lambda	*F*	Significance
BECKMANN	0.99958	0.0326	0.8572
BOLTONI	0.98669	1.0520	0.3082
CLAVULA	0.96531	2.8027	0.0981
CURVATUS	0.99256	0.5843	0.4469
DEFLECTA	**0.87817**	**10.8212**	**0.0015**
EXPANSUS	0.97882	1.6881	0.1977
FAHRAEUS	0.97538	1.9686	0.1646
FRAGILIS	0.97617	1.9042	0.1716
HASSI	0.97389	2.0908	0.1522
JEANNAE	**0.94258**	**4.7520**	**0.0323**
MANITOLI	0.98669	1.0520	0.3082
NATHANI	0.97664	1.8654	0.1759
OLDHAMEN	0.98188	1.4395	0.2339
PANUAREN	0.95638	3.5573	0.0630
PIRATA	0.93639	5.2985	0.0240
R.KENTUC	**0.93057**	**5.8193**	**0.0182**
RECURVAT	**0.92585**	**6.2469**	**0.0145**
SIGMOIDE	**0.92803**	**6.0492**	**0.0161**
STAUROGN	**0.92968**	**5.8997**	**0.0174**
STRENA	0.98769	0.9721	0.3272
SUBERECT	0.99567	0.3389	0.5622
UNICOSTA	0.99401	0.4703	0.4949

Note: Significant species and their values are shown in bold. Species abbreviations as in Table 3.

probably caused by the analysis itself, as in fact sometimes the percentage of cases classified correctly decreases if poor predictors are included in the model. From this point of view, *D. staurognathoides* would probably be a better predictor than *A. fahraeusi.*

Discussion

Interpretations of sedimentological structures in the Gun River Formation by Long and Copper (1994) and Long (1997) suggest that the paleoflow was 15–195° (north–south) during Gun River time, with the exception of some localities in the Lachute Member in the east. This is based on the measurement on gutter casts. The gutter casts could be either parallel or perpendicular to the paleo-shoreline; if the former was the case, then the Gun River Formation would not show a difference between the eastern and western facies. The different conodont faunas from the eastern and the western facies, however, do not coincide with their sedimentological interpretation. Actually, the sedimentological structures from

NATHANI	***OLDHAMEN***	PANUAREN	***PIRATA***	R.KENTUC	RECURVAT	SIGMOIDE	STAUROGN	STRENA	SUBERECT	UNICOSTA
1.00000										
–0.07556	1.00000									
–0.00376	–0.08653	1.00000								
–0.08662	–0.11621	–0.10478	1.00000							
–0.09026	***0.28157***	–0.01932	***–0.15613***	1.00000						
–0.02757	–0.14956	0.68694	–0.13080	–0.03560	1.00000					
–0.00022	0.15723	–0.11109	–0.02238	0.00422	0.05695	1.00000				
–0.00809	0.07244	0.28785	–0.07968	–0.02971	0.21754	0.36023	1.00000			
0.06240	–0.02371	–0.10292	0.16112	–0.04458	–0.08641	–0.02693	–0.09479	1.00000		
–0.03035	0.05634	–0.07963	–0.06462	–0.01634	–0.08147	–0.08970	–0.09774	–0.02912	1.00000	
–0.01550	–0.00763	0.04400	–0.63886	0.01282	0.11993	0.06699	0.14055	–0.04962	–0.13656	1.00000

for the eastern facies and western facies are shown in bold and bold italic, respectively. Species abbreviations as in Table 3.

Table 6. Pooled within-groups correlations between discriminating variables and canonical discriminant functions for 22 species (variables ordered by size of correlation within function).

Function 1	
DEFLECTA	**–0.34700**
RECURVAT	**–0.26365**
SIGMOIDE	**–0.25945**
STAUROGN	**–0.25622**
R.KENTUC	**0.25447**
PIRATA	0.24281
JEANNAE	**0.22995**
PANUAREN	–0.19896
CLAVULA	0.17660
HASSI	0.15253
FAHRAEUS	0.14800
FRAGILIS	–0.14556
NATHANI	0.14407
EXPANSUS	0.13706
OLDHAMEN	0.12656
MANITOLI	0.10819
BOLTONI	0.10819
STRENA	–0.10400
CURVATUS	0.08064
UNICOSTA	0.07409
SUBERECT	–0.06141
BECKMANN	–0.01904

Note: Significant species and their values are shown in bold. Species abbreviations as in Table 3.

the eastern and western facies are not constant (Long 1997); for example, grainstone and hummocky cross-stratification are quite different between the two sides of the island (Long 1997).

Conclusions

Statistical analysis of exceptionally well preserved conodonts from the western and eastern facies of the Gun River Formation on Anticosti Island demonstrates the relationships between lithofacies and conodont faunas. Discriminant analysis provides an excellent tool to differentiate quantitatively the conodont faunas from different lithofacies. From this discriminant analysis, the following conclusions were made:

(1) The environmental preference of the Gun River Formation conodont faunas on Anticosti Island is in general agreement with some earlier studies, which indicated that changes in conodont faunas were closely related to the changes of lithofacies.

(2) Most samples are classified correctly (85%), which means that during Gun River Formation time, sea level remained stable and moderately high, and the western and eastern facies distribution pattern was relatively constant. The overall percentage of samples that are misclassified (15%) was probably caused by brief sea level changes.

(3) The discriminant functions reveal that two species, *I. deflecta* and *R. kentuckyensis*, are the most discriminating variables among the 22 species. The first is the representative of the eastern facies (nearshore), and the latter is the indicator of the western facies (offshore).

(4) The group means and standard deviations give a statistical measurement to indicate that *I. deflecta* has a closer relationship to the species with robust elements, and *R. kentuckyensis* has a closer relationship to the species with slender elements.

(5) Some rare species were restricted to the western facies, such as *R. nathani* and the two species of *Anticostiodus*,

Table 7. Classification output for 80 samples.

Case No.	Actual group	Highest group: Group No.	P(D/G)	P(G/D)	Second-highest group: Group No.	P(G/D)	Discriminant scores
1	1	1	0.5353	0.9724	2	0.0276	1.7067
2	1	1	0.6336	0.9630	2	0.0370	1.5633
3	1	1	0.4321	0.6416	2	0.3584	0.3012
4	1	1	0.2403	0.9913	2	0.0087	2.2610
5	1	1	0.3095	0.9879	2	0.0121	2.1030
6	1	1	0.2007	0.9930	2	0.0070	2.3662
7	1	1	0.6522	0.9610	2	0.0390	1.5374
8	1	1	0.3105	0.9879	2	0.0121	2.1008
9	1	1	0.8562	0.9329	2	0.0671	1.2679
10	1	1	0.8718	0.8706	2	0.1294	0.9254
11	1	1	0.2587	0.9905	2	0.0095	2.2161
12	1	1	0.7326	0.8211	2	0.1789	0.7450
13	1	1	0.4677	0.6700	2	0.3300	0.3605
14	1	1	0.7830	0.8408	2	0.1592	0.8113
15	1	1	0.9969	0.9038	2	0.0962	1.0828
16	1	1	0.7459	0.8265	2	0.1735	0.7626
17	1	1	0.8660	0.9312	2	0.0688	1.2555
18	1	1	0.2203	0.9922	2	0.0078	2.3124
19	1	1	0.2934	0.5050	2	0.4950	0.0359
20	1*	2	0.2891	0.5001	1	0.4999	0.0264
21	1	1	0.3456	0.9859	2	0.0141	2.0299
22	1	1	0.5711	0.7402	2	0.2598	0.5202
23	1	1	0.3456	0.9859	2	0.0141	2.0299
24	1	1	0.3456	0.9859	2	0.0141	2.0299
25	1	1	0.4470	0.6538	2	0.3462	0.3263
26	1	1	0.7902	0.8434	2	0.1566	0.8207
27	1*	2	0.6694	0.7929	1	0.2071	–0.6067
28	1	1	0.4847	0.6827	2	0.3173	0.3879
29	1	1	0.6196	0.7677	2	0.2323	0.5903
30	1	1	0.8002	0.8470	2	0.1530	0.8337
31	1	1	0.5370	0.7189	2	0.2811	0.4694
32	1	1	0.5405	0.9720	2	0.0280	1.6987
33	1	1	0.1353	0.9956	2	0.0044	2.5802
34	1*	2	0.4095	0.6222	1	0.3778	–0.2089
35	1	1	0.4304	0.6402	2	0.3598	0.2983
36	1	1	0.6579	0.7874	2	0.2126	0.6440
37	1	1	0.4149	0.6270	2	0.3730	0.2715
38	1	1	0.8510	0.8641	2	0.1359	0.8988
39	1	1	0.9518	0.8928	2	0.1072	1.0262
40	2	2	0.3059	0.9881	1	0.0119	–2.0577
41	2	2	0.5175	0.9739	1	0.0261	–1.6809
42	2	2	0.3536	0.9854	1	0.0146	–1.9614
43	2*	1	0.3900	0.6047	2	0.3953	0.2270
44	2	2	0.7588	0.9478	1	0.0522	–1.3407
45	2	2	0.3336	0.9866	1	0.0134	–2.0006
46	2*	1	0.3900	0.6047	2	0.3953	0.2270
47	2*	1	0.6044	0.7594	2	0.2406	0.5686
48	2	2	0.6639	0.9597	1	0.0403	–1.4682
49	2	2	0.7854	0.9440	1	0.0560	–1.3060
50	2	2	0.7304	0.9516	1	0.0484	–1.3783
51	2	2	0.4647	0.9781	1	0.0219	–1.7649
52	2	2	0.0897	0.9971	1	0.0029	–2.7308
53	2	2	0.6033	0.7588	1	0.2412	–0.5140
54	2*	1	0.4677	0.6700	2	0.3300	0.3605
55	2	2	0.9025	0.8796	1	0.1204	–0.9112
56	2	2	0.8839	0.9281	1	0.0719	–1.1798
57	2	2	0.5114	0.7018	1	0.2982	–0.3770
58	2	2	0.3596	0.5757	1	0.4243	–0.1175
59	2	2	0.7588	0.9478	1	0.0522	–1.3407
60	2	2	0.6837	0.9574	1	0.0426	–1.4411
61	2	2	0.0446	0.9985	1	0.0015	–3.0419
62	2*	1	0.3214	0.5364	2	0.4636	0.0952
63	2*	1	0.8113	0.9402	2	0.0598	1.3254
64	2*	1	0.4677	0.6700	2	0.3300	0.3605
65	2	2	0.1296	0.9958	1	0.0042	–2.5492
66	2	2	0.3977	0.6118	1	0.3882	–0.1880
67	2	2	0.3087	0.5224	1	0.4776	–0.0158
68	2	2	0.8910	0.8763	1	0.1237	–0.8967
69	2	2	0.2012	0.9930	1	0.0070	–2.3119
70	2	2	0.2072	0.9928	1	0.0072	–2.2951
71	2	2	0.9342	0.9186	1	0.0814	–1.1163
72	2	2	0.0614	0.9980	1	0.0020	–2.9041
73	2*	1	0.9746	0.9102	2	0.0898	1.1186
74	2	2	0.8238	0.8552	1	0.1448	–0.8110
75	2*	1	0.4561	0.6610	2	0.3390	0.3414
76	2	2	0.4645	0.6675	1	0.3325	–0.3022
77	2	2	0.1947	0.9933	1	0.0067	–2.3306
78	2	2	0.1991	0.9931	1	0.0069	–2.3179
79	2	2	0.3412	0.9862	1	0.0138	–1.9856
80	2	2	0.5065	0.6983	1	0.3017	–0.3693

Note: See text for explanation. *, Misclassified in the analysis.

Table 8. Classification results.

Actual group	No. of cases	Predicted group membership: Group 1	Group 2
1 (west)	39	36 (92.3%)	3 (7.7%)
2 (east)	41	9 (22.0%)	32 (78.0%)

Note: Percentage of "grouped" cases correctly classified is 85.00%.

Table 9. Canonical Discriminant functions evaluated at group means (group centroids).

Group	Function 1
1	1.08672
2	–1.03371

but they do not play an important role in separating conodont faunas.

(6) Overall, the two different discriminant models identify the same environmentally sensitive conodont species.

Acknowledgments

C.R. Barnes gratefully acknowledges financial support for this conodont research from Pan-Lithoprobe, the Natural Sciences and Engineering Research Council of Canada (NSERC), and the Earth System Evolution Program of the Canadian Institute for Advanced Research. P. Copper (Laurentian University) supported S.M.L. Pohler financially and logistically in measuring sections and collecting the samples from the eastern facies, which built on his extensive fieldwork in that area. S.L. Duffield, S. Gardiner, and G.S. Nowlan assisted C.R. Barnes in measuring sections and collecting the samples from the western facies. Advice on stratigraphic sections was generously provided by the late T.E. Bolton, M.J. Copeland, P. Copper, and A.A. Petryk. Permission and support to undertake geological fieldwork on Anticosti Island were given by Ministère des

Fig. 5. Histograms of discriminant scores: (*a*) distribution of discriminant scores in the western facies (one symbol represents one sample); (*b*) distribution of the scores in the eastern facies (two symbols represent one sample); and (*c*) combined distribution of the scores for all groups (one symbol represents one sample). 1, group 1 west; 2, group 2 east.

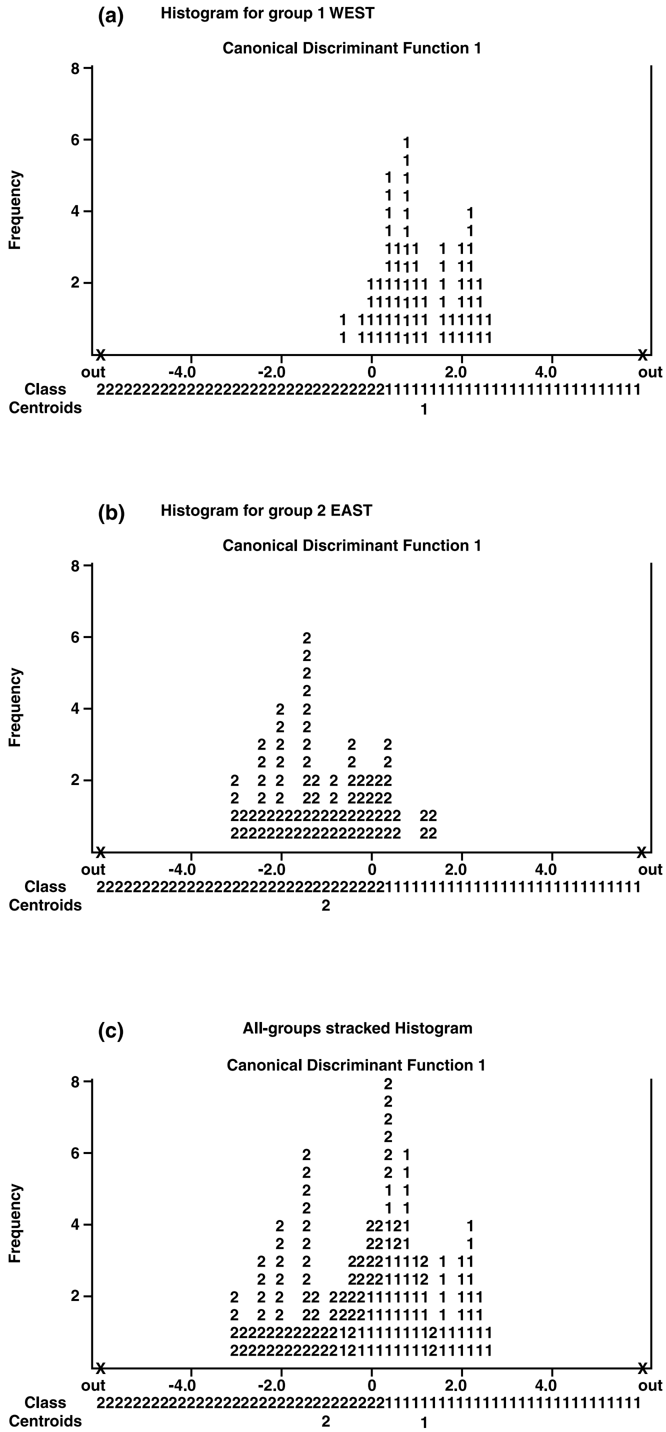
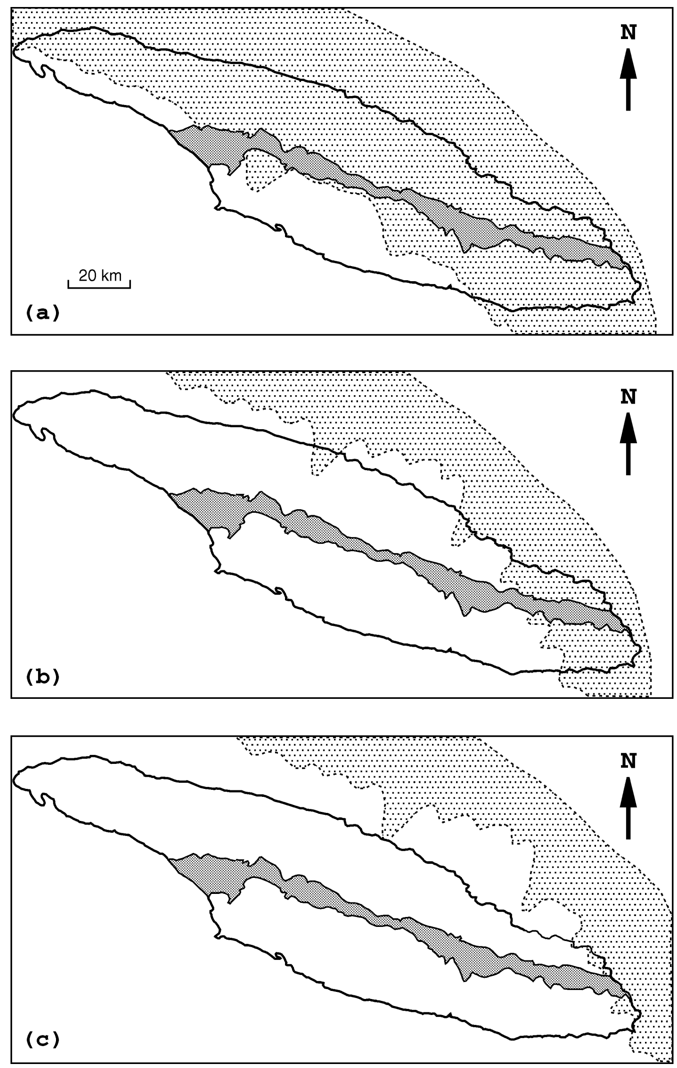


Fig. 6. The distribution of the western and eastern facies during Gun River Formation time: (*a*) represents a brief interval of lower sea level resulting in the eastern facies spreading westwards, which is represented by the misclassified samples (A162, A234, and C71) from the western facies; (*b*) represents the predominant distributional pattern of the two facies, which are represented by all correctly classified samples; and (*c*) represents a brief interval of higher sea level with the western facies expanding eastwards, which is represented by the misclassified samples (Cu1-4, Cu2-1, Cu2-2, Cu3-4, Cu5-4, Cu5-6, Cu5-7, Cu8-2, Cu8-c) from the eastern facies (see Figs. 3 and 4 for the positions of misclassified samples). Legend as in Fig. 2.



Richesses Naturelles, Quebec, and the Ministère du Tourisme, de la Chasse et de la Pêche, Quebec. Critical comments from referees D.G.F. Long and G.S. Nowlan and Associate Editor B.D.E. Chatterton led to improvements to the manuscript.

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