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GLOBAL PERSPECTIVE OF FAMENNIAN-TOURNAISIAN OCEANOGRAPHY : GEOCHEMICAL ANALYSIS OF BRACHIOPODS

by

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(4 figures and 1 table)

ABSTRACT.- No secular shift in seawater isotopic compositions is noted during the Famennian-Tournaisian. Instead, the observed variations in both oxygen and carbon isotopic compositions are ascribed to changing habitat conditions and settings. Modelled water temperatures shows that seas were generally warmer during the Famennian than during the Tournaisian. Tropical seas during the Famennian probably had temperatures ranging from 32-38oC for shallow waters, with temperatures of 17-18oC for deeper habitats, and show a steep latitudinal temperature gradient within the equatorial-subtropical belt. Temperatures and latitudinal variations were more moderate and gradual during the Tournaisian and water temperature ranged from 17-30oC for the equatorial-temperate belts. This general shift in global water temperatures towards more equitable conditions may be related to the postulated late Devonian-early Carboniferous glacial event in southern Gondwanaland. Tropical, shallow epeiric and shelf seas of central Europe were greatly influenced by fluvial run-off and thus were stratified during the Famennian. In the shallow seas, salinities were probably as low as 20 ppt, whereas the deeper parts experienced generally normal salinities (35 ppt). In contrast, normal (30-35 ppt) salinities characterized the shallow and deep waters of the tropical-subtropical Tournaisian seas.

KEY-WORDS.- Famennian-Tournaisian brachiopods, geochemistry, warm-salinity stratified tropical seas.

INTRODUCTION

Brachiopiod shell geochemistry has proven to be a fairly reliable indicator of environmental conditions such as water temperature, redox and with modelling of salinity (e.g., Brand, 1987; Brand & Logan, 1991; Bates & Brand, 1991). Of course this rationale infers that the shell mineralogy and geochemistry are preserved in their pristine state. A co-ordinated textural-trace element-stable isotope approach allows for the identification of the diagenetically least-altered material (e.g., Brand 1987; Brand & Legrand-Blain, this vol.). Thus, only well-preserved material is used in paleoceanographic modelling. Modern and ancient brachiopods physiologically control their Sr, Na and Mg shell chemistries. Despite this complex redistribution of chemical compositions, trends are well established within and between brachiopod populations to allow for the sophisticated interpretation of their geochemical contents (e.g., Bates & Brand, 1991). As a group, brachiopods incorporate stable isotopes in relative equilibrium with ambient seawater (Lowenstam, 1961; Brand, 1989a; Bates & Brand, 1991).

This paper synthetizes brachiopod data for paleoenvironmental reconstructions of important boundary and other tropical-subtropical-temperate seas spanning the Famennian-Tournaisian interval. Geochemical data in conjunction with sedimentological information of specimens from a number of sources and localities will be used to model water temperatures and salinities while considering the physiological/biological thresholds of marine invertebrates and paleogeographic information.

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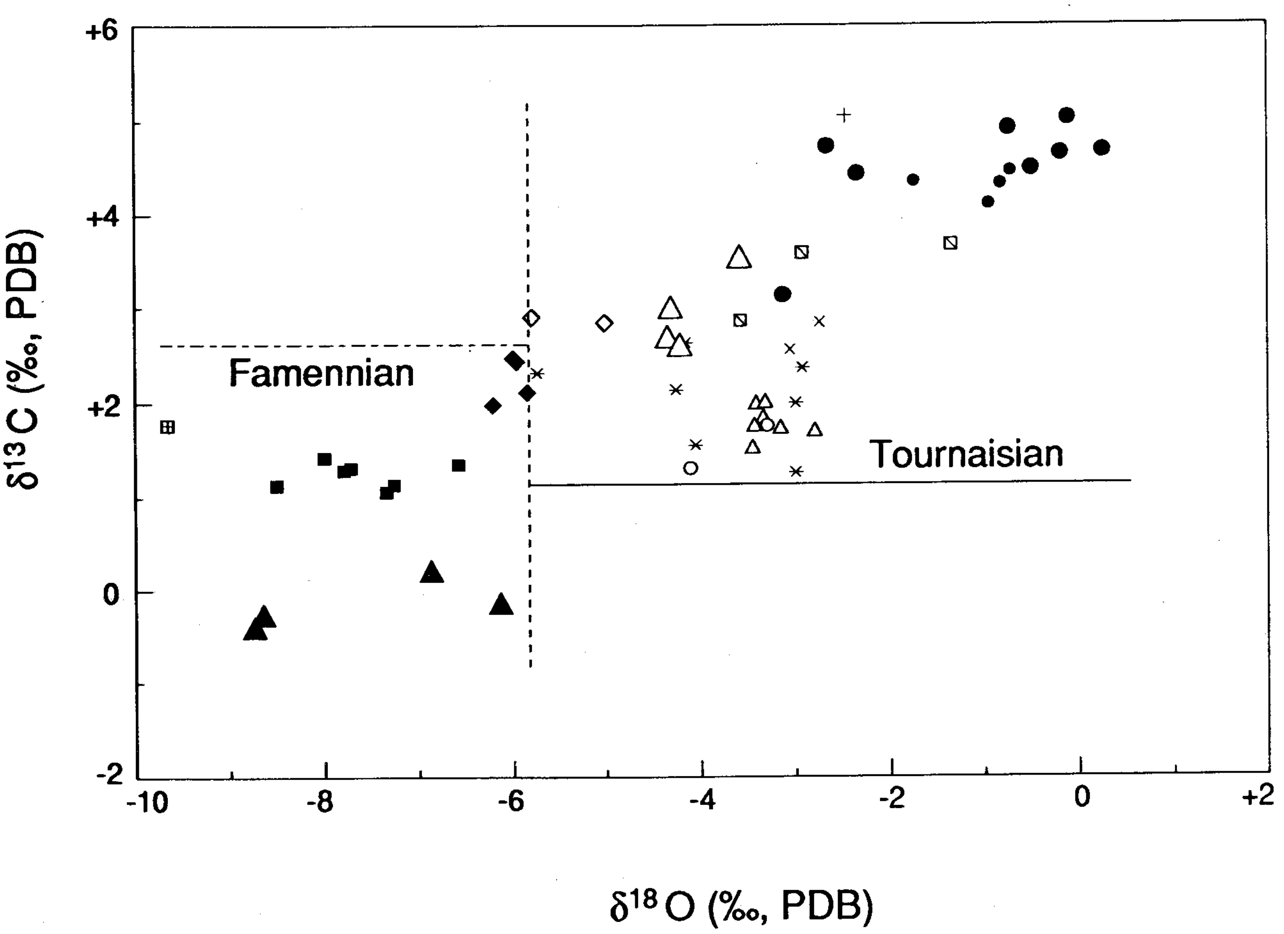

Fig. 1.- Oxygen and carbon isotopic compositions of Famenian-Tournaisian brachiopods from numerous localities and sources. Included are samples from Nanbiancun (◆ and ◊, Zhi-cheng *et al.*, 1988), Wocklum (■), Famenne (□), Monte Cristo (△), Palliser (▲, Brand, 1989a; Mountjoy & Halim-Dihardja, 1991) and Banff (▵, Brand, 1989a), Okafe (□) and Black Rock (×, Popp *et al.*, 1986) Griotte (● and *, Brand & Legrand-Blain, this volume) and Louisiana (•), Glen Park (○) and Lodgepole Formations (+, this study).

METHODOLOGY

Cleaned brachiopod specimens from the Louisiana, Glen Park and Lodgepole Formations were prepared for both trace element and stable isotope analyses following the procedures outlined in Brand & Legrand-Blain (this volume). Accuracy and precision of geochemical procedures are within the prescribed limits for standard reference materials N.B.S. (National Bureau of Standards) 634, 636 (trace elements) and N.B.S. 20 (stable isotopes; Brand, 1989a,b).

PALEOCEANOGRAPHY

The specimens selected for this synthesis are from a number of localities spanning the tropical-subtropical region (one from a temperate locality) of the Famennian-Tournaisian Earth. The observed wide divergence in isotopic data may be the result of differences in climate, habitat, continental flux, secular variation of seawater or a combination of any the above mentined or other unknown parameters (Fig. 1). Overall though, the isotope data of the brachiopods segregate into two fields, with Famennian values generally lighter than those of their Tournaisian counterparts. But, the brachiopod data sets from the Famennian Louisiana Limestone of Missouri and the Griotte Formation of France are the exceptions to the rule, because their $\delta^{13}C$ and $\delta^{18}O$ values are heavier than any recorded by the other Tournaisian brachiopods (Fig. 1). These brachiopods and their heavy values are an important key element in paleoceanographic reconstructions, because they negate the isotopic trend towards more negative values observed by some researchers in boundary specimens and cements (e.g., Veizer *et al.*, 1986; Popp *et al.*, 1986; Carpenter *et al.*, 1990). Consequently, they postulated a large secular shift of seawater $\delta^{13}C$ and $\delta^{18}O$ across the Devonian-Carboniferous boundary. Instead of seawater secular variation, the variances observed in and between the data sets of this and other studies are probably related to differences in habitat of the brachiopods reflected by samples from numerous localities (e.g., Bates & Brand, 1991). Based on sedimentological data, the Louisiana Limestone is considered to be a shallow-water carbonate deposit. The heavy isotope values, however, tend to favour deeper waters relative to the overlying Glen Park Formation. Deeper Louisiana waters would be cooler and probably deficient in organic matter-derived ^{12}C, and thus would fit the model of seawater stratification and habitat segregation advanced by Bates & Brand (1991). Thus, in relation to the overlying Glen Park brachiopods with their lighter $\delta^{13}C$ and $\delta^{18}O$ values, a shallowing of seawater from Louisiana to Glen Park time would best explain the observed isotopic trend (Fig. 1). A similar explanation of changing water depth and distance from shore is also advocated for the Famennian-Tournaisian Griotte brachiopiods at the stratotype section in southern France. This paleoecological model is fully discussed by Brand & Legrand-Blain (this vol.). However, a general cooling trend can not be ruled out based on the isotope values observed at these two localities.

LOCALITIES

Most brachiopod samples spanning the Famennian-Tournaisian are from localities generally within 20°C the paleoequator (Fig. 2; Scotese & McKerrow, 1990). The only exception are the samples by Popp *et al.* (1986) from Afghanistan. Currents for the eastern ocean are purely hypothetical but within the realms of the postulated continental plate configuration. Additional locality and source information are provided in Table 1. New data are briefly described below :

Lodgepole Limestone - this unit is about 300 m thick and subdivided into two/three (depending on area) members in Montana. Dominant lithology is micrites to grainstones with locally abundant crinoids, brachiopods, bryozoans, corals and spicules. In the Paine Member, bioherms are replete in mudstone interspersed with shaly horizons. The uppermost member, where present, is dominantly a micrite-wackestone (Sando & Dutro, 1974).

Glen Park Formation - this unit is about 8 m thick in bluffs along the Mississippi and Illinois Rivers. Lithologically it is a highly variable unit, with conglomerates, sandstones and limestones. The dominantly fine-grained nature of the sediments is interpreted to represent near-shore facies (Willman *et al.,* 1975).

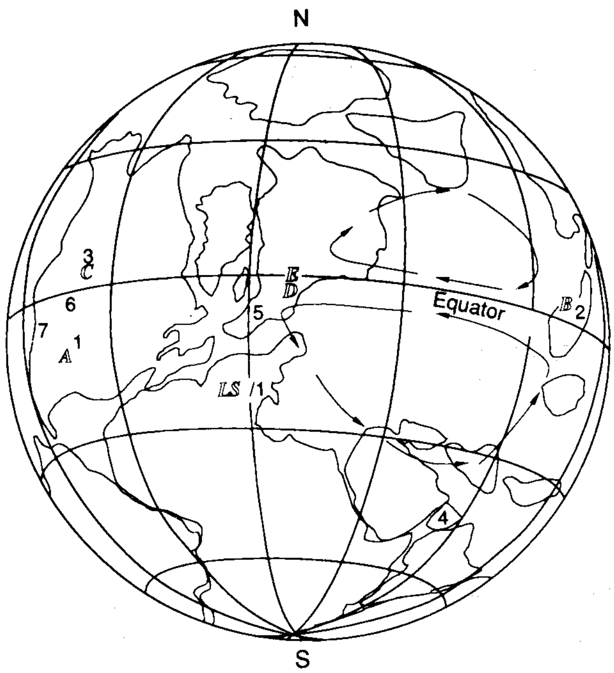

Fig. 2.- Distribution of brachiopod sample localities superimposed on continental plate configuration representing the latest Famennian-earliest Tournaisian (Denham & Scotese, 1988; Scotese & McKerrow, 1990). Continental outlines were simplified and oceanic currents are hypothetical. Tournaisian localities are 1-Glen Park Limestone, Illinois, U.S.A.; 2-Nanbiancun Formation, Guilin, China; 3-Banff Formation, Alberta, Canada; 4-Okafe Formation, Afghanistan; 5-Black Rock Limestone, Burlington, U.K.; 6-Lodgepole Formation, Montana, U.S.A.; 7-Monte Cristo Formation, Nevada, U.S.A.; LS1-Griotte Formation, Montagne Noire, France. Famennian localities are A-Louisiana Limestone, Missouri, U.S.A.; B-Nanbiancun Formation, Guilin, China; C-Palliser Formation, Alberta, Canada; D-Wocklum Formation, Germany; E-Famenne Schiefer, Germany; LS-Griotte Formation, Montagne Noire, France.

Louisiana Limestone - this unit outcrops in eastern Missouri with the overlying Kinderhookian strata of the Hannibal Shale. In the type area, the Louisiana is predominantly micritic limestone with occasional lenses of calcite spar and interspersed brachiopods. Initially it was placed in the Kinderhookian Series, but conodont work demonstrated its latest Devonian age (Scott & Collinson, 1961).

TEMPERATURE

Modelled water temperatures for seawater of normal salinity (sets A and B, Table 1) based on uncorrected isotope data are generally outside the realm of realistic physiological conditions for marine invertebrates (cf. Thompson & Newton, 1988; Brand, 1989b). Temperatures with assumed brackish marine conditions are equally unsatisfactory for the Tournaisian brachiopod populations (set C, Table 1). Constraints for temperature and salinity conditions

Table 1.- Brachiopod oxygen-isotope data and oceanographic properties of Famennian-Tournaisian seas. Water temperatures were modelled using 0 ‰ (A) and -1 ‰ (B) for seawater of normal salinity (35 ppt), and -1 ‰ with 20 ppt salinity (C), and -1 ‰ with fluctuating salinity in bracket (D;cf. Brand, 1989c).

Age Formation	Locality	$\delta^{18}O$ ‰PDB	Temperature °C A	B	C	D	N	Source of data
Tournaisian								
Monte Cristo	U.S.A.	-4.40	39	33	13	28 (32)	4	Brand, 1989a
Lodgepole	U.S.A.	-2.48	28	24	5	24 (35)	1	This study
Black Rock	U.K.	-2.90	31	26	7	22 (33)	2	Popp et al., 1986
Banff	Canada	-3.30	33	28	8	24 (33)	7	Brand, 1989a
Okafe	Afghanistan	-2.60	29	24	6	17 (30)	3	Popp et al., 1986
Glen Park*	U.S.A.	-3.69	35	30	10	26 (33)	2	This study
Nanbiancun*	China	-5.40	44	39	17	30 (30)	2	Zhi-cheng et al., 1988
Griotte*	France	-3.87	36	30	11	27 (33)	7	Brand & Legrand-Blain, this volume
Famennian								
Griotte*	France	-1.17	22	18	1	18 (35)	8	Brand & Legrand-Blain, this volume
Nanbiancun*	China	-6.00	48	42	19	32 (29)	4	Zhi-cheng et al., 1988
Louisiana*	U.S.A.	-1.06	22	17	1	17 (35)	4	This study
Palliser (top)	Canada	-6.80	53	47	24	34 (27)	5	Mountjoy & Halim-Dihardja, 1991
Wocklum	Germany	-7.59	58	51	27	34 (25)	7	Brand, 1989b
Palliser	Canada	-7.84	59	53	28	35 (25)	3	Brand, 1989b
Famenne	Germany	-9.70	72	65	38	38 (20)	1	Brand, 1989b

Note: localities marked by an asterisk represent boundary formations/sections.

encountered in tropical to subtropical seas lead to modelled values (set D, Table 1) well within the habitat range for brachiopods (Fig. 3; Fürsich & Hurst, 1974, 1980). A general, but slight cooling trend is noted in shallow seawater from Famennian to Tournaisian time (Fig. 3). The water temperature of seas covering China during the Famennian, which were probably influenced by warm, tropical currents, was slightly lower than those of the seas of Europe. Furthermore, the river influx of isotopically-light and low salinity waters possibly further modified the shallow seas of Famennian Europe as well as epeiric North America (Fig. 3; discussed further below). Only brachiopods from deeper settings such as the Louisiana Limestone and Griotte Formation, record warm and normal salinity conditions (Fig. 3). Thus, at least the epeiric seas covering the North American craton and southern Europe were probably temperature-depth stratified (Table 1). In addition, Famennian epeiric seawater seems to exhibit a distinct water temperature gradient from equatorial to tropical-subtropical latitudes. Only part of this trend may be explained by differences of water depth between the various localities. Instead it is believed that these represent latitudinal variations indicative of a climatically highly segregated world.

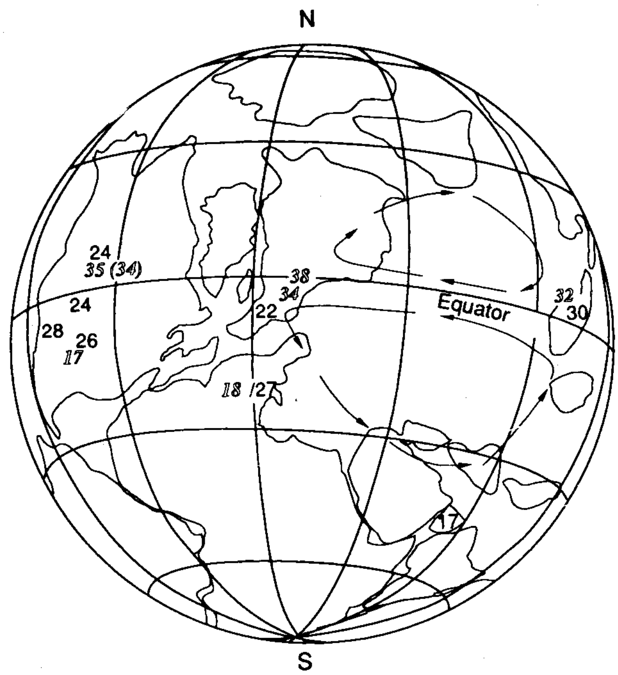

Fig. 3.- Model water temperatures of "global" Famennian-Tournaisian seawater based on calculations of oxygen isotope data from Table 1. Limits considered in modelling were both thermal and salinity thresholds of marine invertebrates (e.g., Thompson & Newton, 1988; Brand, 1989b). Regular and outline fonts are Tournaisian and Famennian specimens, respectively. The Palliser brachiopod data by Mountjoy & Halim-Dihardja (1991) are brackets. Other symbols and explanations as in Fig. 2.

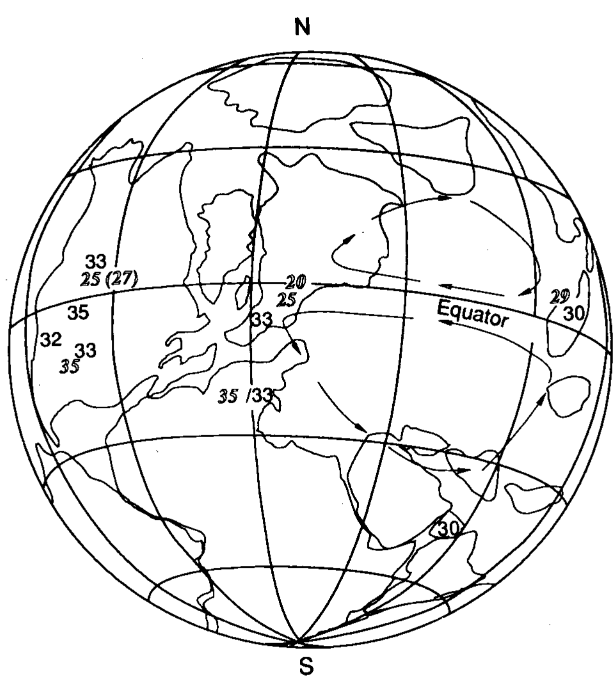

Fig. 4.- Model salinity of "global" Famennian-Tournaisian seawater based on calculations and modelling of oxygen isotope data from Table 1. Regular and outline fonts are Tournaisian and Famennian specimens, respectively. Other symbols and explanations as in Figs. 2 & 3.

Tournaisian paleoceanography is drastically different from that of the tropical-subtropical Famennian. Modelled water temperatures and salinities for Tournaisian seas are within the realm of conditions experienced in tropical regions of modern oceans (Bathurst, 1975) and no apparent or unusually high latitudinal-temperature variation/gradient is noticeable for the studied regions. Continental influx of fluvial waters were probably minimal in the studied areas as documented by a return to deposition of normal marine carbonates and lack of shale (Fig. 3; Brand, 1989c). The data set from Nanbiancun suggests a gradual temperature transition from the inhospitable conditions of the late Devonian, experienced globally in shallow waters, to more optimal oceanic conditions during the early Carboniferous (Table 1.).

It is postulated that late Devonian seas were highly continent influenced by freshwater influx and sea water temperatures cooled drastically towards higher latitudes. In contrast, in the shallow shelf and epeiric seas during the early Carboniferous oceanic conditions similar to the modern world prevailed at that time.

SALINITY

Modelled salinities of Famennian-Tournaisian seas, based on isotopic values of well-preserved brachiopods, illustrate a clear separation into two regimes. Except for the Louisiana and Griotte data, there appears to be a gradual transition in oceanographic conditions from generally low salinity, brackish seas during the Famennian to more normal marine seas during the Tournaisian (Fig. 4). Not only is there a salinity difference between Famennian and Tournaisian seas, the isotope-modelled salinity values suggest salinity stratification in conjunction with a temperature stratification of the Famennian epeiric seas that covered the North American midcontinent, southern France and possibly Germany (Fig. 4). It is possible that the South American glacial event (Caputo, 1985), may have been a major contributing factor for the return to more normal oceanic temperature and salinity conditions and reduction of seawater stratification during the latest Devonian-early Carboniferous. This improvement in global oceanic conditions in water temperature and salinity seems to parallel the recorded biological expansion of this time (Stanley, 1984).

CONCLUSIONS

Evaluation of well-preserved brachiopod material from tropical-subtropical environments spanning the Famennian-Tournaisian suggests the following conclusions :

1. No secular shift in seawater isotopic composition is noted during the studied time periods. Instead observed variations in both oxygen and carbon isotopic compositions are ascribed to changing habit conditions and settings.

2. Modelled water temperatures were generally warmer during the Famennian than during Tournaisian time. Tropical seas during the Famennian had temperatures ranging from 32-38°C for shallow waters, with temperatures of 17-18°C for deeper habitats, and steep latitudinal gradient within the equatorial-subtropical belt. Temperatures were more moderate during the Tournaisian. They ranged from 17-30°C and latitudinal water temperature variations were also more moderate than during the Famennian. This shift in global water temperatures, seawater stratification and latitudinal water-temperature gradient of shallow sea may be related to the late Devonian-early Carboniferous glacial event in southern Gondwanaland.

3. Tropical, shallow epeiric and shelf seas were greatly influenced by fluvial run-off and thus stratified during the Famennian. In the shallower parts of the seas, salinities were probably as low as 20 ppt, whereas the deeper parts experienced generally normal salinities. Overall, more normal (30-35 ppt) salinities characterized the seas of the tropical-subtropical Tournaisian.

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