

Multivariate Analysis of Middle Cambrian Trilobite Biogeography

A Thesis

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by

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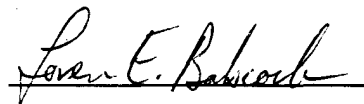
A handwritten signature in cursive script, reading "Loren E. Babcock", written over a horizontal line.

TABLE OF CONTENTS

Introduction.....	1
Paleogeographic hypotheses.....	2
Methodology.....	4
Results and Interpretation.....	6
Geologic Application.....	7
Conclusions.....	8
Acknowledgments.....	9
References.....	9
Figures.....	14
Tables.....	22

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INTRODUCTION

Historically, paleontological data have played a central role in paleogeographic studies (e.g., Wegener, 1928; Wilson, 1966; Theokritoff, 1978, 1984; Samson et al., 1990; Babcock, 1993a). Paleogeographic patterns of the late Paleozoic, Mesozoic, and Cenozoic are fairly well-established from geophysical, structural, petrographic, and other data but paleogeographic reconstructions for the early Paleozoic rely heavily on the use of sedimentologic-stratigraphic and biogeographic evidence. Biogeographic evidence is of special importance for determining the provenance of suspect terranes because other forms of evidence, especially paleomagnetic evidence, commonly have been long ago destroyed or altered by orogenic activities along the margins of continents.

Reconstructions developed partly from biogeographic evidence are controlled by factors relating to the fauna being analyzed, with some faunal elements generating a higher degree of confidence than others (Fortey and Mellish, 1992). Trilobite assemblages are excellent tools for use in paleogeographic reconstruction of lower Paleozoic rocks because of their abundance and their tendency to reflect faunal provinces or biofacies that are temperature related. Thus, such faunal provinces or biofacies seem to reflect latitudinal control or control by the temperatures of major paleoceanographic masses.

The purpose of this study is to analyze semi-quantitatively the biogeographic distributions of Middle Cambrian trilobite genera worldwide. Patterns resulting from the analysis can then be applied to develop an improved understanding of the provenance of suspect terranes or even paleocontinents whose paleogeographic positions are in question. The Middle Cambrian has been chosen for analysis because during that time, trilobites exhibited a relatively high degree of endemism on individual cratons, the world ocean was evidently stratified (thus leading to biofacies differences that were both latitude-dependent and latitude-independent, and because of the

availability of well-described sections worldwide for that interval of time. Trilobites are the most common macrofossils in Middle Cambrian rocks, and have been long interpreted as useful for such paleogeographic work. Although some similar studies have been performed previously (e.g., Jell, 1974; Babcock, 1993a), this is the first to incorporate data derived from much of the world with recent information about trilobite biofacies derived from the work of Babcock (1993a). Results from studies such as those of Jell (1974) and Burrett and Richardson (1980) are useful for identifying major regions of endemism during the Middle Cambrian but unfortunately fail to explain some major biofacies differences near the margins of continents (see Cook and Taylor, 1975; Babcock, 1993a). This work takes into account trilobite biogeographic data derived from both cratonic and continent-margin settings.

PALEOGEOGRAPHIC HYPOTHESES

Current paleogeographic reconstructions (e.g., Scotese 1987) show the Cambrian world as comprising four principal cratonic areas (Figure 1): Laurentia, Baltica, Gondwana, and Siberia, as well as numerous other small tectonic plates. At present, two major paleogeographic hypotheses are being discussed in geologic literature. They are a model proposed by Scotese et al. (1976) and Scotese and McKerrow (1979); and a model proposed by Moores (1991) and Dalziel (1991) and elaborated on by Salda et al. (1992). The latter model has been referred to as the SWEAT model (for a hypothesized southwest U.S.-eastern Antarctic connection during the late Proterozoic to early Paleozoic). Other available paleogeographic models include those of Smith et al. (1981) and Mason (1988). The model of Smith et al. (1981) represented an important early step in interpreting world paleogeography but because of significant improvements in our understanding of paleogeography, this model is now obsolete. The model of Mason is at variance with all available stratigraphic and paleontologic evidence, and will not be considered further in this paper.

According to the hypothesis of Scotese (1987), Laurentia included cratonic North America,

Greenland, western Newfoundland, northern Ireland and Scotland, Spitsbergen, western Norway, and the Chukotsk Peninsula of eastern Siberia (Babcock, 1993a). During the Cambrian, Laurentia was situated in tropical latitudes. At times, extensive carbonate platforms developed in warm, shallow seas. Platform development lead to the establishment of separate trilobite faunas in restricted-shelf seas that differed markedly in composition from those of the open-shelf, which had unrestricted access to open water (Palmer, 1969; Robison, 1964; Babcock, 1993a)

Siberia, which consisted of the present-day Siberian platform, Mongolia, Manchuria, and Taymyr, was also in low latitudes during the Cambrian (Scotese and Denham, 1988). It too was the site of carbonate platform development during some intervals of the Cambrian (Babcock, 1993a).

Baltica, which consisted of northeastern Europe exclusive of the British Isles and western Norway, was probably in moderately high to high southern latitudes during most of the Cambrian (Scotese, 1988). Shelf sedimentation was dominated by fine-grained siliciclastic sediments, including so-called alum shales. Carbonate units comprise a minor part of the Cambrian section (Babcock, 1993a).

Major components of Gondwana were South America, Africa, Florida, Arabia, Turkey, Iran, Afghanistan, India, Madagascar, Australia, and parts of Antarctica. Gondwana extended from tropical to polar latitudes (Scotese, 1988). England (Wales, southern Ireland, and southern England), Acadia (eastern New England and maritime Canada except for eastern Nova Scotia and western Newfoundland), and Amorica (Bohemia, southern Germany, France, Iberian Peninsula, northern Morocco, and eastern Nova Scotia) comprised three important peri-Gondwanan terranes. All were located in polar or subpolar latitudes of the North African sector of Gondwana. Use of the terms England, Acadia, and Amorica follows Young (1986). Scotese (1987) grouped these areas into one paleogeographic unit called Avalonia.

Other important tectonic blocks include those of Kazakhstania (including present-day Kazakhstan, Tien Shan, and the Aral Sea area) and pieces representing present-day China

(Scotese, 1988). Recent evidence suggests that Kazakhstania is composed of several fused microcontinental blocks, and includes an archipelago located in low paleolatitudes (Cook and Taylor, 1989). Considerable uncertainty remains concerning the paleogeographic position of tectonostratigraphic terranes of present-day China.

Major differences between the paleogeographic model of Scotese (1978) and the SWEAT model (Dalziel, 1991; Moores, 1991) for the Cambrian involve the paleogeographic positions of cratonic blocks (compare Figures 1, 2). According to the SWEAT hypothesis, Laurentia was situated in tropical latitudes and was closely associated with the South America sector of Gondwana, which was also in tropical latitudes. The African sector of Gondwana occupied an area from tropical to high or polar latitudes and was closely associated with South America. East Antarctica and Australia were closely associated with Laurentia and were situated in tropical to sub-tropical latitudes. The Indian sector of Gondwana was situated in tropical latitudes and was closely associated with East Antarctica and Australia. According to the Scotese hypothesis, Laurentia was also situated in tropical latitudes, but was not closely associated with the South American sector of Gondwana, which was situated in tropical to sub-tropical latitudes. The African sector of Gondwana occupied an area from high or polar latitudes to tropical latitudes and was closely associated with the East Antarctica and Indian sectors of Gondwana, both situated in tropical to sub-tropical latitudes. The Australian sector of Gondwana was situated in tropical to sub-tropical latitudes and was not closely associated with Laurentia.

METHODOLOGY

Competing paleogeographic models can be tested in part using paleogeographic data because such data provide information about whether a specific hypothesized paleogeographic pattern is reasonable. Multivariate analytic techniques have utility in biogeographic analysis (Hazel, 1970) because they allow for the rapid analysis of data from a large number of fossil organisms and from a variety of paleogeographic settings. One further advantage of using such

programs to determine biogeographic patterns is that much subjectivity is removed from the analysis.

The trilobite genera used in this study were separated into two groups, agnostoids (see Babcock, 1993b) and nonagnostoids. Agnostoids were small (generally 1 cm or less in adult length), pelagic, and most species were widely distributed in the world ocean (Robison, 1976, 1984). Nonagnostoids are inferred to be a paraphyletic group (Babcock, 1993b) mostly consisting of benthic, shelf-adapted genera that were commonly endemic to individual Paleozoic continents (e.g. Palmer, 1973; Theokritoff, 1979; Fortey and Mellish, 1992). This endemism gives nonagnostoid genera greater utility in paleogeographic reconstructions (Palmer, 1969; Samson et al., 1990; Babcock, 1993a)

Binary (presence-absence) data were analyzed using cluster analysis (CA). The analysis was performed using version 5.0 of SYSTAT on an Apple Macintosh IIfx computer.

In Q-mode analysis samples (paleocontinents) were compared to each other on the basis of the genera that they contain. A dissimilarity coefficient (Euclidean distance) was calculated for each pair of samples and the resulting values were clustered to form a dendrogram that shows the faunal relationships of the samples on a scale of 0 to 1 (see Hazel, 1970).

Data for the analyses were collected from literature sources (Table 1). Two data matrices were constructed, one of nonagnostoid (Figure 7) and the other of agnostoid taxa (Figure 8). All genera that were present in only one locality were eliminated from the matrices. Such taxa may be important components of individual collections, but they yield little comparative information (Babcock, 1993a). The nonagnostoid matrix contained 55 genera from seven localities. The agnostoid matrix contained 28 genera from six localities.

Paleozoic terranes included in the analysis are Australia; Baltica; North and South China; deep-shelf or slope of Laurentia; shallow, cratonic Laurentia; the peri-Gondwanan terranes of England, Arcadia, and America; and Siberia (Table 1).

RESULTS AND INTERPRETATION

Q-mode analysis of the nonagnostoid data matrix indicated several relationships were present (Figures 3, 5). First, two major clusters were formed separating the terranes of Laurentia (situated in warm, low latitude waters), Australia (situated in mid to high latitudes), and North and South China from the peri-Gondwanan terranes (situated in high or polar latitudes), Baltica (situated in mid to high latitudes), deep-shelf or slope of Laurentia (situated in low latitudes), and Siberian terranes (situated in low to mid latitudes) with a coefficient of 0.75. This suggests that warm-water genera (these that lived above the permanent thermocline; see Babcock, 1993a) were highly endemic, isolated from widespread migration by the temperature-stratified world ocean. Second, the faunas of Australia and China show strong similarities by having the same coefficient of 0.59 and differ somewhat from Laurentia having a coefficient of 0.64. This suggests that Australia and China were situated relatively close, which would have allowed for faunal migration in warm water between the two areas. This accords with the interpretation that these two areas were once united in Gondwana. The terranes of Baltica, deep Laurentia, and Siberia all clustered in the 0.51 to 0.53 range, and were separated from the peri-Gondwanan terranes, which had a coefficient of 0.56. This suggests that migration was occurring below the permanent thermocline in cool waters. Cool waters were deep in low latitudes (such as Siberia and Laurentia), and shallow or deep in high latitudes (peri-Gondwanan terranes). A statistical significance of 0.95 was achieved for the cluster analysis.

Q-mode analysis of agnostoids resulted in two major clusters (Figures 4, 6). Baltica, Laurentia, peri-Gondwanan terranes, and Siberia all clustered in the 0.50 to 0.55 range and were separated from Australia, which has a dissimilarity coefficient of 0.80. Agnostoids may have dispersed in warm or cool water. There is a slight hint that peri-Gondwanan terranes, Siberia, Baltica, and possibly Laurentia, had faunas that were somewhat distinct from Australia. Maybe there was some warm-/cool-water separation of some agnostoids? More study of this question is needed.

R-mode analysis of nonagnostoid fauna resulted in two major groups being formed (Figure 5.). These groups indicate which genera characterize which terranes (i. e., which genera tend to co-occur). This clustering could reflect either adult lifestyle or larval dispersal patterns, although in most examples, larval dispersal is more likely the more important factor.

During some intervals of the early Paleozoic the world ocean was evidently thermally or otherwise density stratified (Taylor & Forester, 1979; Babcock, 1993a. During times of thermal stratification, the ocean is interpreted to have been divided into two general realms: 1, a psychrosphere, consisting of cool high-latitude shallow waters and deep waters at all latitudes; and 2, a thermosphere, consisting of low-latitude warm waters and temperature-variant waters above the permanent thermocline. Temperature seems to be a first-order control on the distribution of marine fauna (Palmer, 1969; Taylor and Forester, 1979; Fortey and Mellish, 1992; Babcock, 1993a). Both Holocene and Paleozoic faunal distributional evidence suggest certain trends are present in a thermally stratified ocean. First, on a global scale, generic-level fauna resemblance is highest between cold-water biofacies regardless of water depth or latitude. Second, in general, warm-water biofacies are most similar to each other and least similar to cold-water biofacies (Taylor & Forester, 1979).The patterns that emerged from my analyses support the hypotheses that water temperature had a major influence on the distribution of trilobite faunas (Palmer, 1969; Taylor and Forester, 1979; Cook and Taylor, 1975), and that the world ocean was thermally stratified during the Middle Cambrian (Babcock, 1993a).

GEOLOGIC APPLICATION

The relationships resulting from the cluster analysis of Middle Cambrian trilobites in this study can be used to test the hypotheses of competing paleogeographic models (Scotese and Denham, 1988; vs. Dalziel, 1991; Moores, 1991).

Hypothesized continent-continent relationships of the Scotese and Denham (1988) model

were tested by comparing them with relationships that emerged from the cluster analysis (Table 2). In general, the hypothesized relationships were consistent with those that resulted from the cluster analysis. However, the relationship between Australia and Laurentia, in which Laurentia was situated in low or tropical latitudes and widely separated from mid-to high-latitude (Figure 1), is at variance with my results. Trilobite biogeography data instead tend to support a close relationship between Australia and Laurentia during the Middle Cambrian (see Figure 3).

A test of the Moores (1991) and Dalziel (1991) model was conducted by considering only one continent-continent relationship (Australia and Laurentia). Only one association could be considered for two reasons: first, the model does not address the paleogeographic locations of Baltica, Siberia, and the peri-Gondwanan terranes, second, biogeographic data necessary to analyze the relationships between Laurentia and South America, and Laurentia and Antarctica are not readily available at present (Table 3). The hypothesized relationship between Australia and Laurentia, in which Laurentia was situated in low to tropical latitudes and closely associated with mid- to high-latitude Australia (Figure 2), is consistent with the relationship that emerged from my cluster analysis.

CONCLUSIONS

This analysis of Middle Cambrian trilobite biogeography supports the hypotheses that water temperature had a major influence on the distribution of trilobite faunas, and that the world ocean was thermally stratified during the Middle Cambrian. Migration between continents was influenced by the thermally stratified ocean, warm-water taxa (those that lived above the permanent thermocline) were evidently highly endemic and tend not to disperse between widely separated paleocontinental regions. Cool-water taxa were widespread in shallow or deep high latitude waters and in cool deep low-latitude waters below the permanent thermocline.

The continent-continent relationships hypothesized by Scotese and Denham (1988) were tested using the relationships that emerged from the cluster analysis of Middle Cambrian trilobites. All hypothesized relationships accorded well with the study results except for the relationship

between Australia and Laurentia. The Scotese and Denham (1988) model has Australia and Laurentia widely separated, whereas the study results suggest that the two were more closely associated. The model of Moores (1991) and Dalziel (1991) was also tested using the hypothesized relationship between Australia and Laurentia. The hypothesis that Australia and Laurentia were closely associated during the Middle Cambrian is supported by the results of this study. However, additional tests of the Moores (1991) and Dalziel (1991) hypothesis were not possible.

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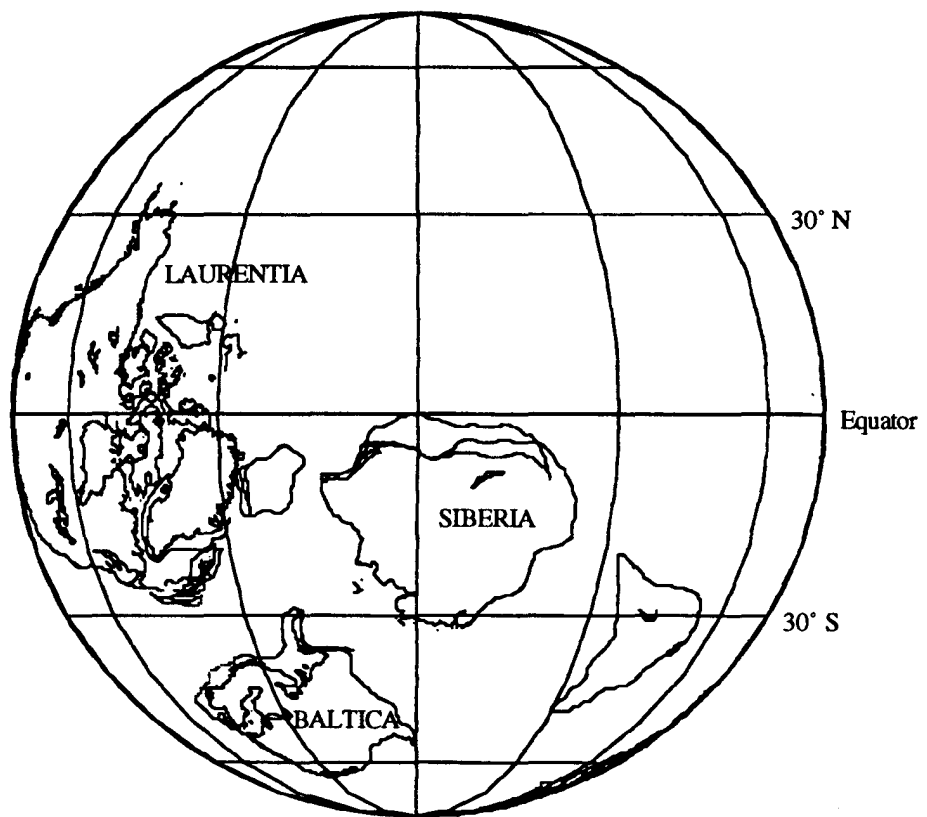
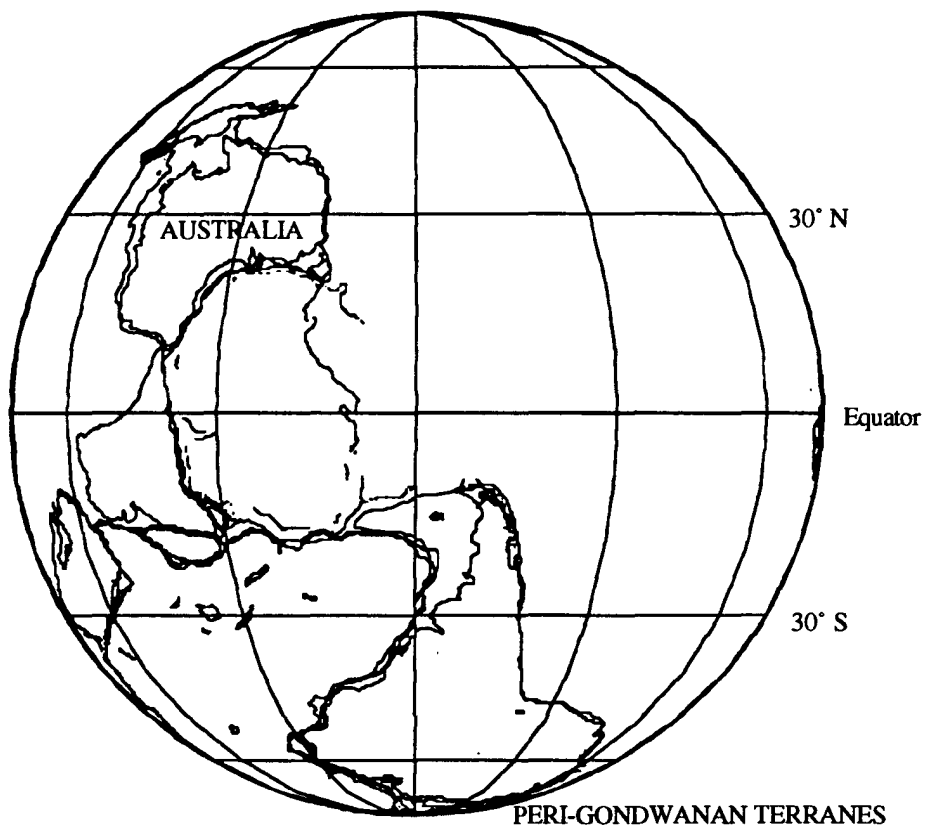


FIGURE 1. Maps showing hypothesized paleocontinental positions according to Scotese and Denham (1988). Paleocontinental areas discussed in the text are labeled.

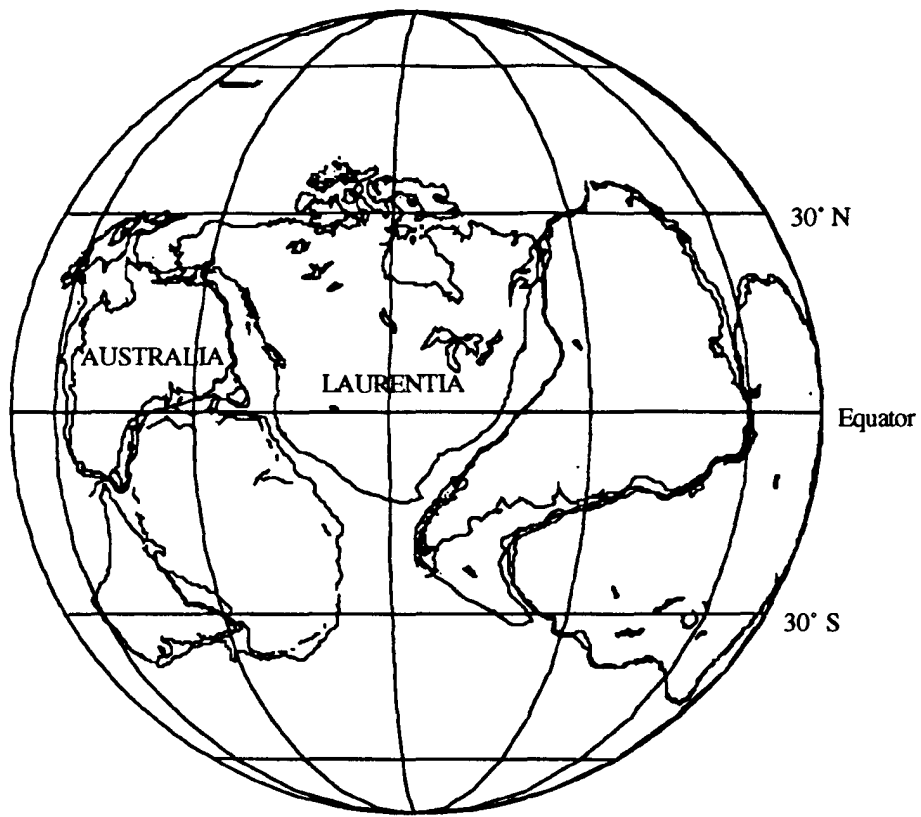


Figure 2. Map showing hypothesized paleocontinental positions according to Dalziel (1991). Paleocoastal areas discussed in the text are labeled.

Nonagnostoids, Q-Mode

Euclidean Distance

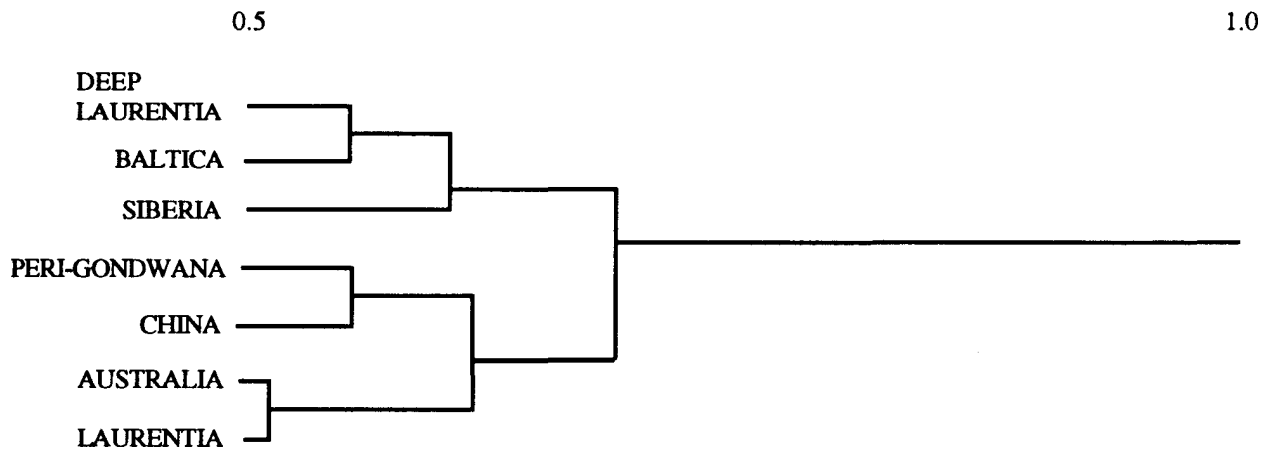


Figure 3. Dendrogram resulting from Q-mode cluster analysis of presence-absence data on Middle Cambrian nonagnostoid trilobites. Distance metric is Euclidean distance.

Agnostoid, Q-Mode

Euclidean Distance

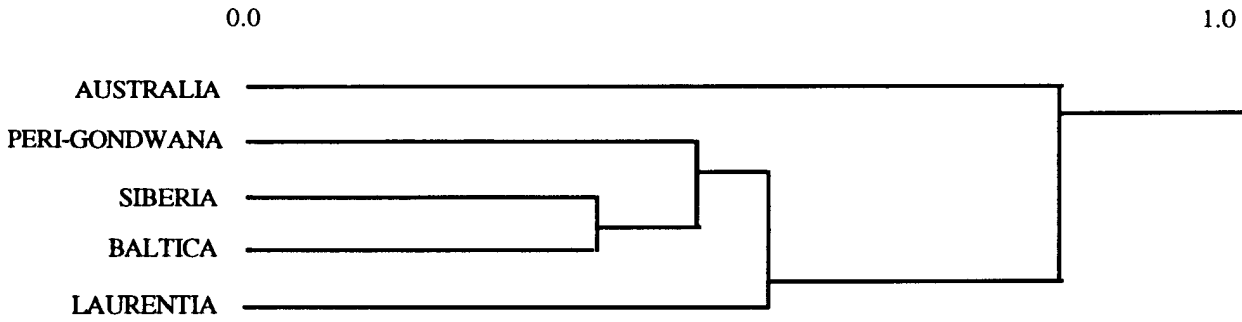


Figure 4. Dendrogram resulting from Q-mode cluster analysis of presence-absence data on Middle Cambrian agnostoid trilobites. Distance metric is Euclidean distance.

DISTANCE METRIC IS EUCLIDEAN DISTANCE
 SINGLE LINKAGE METHOD (NEAREST NEIGHBOR)

D
 E
 E
 P C
 LBSAHL
 AAIVUA
 ULBANSU
 RTRLATR

DORYPYGE	.	..
SOLENOFA	..	.
FORCHHAM	.	.
PIANASPI	.	.
ELLIPSOC	..	
PARASOLE	..	
CENTROPL	...	.
DASOMETO	...	
ANOMOCAR	...	
AGRAULOS	...	
ANOMOCAI	...	
PARADOXI	...	
LIOSTRAC	..	
HARTSHIL	.	..
BAILIELL	.....
ELYX	.....
BAILIASP	.....
EODISCUS	.....
CLARELLA	.	.
ANOMOCAO	..	
CTENOCEP	...	
ACONTHEU	...	.
KOOTENIA	...	..
CORYNEXO	..	..
OLENOIDE	.	..
BOLASPID	.	.
BONNETER	.	.
CHANCIA	.	.
PAGETIA		..
HOLTERIA		..
CATILLIC		..
BLOUNTIA		..
AGELAGMA		..
CATILLIC		..
HOLTERIA		..
MODOCIA		..
CREPICEP		...
BURLINGI	.	.
SOLENOPL	..	.
BATHYURI	.	.

Figure 5. Matrix showing results of clustering in Q-mode (top) and R-mode (left) of presence-absence data on Middle Cambrian nonagnostoid trilobites. At the intersection of the clusters, two large groups of data points are present, one representing mostly cool-water or wide-spread taxa (upper left) and the other representing mostly warm-water taxa (lower right). Some taxa, like *Kootenia*, *Olenoides*, and *Corynexochus*, overlap the two groups. These are interpreted to be widespread, warm-water (pantropical) taxa.

DISTANCE METRIC IS EUCLIDEAN DISTANCE
 SINGLE LINKAGE METHOD (NEAREST NEIGHBOR)

	AASBL
	UVIAA
	SABLU
	TLRTR
PSEUDAGN	..
XESTAGNO	.
PSEUDAGO	.
PERATAGN	.
INMITAGN	.
HADRAGNO	.
DISCAGNO	.
CONNAGNO	.
AGNOSTON	.
AGNOSTAS	.
BLYSTAGN	.
LEIOPYGE	.
GRANDAGN	.
DELAGNOS	.
AGNOSTAR	.
AGNOSTOG	.
ASPIDAGN	.
CYCLAGNO	.
GLYPTAGN	.
IDOLAGNO	.
OXYAGNOS	.
PLURINOD	.
TRIADSPI	.
PSEUDOPH	..
DOLICHAG	..
PHOIDAGN	..
LEJOPYGE	...
DORYAGNO	...
CONDYLOP	...
CICERAGN	..
CLAVAGNO	..
GONIAGNO	..
AGNOSTUS	...
PERONOPS	...
OIDALAGN	..
AMMAGNOS	..
OEDOREAC	..
HOMAGNOS	...
LINGUAGN
DIPLAGNO
COTALAGN
HYPAGNOS
PTYCHAGN
PHALACRO
TOMAGNOS
TORAGNOS	..
BALTAGNO	.
TOMAGNOT	.
KORMAGNO	.
UTAGNOST	.

Figure 6. Matrix showing results of clustering in Q-mode (top) and R-mode (left) of presence-absence data on Middle Cambrian agnostoid trilobites. Distinct clusters do not emerge in R-mode clustering.

TAXAŞ	AVAL	SIBR	AUST	BALT	LAUR	DEEPLAUR	CHINA
AGELAGMA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
ACONTHEU	1.000	1.000	1.000	1.000	0.000	0.000	0.000
AGRAULOS	0.000	1.000	0.000	1.000	0.000	1.000	0.000
ANOMOCAR	0.000	1.000	0.000	1.000	0.000	1.000	0.000
ANOMOCAL	0.000	1.000	0.000	1.000	0.000	1.000	0.000
ANOMOCAO	0.000	1.000	0.000	1.000	0.000	0.000	0.000
BATHYURI	1.000	0.000	0.000	0.000	1.000	0.000	0.000
BLOUNTIA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
BONNETER	0.000	1.000	0.000	0.000	1.000	0.000	0.000
BURLINGI	0.000	0.000	0.000	1.000	1.000	0.000	0.000
BAILLELL	1.000	1.000	0.000	1.000	0.000	1.000	1.000
BAILIASP	1.000	1.000	0.000	1.000	0.000	1.000	0.000
BOLASPID	0.000	1.000	0.000	0.000	1.000	0.000	0.000
CLARELLA	1.000	0.000	0.000	1.000	0.000	0.000	0.000
CENTROPL	0.000	1.000	1.000	1.000	0.000	1.000	0.000
CTENOCEP	1.000	1.000	0.000	1.000	0.000	0.000	0.000
CREPICEP	0.000	0.000	1.000	0.000	1.000	0.000	1.000
CATILLIC	0.000	0.000	1.000	0.000	1.000	0.000	0.000
CATILLIC	0.000	0.000	1.000	0.000	1.000	0.000	0.000
CHANCIA	0.000	1.000	0.000	0.000	1.000	0.000	0.000
CORYNEKO	0.000	1.000	1.000	1.000	1.000	0.000	0.000
DORYPYGE	0.000	0.000	1.000	1.000	0.000	0.000	1.000
DASOMETO	0.000	1.000	0.000	1.000	0.000	1.000	0.000
ELLIPSOC	0.000	0.000	0.000	1.000	0.000	1.000	0.000
ELYX	1.000	1.000	0.000	1.000	0.000	1.000	0.000
EODISCUS	1.000	1.000	0.000	1.000	0.000	1.000	0.000
FORCHHAM	0.000	1.000	0.000	0.000	0.000	1.000	0.000
HOLTERIA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
HOLTERIA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
HARTSHIL	1.000	1.000	0.000	0.000	0.000	1.000	0.000
KOOTENIA	1.000	1.000	1.000	1.000	1.000	0.000	0.000
LIOSTRAC	1.000	1.000	0.000	0.000	0.000	0.000	0.000
MODOCIA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
OLENOIDE	0.000	1.000	1.000	0.000	1.000	0.000	0.000
PAGETIA	0.000	0.000	1.000	0.000	1.000	0.000	0.000
PARADOXI	0.000	1.000	0.000	1.000	0.000	1.000	0.000
PARASOLE	0.000	0.000	0.000	1.000	0.000	1.000	0.000
PIANASPI	0.000	1.000	0.000	0.000	0.000	1.000	0.000
SOLENOPL	0.000	0.000	0.000	1.000	1.000	1.000	0.000
SOLENOPA	0.000	1.000	1.000	1.000	0.000	0.000	0.000

Figure 7. Data set used in cluster analysis of Middle Cambrian nonagnostoid trilobites. Presence of a genus in a region is indicated by a 1, and absence is indicated by a 0. AVAL= "Avalonia" (peri-Gondwanan terranes); SIBR= Siberia; AUST= Australia; BALT= Baltica; LAUR= Laurentia; DEEPLAUR= Deep shelf or slope Laurentia; CHINA= China.

TAXAŞ	AVAL	SIBR	AUST	BALT	LAUR
AGNOSTUS	0.000	1.000	1.000	1.000	1.000
AMMAGNOS	0.000	0.000	1.000	0.000	1.000
COTALAGN	1.000	1.000	1.000	1.000	1.000
CONDYLOP	1.000	1.000	0.000	1.000	0.000
CLAVAGNO	0.000	1.000	1.000	1.000	0.000
CICERAGN	0.000	1.000	0.000	1.000	0.000
DIPLAGNO	1.000	1.000	1.000	1.000	1.000
DOLICHAG	0.000	1.000	1.000	0.000	0.000
DORYAGNO	1.000	1.000	0.000	1.000	0.000
CONIAGNO	0.000	1.000	1.000	1.000	0.000
HYPAGNOS	1.000	1.000	1.000	1.000	1.000
HOMAGNOS	1.000	1.000	1.000	0.000	1.000
KORMAGNO	0.000	0.000	0.000	0.000	1.000
LINGUAGN	1.000	1.000	1.000	1.000	1.000
LEJOPYGE	0.000	1.000	0.000	1.000	1.000
OEDORHAC	0.000	0.000	1.000	0.000	1.000
OIDALAGN	0.000	0.000	1.000	1.000	1.000
PERONOPS	0.000	1.000	1.000	1.000	1.000
PTYCHAGN	1.000	1.000	1.000	1.000	1.000
PHALACRO	1.000	1.000	0.000	1.000	1.000
PHOTDAGN	0.000	1.000	1.000	0.000	0.000
PSEUDOPH	0.000	1.000	1.000	0.000	0.000
TOMAGNOS	1.000	1.000	0.000	1.000	1.000
TOMAGNOT	0.000	0.000	0.000	0.000	1.000
TORAGNOS	0.000	0.000	0.000	1.000	1.000
UTAGNOST	0.000	0.000	0.000	0.000	1.000
GRANDAGN	0.000	0.000	1.000	0.000	0.000
LEIOPYGE	0.000	0.000	1.000	0.000	0.000
DELAGNOS	0.000	0.000	1.000	0.000	0.000
BLYSTAGN	0.000	0.000	1.000	0.000	0.000
AGNOSTAR	0.000	0.000	1.000	0.000	0.000
AGNOSTAS	0.000	0.000	1.000	0.000	0.000
AGNOSTOG	0.000	0.000	1.000	0.000	0.000
AGNOSTON	0.000	0.000	1.000	0.000	0.000
ASPIDAGN	0.000	0.000	1.000	0.000	0.000
CONIAGNO	0.000	0.000	1.000	0.000	0.000
CYCLAGNO	0.000	0.000	1.000	0.000	0.000
DISCAGNO	0.000	0.000	1.000	0.000	0.000
GLYPTAGN	0.000	0.000	1.000	0.000	0.000
HADRAGNO	0.000	0.000	1.000	0.000	0.000
IDOLAGNO	0.000	0.000	1.000	0.000	0.000
INNITAGN	0.000	0.000	1.000	0.000	0.000
OXYAGNOS	0.000	0.000	1.000	0.000	0.000
PERATAGN	0.000	0.000	1.000	0.000	0.000
PLURINOD	0.000	0.000	1.000	0.000	0.000
PSEUDAGN	1.000	0.000	1.000	0.000	0.000
PSEUDAGO	0.000	0.000	1.000	0.000	0.000
TRIADSPI	0.000	0.000	1.000	0.000	0.000
XESTAGNO	0.000	0.000	1.000	0.000	0.000
BALTAGNO	0.000	0.000	0.000	0.000	1.000

Figure 8. Data set used in cluster analysis of Middle Cambrian agnostoid trilobites. Presence in a region is indicated by a 1, and absence is indicated by a 0. AVAL= "Avalonia (peri-Gondwanan terranes); SIBR= Siberia; AUST= Australia; BALT= Baltica; LAUR= Laurentia.

Table 1. Listing of tectonic plates discussed in the text with corresponding present-day region (s) used in the analysis with references.

Tectonic Plate	Present-Day Region Used in Analysis	References
Australia	eastern Australia	Öpik, A. A., 1961, 1967
Baltica	Sweden, Norway	Westergård, A. H., 1946, 1953
China	North China	Lu et al., 1974; Tian, lin et al., 1983; W. Zhang and Jell, 1987
Laurentia	British Columbia, North Greenland, central Pennsylvania, Quebec, western Utah	Hood, K. C., Robison, R. A., 1988; Rasetti, F., 1948, 1963, 1965; Robinson, R. A., 1964, 1971, 1988; Babcock, L. E., 1993b
Peri-Gondwana	southeastern Newfoundland	Babcock, L. E. ,1993a; Hutchinson, R. D.,1962
Siberia	Siberia	Egorova, L. I. et al. , 1982

Table 2. Hypothesized biogeographic similarities of paleocontinents based on relative proximity according to the plate tectonic model of Scotese and Denham (1988) for the Middle Cambrian. Continents that are close according to the model are expected to have closely similar faunas in warm water whereas continents that are distantly separated are expected to have dissimilar faunas.

<u>Continent Association</u>	<u>Expected Relationship</u>		<u>Data-Supported Relationship</u>	
	<u>Similar</u>	<u>Dissimilar</u>	<u>Similar</u>	<u>Dissimilar</u>
AUSTRALIA-LAURENTIA		X	X	
BALTICA-LAURENTIA		X		X
BALTICA-SIBERIA		X	X	
DEEP LAURENTIA-BALTICA	X		X	
DEEP LAURENTIA-SIBERIA	X		X	
PERI-GONDWANA-LAURENTIA		X		X
SIBERIA-LAURENTIA	X		X	

Table 3. Hypothesized biogeographic similarities of paleocontinents based on relative proximity according to the plate tectonic model of Moores (1991) and Dalziel (1991) for the Middle Cambrian. Continents that are close according to the model are expected to have closely similar faunas in warm water whereas continents that are distantly separated are expected to have dissimilar faunas. Relationships not addressed by the model are noted.

<u>Continent Association</u>	<u>Expected Relationship</u>		<u>Data-Supported Relationship</u>	
	<u>Similar</u>	<u>Dissimilar</u>	<u>Similar</u>	<u>Dissimilar</u>
AUSTRALIA-LAURENTIA	X		X	
BALTICA-LAURENTIA	not addressed			
BALTICA-SIBERIA	not addressed			
DEEP LAURENTIA-BALTICA	not addressed			
DEEP LAURENTIA-SIBERIA	not addressed			
PERI-GONDWANA-LAURENTIA	not addressed			
SIBERIA-LAURENTIA	not addressed			