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REVIEW OF LATE DEVONIAN AND EARLY CARBONIFEROUS CONODONT BIOSTRATIGRAPHY AND BIOFACIES MODELS AS APPLIED TO THE ARDENNE SHELF

by

Roland DREESEN [1], **Charles A. SANDBERG** [2] & **Willi ZIEGLER** [3]

(11 figures)

ABSTRACT. - The history of Upper Devonian to Lower Carboniferous conodont biostratigraphy and ecostratigraphy is briefly reviewed with special emphasis on application to the Belgian shelf environments.

During the past decade several conodont biofacies models have been proposed which are successfully applied to Upper Devonian and Lower Carboniferous deposits in the Western United States and in Northwestern Europe.

RESUME. - L'historique de la biostratigraphie et de l'écostratigraphie basées sur les Conodontes du Dévonien supérieur et du Carbonifère inférieur est brièvement revue en mettant l'accent sur les applications au milieu de plateforme en Belgique.

Dans la dernière décade, plusieurs modèles de biofaciès à conodontes ont été proposés. Ils ont été appliqués avec succès aux roches sédimentaires du Dévonien supérieur et du Carbonifère inférieur des Etats-Unis et du Nord-Ouest de l'Europe.

INTRODUCTION

The West German Late Devonian conodont zonation (Ziegler, 1962) proved to be recognizable not only in Western Europe but also worldwide. This standard Late Devonian conodont zonation was successfully applied as an excellent biostratigraphic tool, subdividing the approximately 15 million years of the Late Devonian into 28 zones. Many detailed studies updated, revised, and completed the standard zonation (Ziegler, 1966, 1969, 1971; *in* Klapper & Ziegler, 1979; Sandberg & Ziegler, 1973, 1979; Ziegler, Klapper & Johnson, 1976; Ziegler, Sandberg & Austin, 1974), while improving the understanding of taxonomy and evolutionary pattern of key platform conodont genera such as *Palmatolepis, Ancyrognathus, Ancyrodella, Scaphignathus, Bispathodus* and *Polygnathus.* Following Weddige & Ziegler's (1979) autochronologic concept - that is, all geologic time ideally is represented by the taxa and the morphotypes of only one taxonomic group and their continuous evolution - Ziegler & Sandberg (1984) revised the upper part of the standard Late Devonian conodont zonation to replace the former *velifer, styriacus* and *costatus* zonal groups, which had been based primarily on genera other than *Palmatolepis.* This *Palmatolepis*-based revision of the upper part of the standard Late Devonian zonation provided not only an autochronologic sequence, but also a zonal sequence that is based mainly on pelagic taxa. The pelagic affinity of *Palmatolepis* was, and still is, a major problem in recognizing the standard conodont zones within shallow-marine and nearshore environments, such as those of the Frasnian and Famennian Ardennes shelf settings.

Likewise, the *Siphonodella* zonation proposed by Sandberg, Ziegler and others (1978) and the post-*Siphonodella* zonation proposed by Lane, Sandberg & Ziegler (1980) have proven useful in pelagic and hemipelagic facies of Europe and North America, and have thus become the worldwide standard zonation for the early part of the Early Carboniferous (Early Mississippian). Consequently, the use of Sandberg, Ziegler and others (1978), and Lane, Sandberg & Ziegler (1980) provide a worldwide succession of 38 conodont zones from the base of the Frasnian into the early Visean.

1 *INIEB, rue du Chéra, B-4000 Liège, Belgium.*
2 *U.S. Geological Survey, Box 25046, Denver Federal Center, Denver, Colorado 80225, U.S.A.*
3 *Forschungsinstitut Senckenberg, Senckenberganlage 25, D-6000 Frankfurt am Main 1, Federal Republic of Germany.*

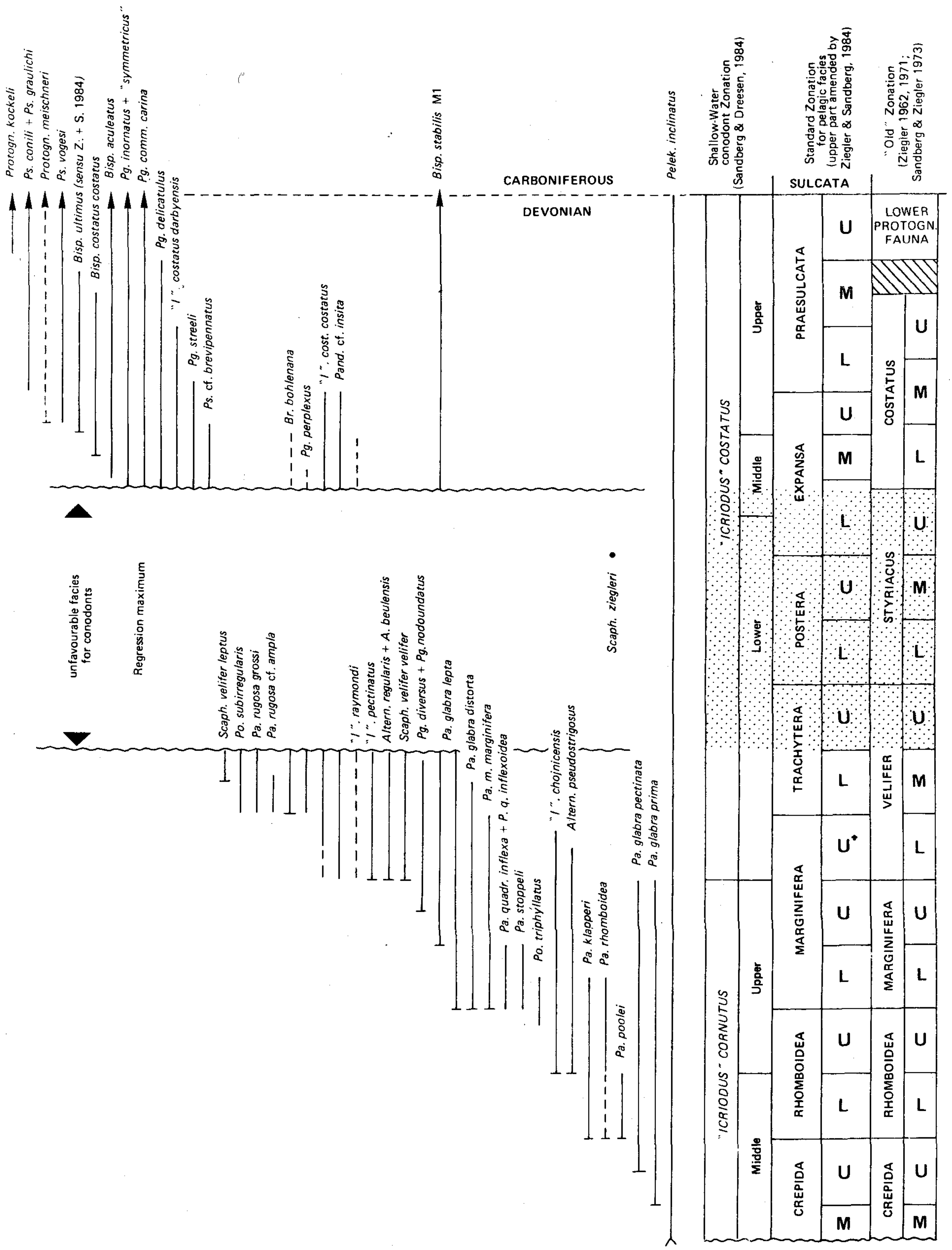


Figure 1. - Range chart of important Late Famennian conodont species in Belgium
Shaded area represents conodont zones not yet recognized on the Ardenne shelf (unfavourable facies).
Spot samples from this unfavourable facies yield conodonts typical of Scaphignathid and Pandorinellid biofacies (see further).

On the other hand, extensive shallow-water, nearshore to restricted-marine environments characterize most of the "classical" Dinantian shelf areas in Belgium and the British Isles, so that the pelagic *Siphonodella* zonation is somewhat difficult, locally even impossible, to apply. Therefore, European conodont workers have proposed local (conodont assemblage) zones for the Dinantian based on mixed, often shallow-water, conodont biofacies, using environmentally restricted genera such as *Clydagnathus, Patrognathus, Mestognathus,* which provide a tool for local intrabasinal correlations (Rhodes, Austin & Druce, 1969; Austin, 1973, 1974; Groessens, 1974).

BIOFACIES

The concept of a conodont paleoecology, involving different, distinctive, and coeval conodont biofacies, has been slow to develop. Nevertheless, during the past decade serious attempts have been made in conodont ecostratigraphy and several conodont biofacies models have been proposed, especially for the Late Devonian and Early Carboniferous. Apparently, environmental factors other than a simple stratification of living-depth zones (the Seddon-Sweet ecologic model, 1971) are required. These factors also become more influential in increasingly shallower waters, where many specialized ecologic niches become segregated and localized by different depositional environments and by greatly varying water salinities, currents, circulations, and temperatures.

Sandberg (1976) recognized five conodont biofacies based on percentages of platform genera at many sections within paleotectonic and paleoecologic reconstructions of the former Upper *styriacus* (now Lower *expansa*) Zone in the Western United States. In a shoreward direction, these are the biofacies, which are typified by the abundance ratios of characteristic forms, and which occupy linear belts paralleling the former coastline :

I. Palmatolepid-bispathodid biofacies (continental slope and rise);
II. Palmatolepid-polygnathid biofacies (shallow to moderately deep water on the continental shelf);
III. Polygnathid-icriodid biofacies (moderately shallow water on the outer cratonic platform);
IV. Polygnathid-pelekysgnathid biofacies (shallow water of normal salinity on the inner craton);
V. Clydagnathid biofacies (very shallow, brackish to normally saline, perhaps hypersaline, water on offshore banks and in associated lagoons).

Sandberg & Ziegler (1979) recognized that three other biofacies - the scaphignathid (VI), pandorinellinid (VII), and patrognathid (VIII) biofacies - were also present within the same linear belt in nearshore settings comparable to that of the clydagnathid biofacies, but differing in salinity, bottom sediments, aeration, and other environmental factors.

Finally, a ninth biofacies, the anthognathid (IX) biofacies, was recognized to occur in a hypersaline environment of the Upper *postera* Zone in Utah (Sandberg & Dreesen, 1983, 1984). These authors also changed the notation icriodid to "icriodid", because true *Icriodus* died out in the early Famennian and later "*Icriodus*" were really triple-row *Pelekysgnathus* that inhabited shallower habitats than true *Icriodus.*

Sandberg & Gutschick (1984) proposed a new conodont biofacies model for the Early Mississippian *anchoralis-latus* Zone in the Western United States, which revised, updated, and improved earlier versions by Sandberg & Gutschick (1979) and Gutschick & Sandberg (1983). Seven Mississippian conodont biofacies are recognized and named after the one or two conodont platform genera that form the bulk of faunas in each paleotectonic setting :

I. Bispathodid biofacies (starved basin);
II. Scaliognathid-doliognathid biofacies (foreslope toe and starved basin);
III. Gnathodid-pseudopolygnathid biofacies (foreslope);
IV. Eotaphrid biofacies (carbonate-platform margin, shelfedge);
V. Hindeodid biofacies (outer platform);
VI. Pandorinellinid biofacies (inner platform and tidal lagoon);
VII. Mestognathid biofacies (tidal lagoon and sabkha).

Shallow-water conodonts are regarded to have had their own evolution within their habitat. Sandberg & Ziegler (1979) believed that the common root that gave rise to the development of those specialized asymmetric forms was *Pandorinellina insita* (Stauffer), which is known to occur first within the basal Frasnian. Succeeding forms (*P.* cf. *insita*) gave rise during the Famennian to *Scaphignathus, Patrognathus,* and *Clydagnathus.*

Recently, the recognition of differences in habitats, apparatuses, and ranges of Late Devonian *Icriodus,* "*Icriodus*", and *Pelekysgnathus* has lead to a refinement of their biofacies interpretations and to the construction of an alternate icriodontid zonation (Sandberg & Dreesen, 1984). This shallow-water zonation is related to the mainly *Palmatolepis*-based standard zonation (for pelagic biofacies) by the usage of stragglers (conodonts living or deposited outside their optimum habitat). Studies of the Frasnian to early Famennian foreslope mudmound tracts of Belgium and of the partly contemporaneous basinal Kellwasser Limestones of West Germany have provided evidence of close association of nearshore and pelagic biofacies at different water depths and mixtures of their faunas (due to downslope transport) that closely integrate ranges of icriodontids and those of key species and subspecies of the standard

New Zonation		Definition of lower limit by first appearance of:	Guide to recognition of Zone in pelagic biofacies	New Zonation		Old Zonation		
praesulcata	Upper	*Protognathodus kockeli*	*Protognathodus kockeli*	praesulcata	**Upper**	Lower	**Protognathodus**	praesulcata
	Middle		Extinction in the lower part of this zone: *B. ultimus, B. costatus, Ps. m. trigonicus, Pa. gr. expansa.*		**Middle**	Upper	costatus	
	Lower	*Siphonodella praesulcata*	*Siph. praesulcata, Pa. gr. gonioclymeniae, Ps. m. trigonicus, B. costatus, B. ultimus, Pa. gr. expansa.*		**Lower**	Middle		
expansa	Upper	*Bispathodus ultimus*	*Pa. gr. expansa + B. ultimus*; last occurrence of *Pa. r. rugosa, Pa. r. ampla*; first occurrence of *Pa. gr. gonioclymeniae + Ps. m. trigonicus.*	expansa	**Upper**	Lower		
	Middle	*Bispathodus aculeatus*	*Pa. gr. expansa, B. aculeatus + Ps. m. marburgensis, Pa. r. rugosa, Ps. brevipennatus, B. jugosus; Pa. p. helmsi* has last rare occurrences.		**Middle**			
	Lower	*Palmatolepis gracilis expansa*	*Pa. gr. expansa + Ps. brevipennatus, Ps. marburgensis marburgensis + B. jugosus + Pa. r. rugosa; Pa. gr. manca + Po. styriacus, Pa. p. maxima* become extinct within this zone.		**Lower**	Upper	styriacus	
postera	*Upper*	*Palmatolepis gracilis manca*	*Pa. p. postera, Pa. gr. manca, Po. styriacus, Bispathodus bispathodus* occurs first within this zone.	postera	**Upper**	Middle		
	Lower	*Palmatolepis perlobata postera*	*Pa. p. postera + Ps. granulosus + Po. styriacus, Pa. r. ampla* has first appearance in this zone.		Lower	Lower		
trachytera	Upper	*Pseudopolygnathus granulosus*	*Pa. r. trachytera + Ps. granulosus, Pa. p. helmsi; Pa. p. grossi, Pa. p. maxima.*	trachytera	**Upper**	Upper	velifer	
	Lower	*Palmatolepis rugosa trachytera*	*Pa. r. trachytera, Sc. velifer velifer, Pa. p. helmsi*; last occurrence of *Pa. g. distorta* in this zone.		**Lower**	Middle		
marginifera	Uppermost	*Scaphignathus velifer velifer*	*Pa. m. marginifera + Sc. velifer velifer, Pa. p. maxima, Pa. r.* cf. *ampla, Pa. g. distorta.*	marginifera	**Uppermost**	Lower		
	Upper	*Palmatolepis marginifera utahensis*	*Pa. m. marginifera + Pa. m. duplicata, Pa. m. utahensis,* without *Pa. q. inflexa* and *Pa. q. inflexoidea; Pa. g. distorta.*		**Upper**	Upper	marginifera	
	Lower	*Palmatolepis m. marginifera*	*Pa. m. marginifera + Pa. quadrantinodosa inflexa, Pa. q. inflexoidea, Pa. klapperi, Pa. stoppeli; Pa. glabra distorta* has first occurrence.		**Lower**	Lower		

Figure 2. - Reprint from Ziegler and Sandberg, 1984, fig. 1.

zonation. In the original bathymetric setting, downslope transport of mound talus and slope deposits as debris flows and turbidites episodically mixed conodonts of the shallower polygnathid-"icriodid" biofacies with those of the nearby, deeper palmatolepid-polygnathid biofacies. Moreover, occasional upslope stragglers date even some of the purer polygnathid-"icriodid" faunas. Similarly, the mixing of biofacies-controlled genera within the regressive megasequence of the Belgian Famennian has been explained as the result of sedimentologic processes such as tidal currents and storm surges (Dreesen & Thorez, 1980; Dreesen, 1984; Sandberg & Dreesen, 1984).

As a result of these ecostratigraphic studies, differences in the normal or optimal distribution or supposed habitat of some important platform conodonts became obvious. At the same time, differences in first occurrences of key species of pelagic conodonts with respect to the standard conodont zonations could now be explained as the result of differences in biofacies. *Palmatolepis* is interpreted as an offshore or pelagic genus. *Pelekysgnathus* (both single-row species and triple-row "*Icriodus*") is interpreted to be a nektobenthic, nearshore genus that lived primarily in the euphotic zone and at water depths so shallow that its habitat was controlled by bottom conditions. *Icriodus* is interpreted to be an euphotic genus that lived in most environments, including pelagic, during the early Late Devonian (Frasnian) but died out during the early Famennian. The distribution of *Polygnathus* is more complex; representatives of the *P. nodocostatus* group occur in more offshore and/or deeper water, whereas those of the *P. semicostatus* group occur in more nearshore and/or shallower water. The *P. communis* group preferred the highest (nearsurface or euphotic) part of the water column. Late Devonian species of the asymmetric genera *Clydagnathus, Patrognathus, Pandorinellina,* and *Scaphignathus* lived principally in shallow nearshore or restricted-marine water, in relation to bottom conditions. *Bispathodus* (including morphologically similar platform genera such as *Branmehla* and *Mehlina*) occurs abundantly in pelagic, far-offshore settings, but it is equally common in the most nearshore settings. This group is interpreted to have lived in the euphotic zone in the highest part of the water column. Thus it occurs widely, independent of bottom conditions, in all but the most nearshore, restricted biofacies (Sandberg, 1979; Gutschick & Sandberg, 1983). The distribution pattern and biofacies affinities of some other Late Devonian platform conodont genera such as *Polylophodonta, Nothognathella, Pseudopolygnathus* and *Protognathodus,* are less clear and require further detailed investigation.

Habitats of Dinantian platform conodonts have also been interpreted from their distributions, associations, and abundances in different paleotectonic settings during the *anchoralis-latus* Zone in Utah and adjacent parts of the Western United States (Sandberg & Gutschick, 1984) : *Bispathodus* and *Polygnathus communis communis* were ubiquitous, euryhaline dwellers of the euphotic zone. *Scaliognathus* and *Doliognathus* were mesopelagic nektonic dwellers of the dysphotic and aphotic zones. *Bactrognathus* was a nektonic slope dweller. *Gnathodus* and *Pseudopolygnathus* were nektobenthic slope dwellers whose habitats bottomed out seaward against the dysaerobic zone. *Eotaphrus* was a dweller of well-aerated shallow water of the upper foreslope and platform margin. The favored habitat for *Hindeodus* would have been the outer platform, whereas *Pandorinellina* is interpreted as an inner-platform dweller above wave base and *Mestognathus* is interpreted mainly as a hypersaline lagoonal dweller.

Besides their value as accurate biostratigraphic correlation tools and as facies indicators, conodonts have proved to be very useful in dating stratigraphic events. Although the short length and importance of biostratigraphic zones in portraying geologic history have long been recognized, conodont-based timespans have only recently been applied to paleogeographic reconstructions by Sandberg & Poole (1977), Sandberg & Gutschick (1980), and Sandberg and others (1983). An average timespan of about 0.5 m.y. for Late Devonian conodont zones was obtained by dividing a radiometric timespan of 13-15 m.y. for the Late Devonian by 28 conodont zones. The authors argued for the approximately equal length of Late Devonian conodont zonal timespans on the basis of steady, rapid evolution of a single phylogenetic lineage in favorable tropical environments. A slightly longer timespan of about 1.3 m.y. for Early Carboniferous conodont zones was calculated by Sandberg & Gutschick (1979) and revised to about 1.5 by Sandberg (1980).

Using this methodology, Middle Devonian to Late Mississippian eustatic changes and epeirogenic events that influenced them were dated in millions of years before or after the time of the Devonian-Carboniferous boundary by means of a biostratigraphic time scale based on conodont zones (Sandberg and others, 1983; Johnson and others, 1985). Similarly, a maximum time span of about 0.5 to 1 m.y. has been calculated for the hiatus or nondepositional event preceeding or accompanying the formation of oolitic ironstones on the Ardennes shelf during the early and early late Famennian (Dreesen, 1982, 1984).

LATE FAMENNIAN CONODONT ZONATION

Ziegler's (1962) standard conodont zonation for the Late Devonian remains virtually unchanged; it has withstood critical testing because it was based on a condensed sequence of hemipelagic limestones that were deposited in a moderately deep-water setting on submarine rises. The zonation did not suffer from overlaps and gaps in the ranges of species, as might have occurred had it been pieced together from several

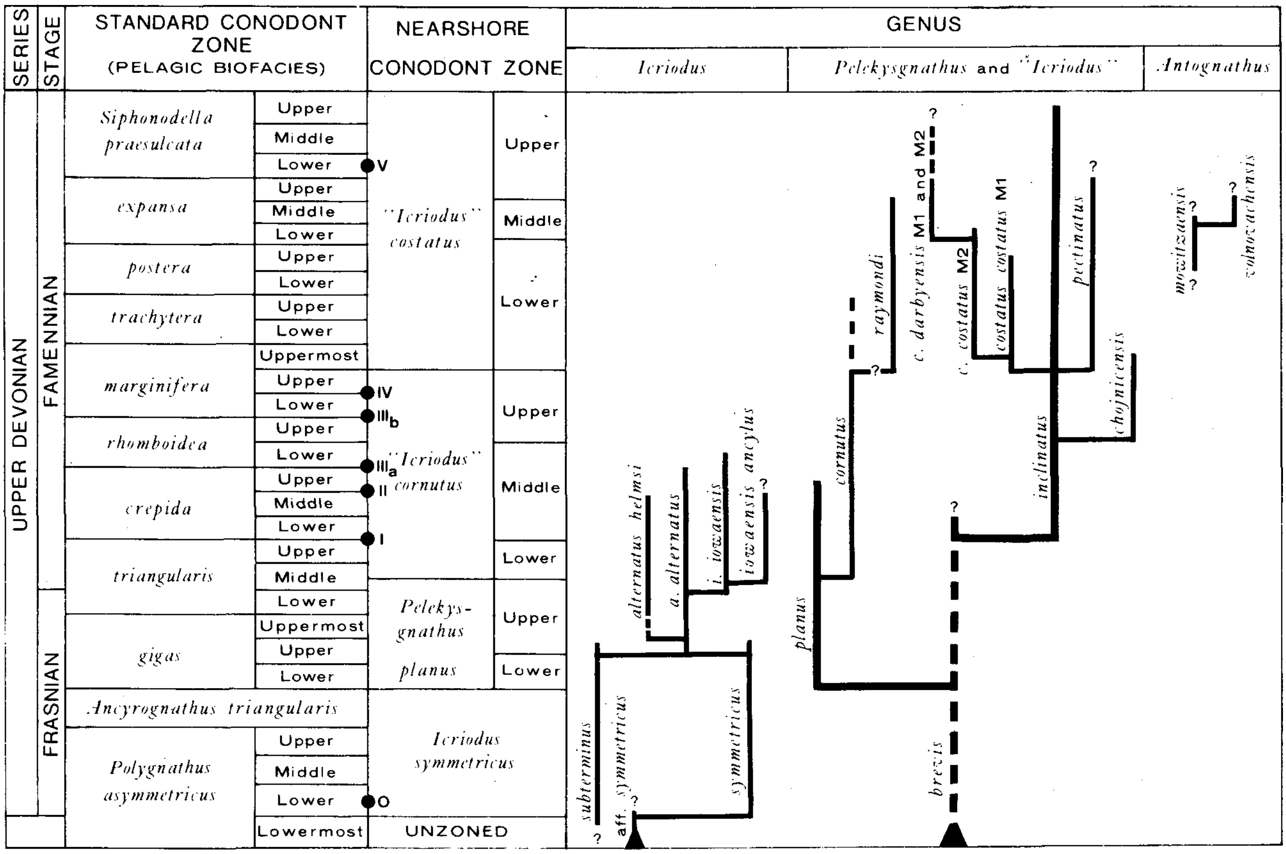


Figure 3. - Reprint from Sandberg and Dreesen, 1984, fig. 1.
Roman numerals 0-V show zonal positions of seven oolitic ironstone levels of Dreesen (1982).

sections that represented different paleotectonic settings and biofacies. Over the years this standard zonation has undergone some minor changes, additions, and modifications. Sandberg & Ziegler (1973) added a Lower *Palmatolepis rhomboidea* Zone, changed the former *Pa. rhomboidea* Zone to Upper *Pa. rhomboidea* Zone, and changed the name of the *Pa. quadrantinodosa* Zone to *Pa. marginifera* Zone. Ziegler, Sandberg & Austin (1974) monographed the *Bispathodus* group and changed the name of the *Spathognathodus costatus* Zones to *Bispathodus costatus* Zones. Sandberg, Ziegler and others (1978) added a *Siphonodella praesulcata* Zone, which partly overlaps and partly extends above the *B. costatus* Zone to the top of the Devonian, and recognized a time-equivalent *Protognathodus* (or protognathodid) biofacies.

The most important change, however, was the recent *Palmatolepis*-based revision of the upper part of the standard Late Devonian Conodont zonation between the top of the Upper *Pa. marginifera* Zone and the earliest Carboniferous *Siphonodella sulcata* Zone (fig. 2 and Ziegler & Sandberg, 1984). This revision was necessary because of biofacies influences on the formal zonal scheme-- i.e., usage of shallow-water nominal species for groups of zones in a supposedly deeper water pelagic setting. The changes were enabled by a new phylogenetic model of *Palmatolepis,* by range extensions bridging former gaps between the records of some *Palmatolepis* taxa, and by further taxonomic revisions of some double-rowed *Bispathodus* taxa. A new zone, the Uppermost *Pa. marginifera* Zone, was added to the former Lower and Upper *Pa. marginifera* Zones, and replaced the former Lower *Sc. velifer* Zone. The former Middle and Upper *Sc. velifer* Zones are now replaced by the new Lower and Upper *Pa. trachytera* Zones. Lower and Upper *Pa. postera* Zones replace the former Lower and Middle *P. styriacus* Zones. The new *Pa. expansa* zonal group includes the former Upper *P. styriacus* and the Lower and part of the Middle *Bi. costatus* Zones. The three new *Siphonodella praesulcata* Zones are formally incorporated in the revised standard Late Devonian zonation, rather than being considered part of an alternate, coeval zonal scheme.

Siphonodella was chosen as a zonal index, although it occurs distinctly below the highest ranges of the youngest *Palmatolepis* taxa. In this way, two major autochronologic zonal successions were linked to one another. The Middle *praesulcata* Zone is less strongly based than the Lower and Upper *praesulcata* Zones, but it bridges the gap between the former Upper *costatus* Zone (Ziegler, 1962, 1971; *in* Klapper & Ziegler, 1979) and the former Lower *Protognathodus* fauna (Ziegler,

1969) or *Protognathodus* biofacies (Sandberg, 1979). The upper boundary of the Upper *praesulcata* Zone, at the entry of *Siphonodella sulcata* (Huddle), was proposed to define the lower boundary of the Carboniferous System by the IUGS Working Group on the Devonian-Carboniferous Boundary, meeting in Washington, D.C., in May 1979.

This *Palmatolepis*-based upper part of the standard Late Devonian zonation (Ziegler & Sandberg, 1984) is applicable mainly to the farthest offshore biofacies - the palmatolepid-bispathodid and palmatolepid-polygnathid biofacies. Simultaneously, Sandberg & Dreesen (1984) proposed an alternate icriodontid-based zonation that comprises only 10 zones as opposed to the 28 zones of the standard zonation (fig. 3). However, this zonation is applicable to the next two shoreward biofacies - the polygnathid-"icriodid" and polygnathid-pelekysgnathid biofacies - as well as to some occurrences of the five most nearshore (restricted-marine) biofacies - the scaphignathid, pandorinellinid, patrognathid, clydagnathid, and antognathid biofacies. Although nearshore conodont zones are equivalent to from 1.5 to 5.5 standard zones, positions exist where nearshore and standard zone boundaries do not coincide, so that the nearshore zones might be used to subdivide the standard zones.

Conodonts that lived in the five shallowest biofacies (V-IX) must have lived in water so shallow that they were controlled by bottom conditions and therefore could have been nektobenthic. These shallow-water biofacies include nearshore and peritidal settings such as bays, estuaries, and lagoons (Western United States) or tidal flats, tidal lagoons and evaporitic lagoons with a wide range of salinities (southern Belgium). The Famennian species of *Clydagnathus, Patrognathus,* and *Scaphignathus* evolved from the *Pandorinellina* stock, members of which are characterized by an asymmetric platform. Most probably these forms gave rise in the Early Carboniferous to other asymmetric form-genera such as *Cavusgnathus, Cloghergnathus,* and *Mestognathus* (Austin, 1976; von Bitter, 1976; Austin & Davies, 1984). These are apparent homeomorphs of older Famennian genera that occupied similar nearshore to restricted-marine environments. The problematic *Scaphignathus ? subserratus* (Branson & Mehl) and *Polygnathus ? pseudostrigosus* Dreesen and Dusar have been excluded from this group of asymmetric shallow-water conodonts and assigned to a more offshore genus *Alternognathus* by Ziegler & Sandberg (1984). *Alternognathus* has a lower-surface morphology identical to that of early species of *Siphonodella* and may have given rise to that genus.

Range of conodont species in terms of the new Famennian zonation are shown in figure 4.

FAMENNIAN CONODONT BIOFACIES MODELS

LOWER EXPANSA ZONE OF WESTERN UNITED STATES

More than 75 widespread measured sections (Sandberg, 1976; Sandberg & Poole, 1977; Sandberg and others, 1983) have been used for documenting conodont biofacies and icriodontid distribution within the Lower *expansa* (former Upper *styriacus*) Zone in the Western United States. The conodont biofacies are named for the one or two predominant platform elements, the inferred living-depth zones of which best characterize the water depths of the particular biofacies. For all biofacies, the nominate platform genera constitute at least 65 percent of the total population of platform elements. The five biofacies (I-V) established by Sandberg (1976) occupy long, relatively narrow belts paralleling a former east-west coastline in an equatorial region. The biofacies do not demonstrate any significant longitudinal changes in faunas and only slight latitudinal (seaward) ecologic straggling or post-mortem mixing of conodonts from one biofacies belt to another. A belt shoreward of the inner shelf contains various restricted-marine and peritidal settings (offshore bars, bays, lagoons, estuaries) characterized by shallow-water biofacies (V-IX). The nine currently recognized biofacies (I-IX) are shown in figure 5 together with the type of icriodontid fauna they contain.

The two most seaward biofacies (I, II) lack indigenous icriodontid faunas and contain only simple cones (C, K elements) that, because of their shape and small mass, must have been transported seaward by surface currents, incapable of carrying the larger, heavier platform (I) elements. The stratigraphic units containing the various rock types and conodont biofacies are shown across the bottom of the model (fig. 5).

FAMENNIAN REGRESSIVE MEGACYCLE OF BELGIUM

The Belgian model (fig. 6) differs somewhat fom the Western United States model because it does not depict a single time-slice or zone, but rather a regressive megacycle that passes through five Famennian zonal groups from the *crepida* to *postera* Zones, progressing in a landward direction. This deviation from single-zone reconstruction was necessary because of erosion of some older offshore lithofacies during the regression and because of later regional folding and thrust faulting, which make it impossible to find exposures of the offshore and nearshore biofacies of any one zone. Another exception is that biofacies I is called simply palmatolepid biofacies. This change is necessary because the genus *Bispathodus* did not evolve until the *marginifera* Zone and hence it was not available as a constituent of the pelagic faunas of the *crepida* zone.

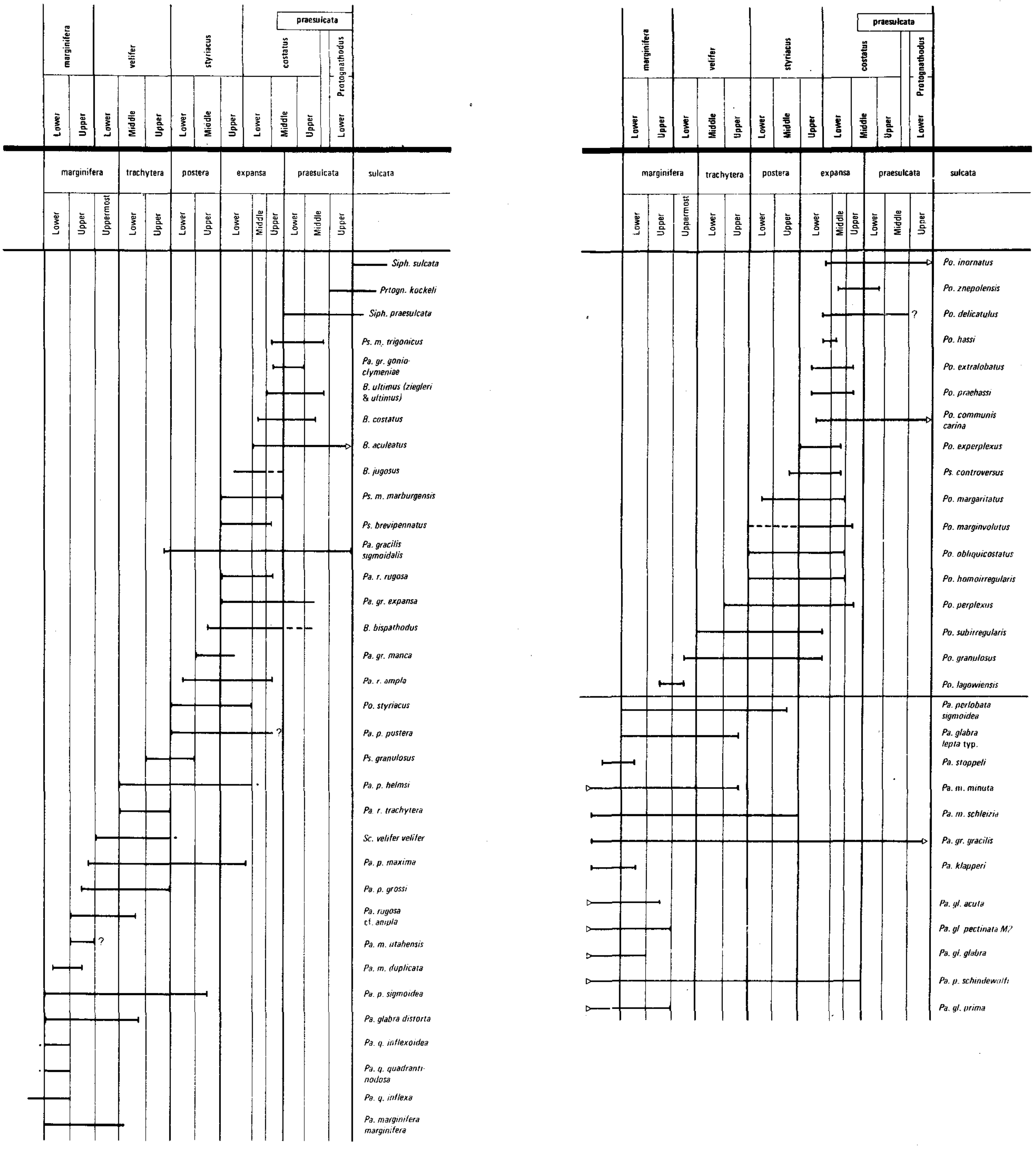


Figure 4. - Reprint from Ziegler and Sandberg, 1984, figs. 2, 3, 4

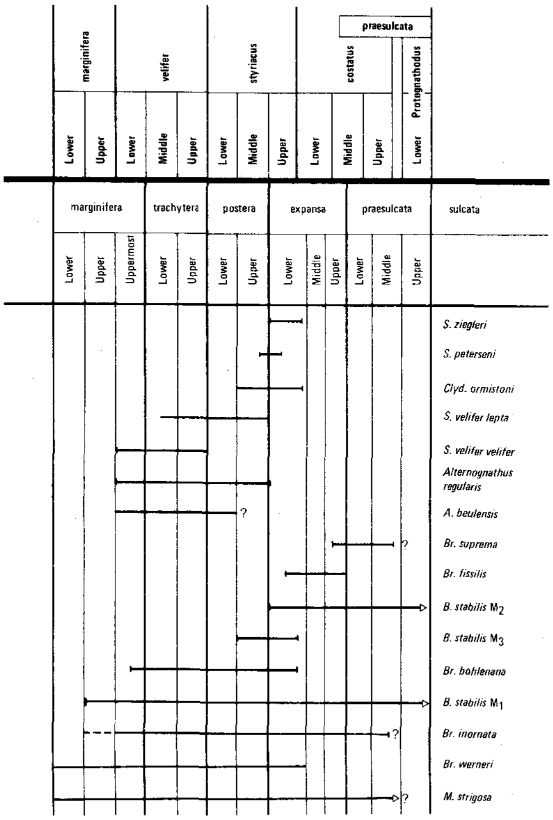


Figure 4 (continued)

The Belgian model shows that the paleoecologic interpretations of icriodontids established in the Western United States are indeed applicable to a totally different sedimentary regime in which coarse clastic rocks predominate over carbonate rocks. It also provides a detailed depiction of the diverse microenvironments of the two innermost biofacies belts, those containing biofacies IV and biofacies V-IX, in the Western United States. In the most nearshore settings-tidal lagoon and sabkha-scaphignathid biofacies (VI) and pandorinellinid biofacies (VIII) were found in the *postera* Zone. This innermost biofacies belt has not been thoroughly investigated to ascertain whether it might also contain biofacies V, VII, and IX. Mixed conodont biofacies are very frequent, and they result from various sedimentologic processes, such as storm surges, tidal currents, debris flows (fluxoturbidites), and short-term transgressive pulses (related to synsedimentary tectonics).

A special sedimentological and biostratigraphical feature of the Famennian Ardennes shelf is the occurrence of oolitic ironstone levels, the stratigraphic position of which is shown in fig. 3. These event-stratigraphical marker beds represent condensed deposits which can be traced over several tens of kilometers on the shelf in both the Dinant and Vesdre Synclinoria (see fig. 6).

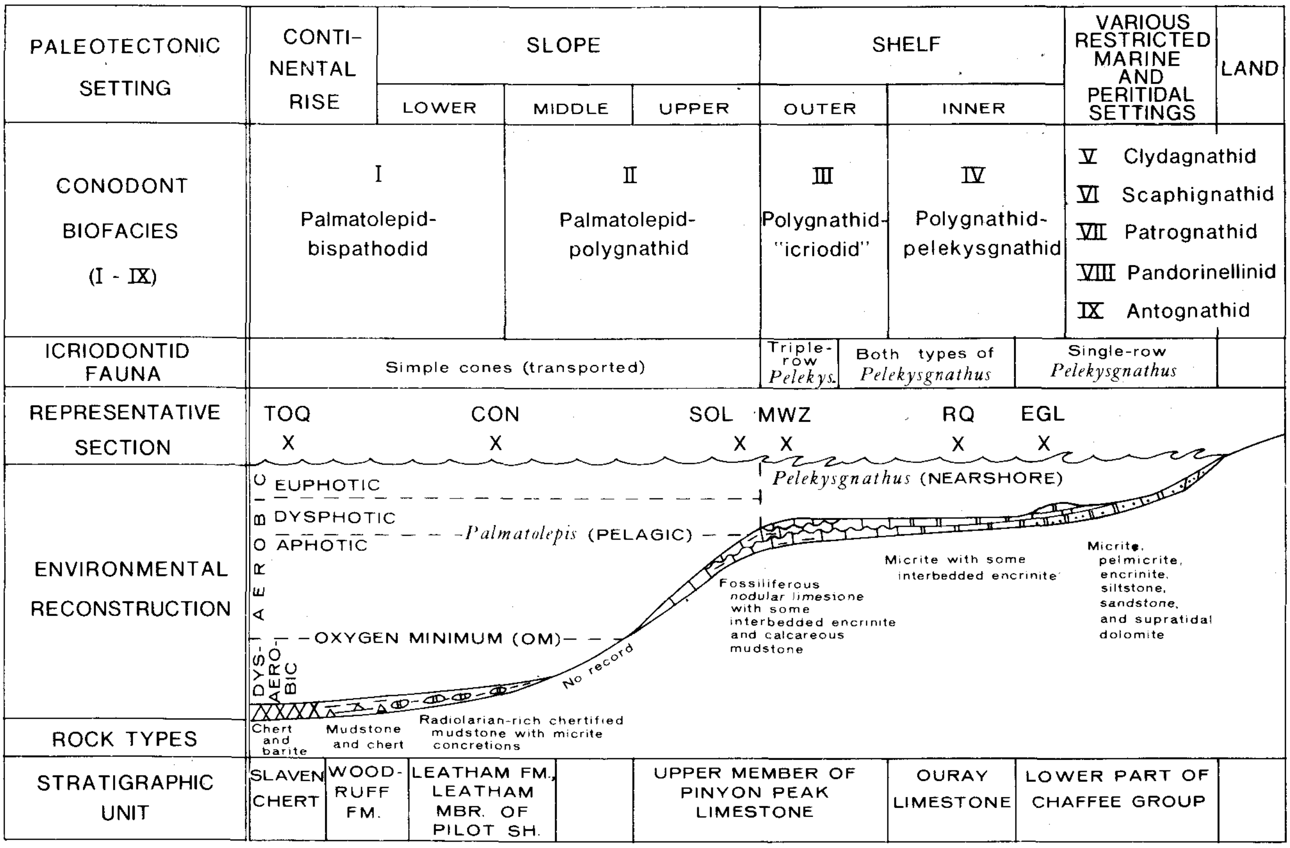


Figure 5. - Reprint from Sandberg and Dreesen, 1984, fig. 4

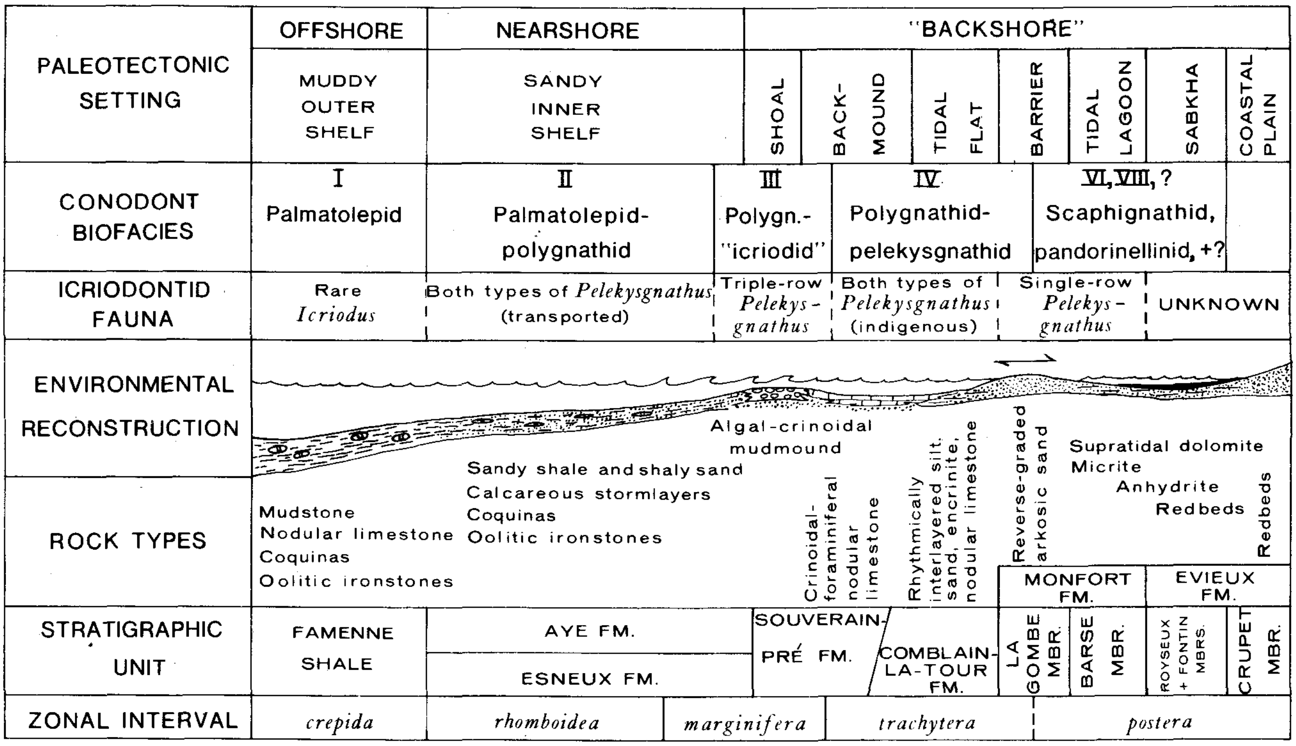


Figure 6. - Reprint from Sandberg and Dreesen, 1984, fig. 8

EARLY CARBONIFEROUS (EARLY MISSISSIPPIAN) CONODONT ZONATION

A *Siphonodella*-based standard conodont zonation for the earliest Mississippian was provisionally proposed by Sandberg & Ziegler (1976) and later formalized by Sandberg, Ziegler and others (1978). This zonation was later combined with the standard zonation of Lane, Sandberg & Ziegler (1980) for the higher part of the Early Mississippian. The combined standard zonation is shown on figure 7. This zonation is based primarily on the first occurrences of species of *Siphonodella* that in most cases are the nominal species of zones (fig. 8). The base of the Mississippian in North America and the base of the Carboniferous worldwide can be defined in offshore marine sequences within the *Siphonodella* phylogeny by the evolutionary change from *S. praesulcata* to *S. sulcata* at the base of the *sulcata* Zone. The top of the *Siphonodella* zonation is defined by the last occurrence of the genus. This extinction marks the top of the Kinderhookian in North America and an important biostratigraphic break worldwide. Fortuitously, this extinction occurred almost simultaneously with the evolution of a new gnathodid species, *G. typicus*, from *G. delicatus*.

As in the case of the *Palmatolepis*-based standard Late Devonian conodont zonation, the *Siphonodella*-based zonation is applicable mainly to open-marine,

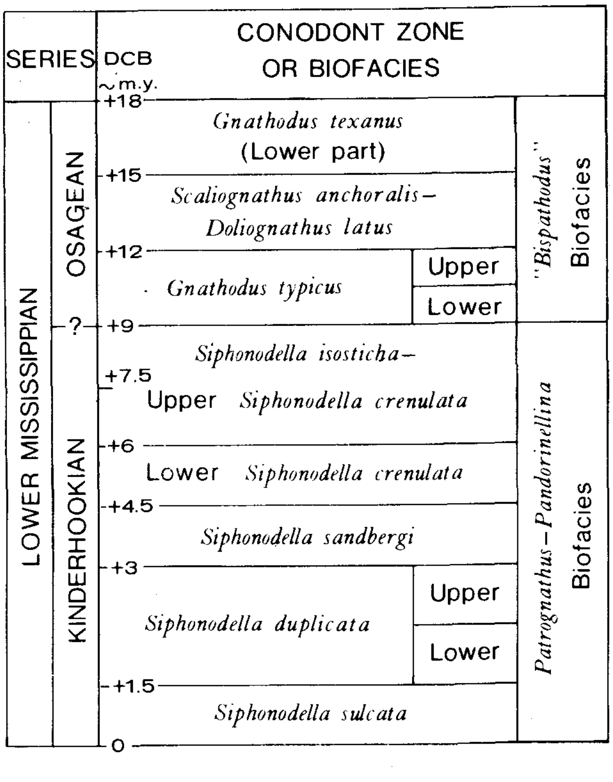


Figure 7. - Reprint from Sandberg, Gutschick, Johnson, Poole and Sando, 1983, fig. 4

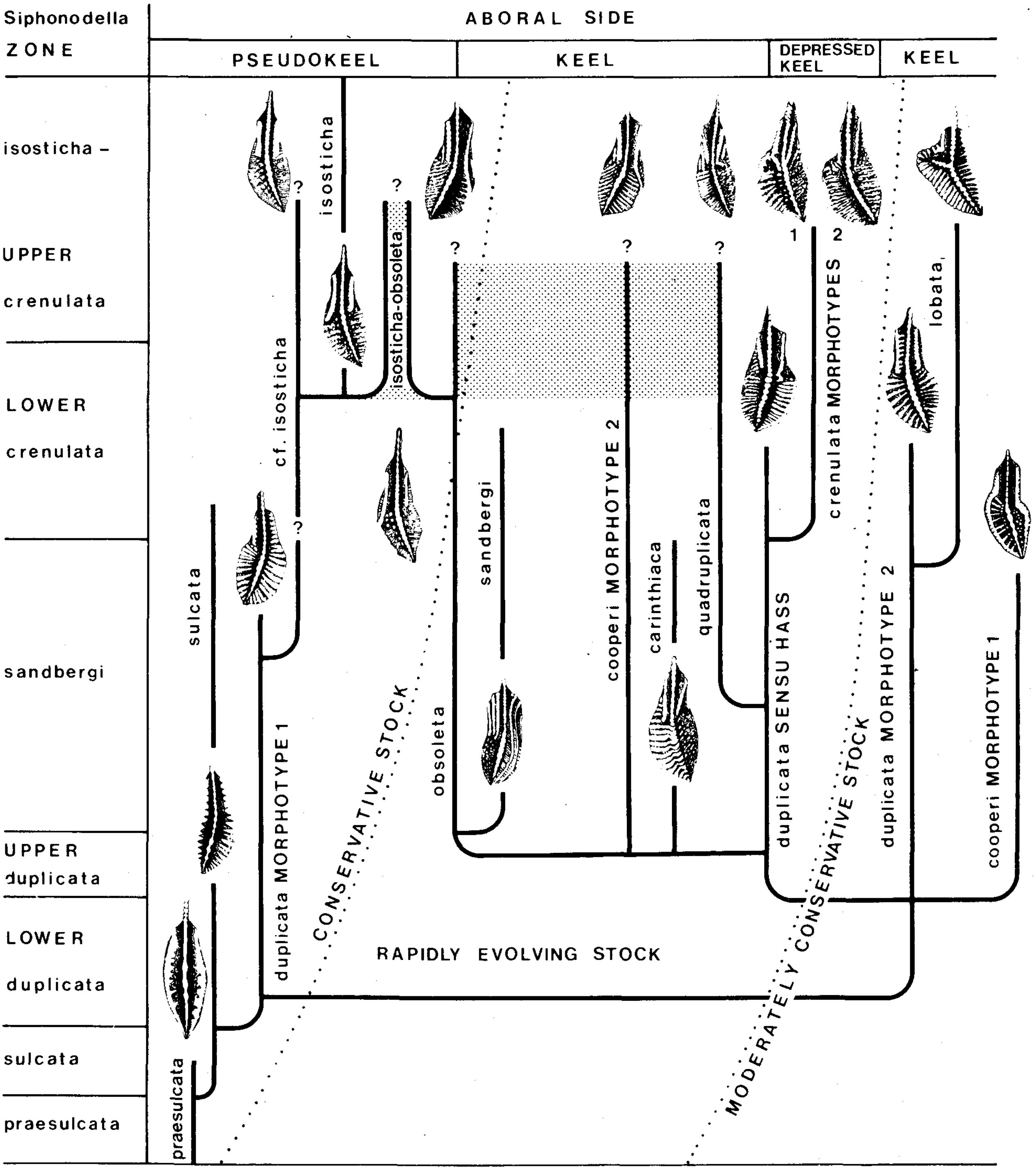


Figure 8. – Reprint from Sandberg, Ziegler, Leuteritz and Brill, 1978, fig. 1

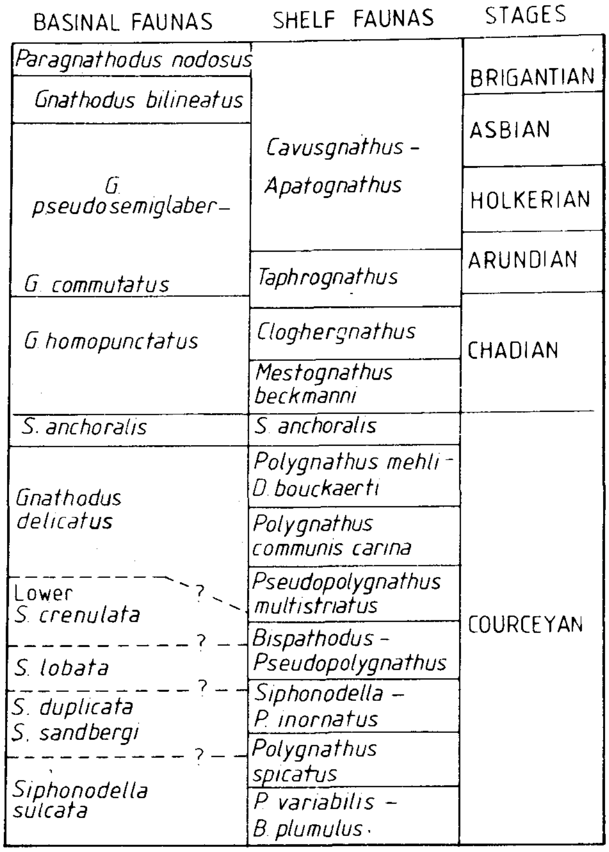
offshore, pelagic to hemipelagic settings, although stragglers can be found in more nearshore, shallow-marine environments. The pelagic affinity of *Siphonodella* made it necessary to distinguish a pelagic (basinal) *Siphonodella* biofacies and a nearshore *Patrognathus-Pandorinellina* biofacies (Sandberg & Gutschick, 1983). Earlier studies (Sandberg, Ziegler and others, 1978) revealed the existence of a *Protognathodus* fauna or biofacies, as a time-equivalent fauna of the earliest *Siphonodella* Zone. However, recent investigations (Lane, Sandberg & Ziegler, 1980) demonstrated that *Protognathodus* is widely distributed and that its paleoecologic controls are not yet established; *Protognathodus* has been found in nearshore (lagoonal), moderately deep to deep offshore, and lower-slope settings.

Within the type Dinantian carbonate-shelf rocks of Belgium and the British Isles, the *Siphonodella*-based standard zonation cannot be applied. This is because of the persistence of shallow to extremely shallow water over very broad areas of the shelf during most of the Dinantian. Austin & Davies (1984) suggested that lack of competition in unfavorable shallow-water environments resulted in the success of long-ranging species. Therefore, correlations based on these species are only of local relevance.

A clear distinction exists in time-equivalent rocks between the early Dinantian (Tournaisian) conodonts of the shelf environment, characterized by the presence of *Clydagnathus* and *Patrognathus,* and those of the basinal environment, which contain *Siphonodella* and *Protognathodus.* In practice, different conodont assemblage zones (from mixed conodont biofacies) are used for local correlations (fig. 9), although the authors are aware of the fact that some, if not all, of the faunal changes reflect changing lithofacies rather than evolutionary lineages of conodonts.

A similar approach (a "multi-biofacies" conodont assemblage zonal scheme) has been applied to the Belgian Dinantian by Groessens (1974); this scheme is shown in figure 10. Three acrozones and nine subzones were defined by Groessens within the lower Dinantian (Tournaisian) of Belgium. The lowest or *Siphonodella* Zone groups several of the *Siphonodella*-based standard zones and reflects an impoverished, monotonous (shallow-water) conodont fauna. The base of the next acrozone, the *Polygnathus communis carina* Zone, corresponds to the base of the Lower *Gnathodus typicus* Zone of Lane, Sandberg & Ziegler (1980).

As a result of the newly proposed (Sandberg & Gutschick, 1984) conodont biofacies models and interpreted paleoecology of platform conodonts for the Early Mississippian *anchoralis-latus* Zone, it is quite possible that some of the younger zones and subzones of the Belgian Dinantian (Groessens, 1974) represent successive biofacies rather than conodont chronozones. Moreover, differences in conodont biofacies would explain why conodont assemblage-zonal boundaries coincide with the main sedimentary phases of the Waulsortian reefs and their proximal off-reef equivalents in Belgium (Lees and others, 1977). Consequently, great care should be exercised in using conodont assemblage-zonal boundaries as time lines in paleogeographic reconstructions.



BASINAL FAUNAS	SHELF FAUNAS	STAGES
Paragnathodus nodosus	*Cavusgnathus - Apatognathus*	BRIGANTIAN
Gnathodus bilineatus		
G. pseudosemiglaber–		ASBIAN
		HOLKERIAN
G. commutatus	*Taphrognathus*	ARUNDIAN
G. homopunctatus	*Cloghergnathus*	CHADIAN
	Mestognathus beckmanni	
S. anchoralis	*S. anchoralis*	COURCEYAN
Gnathodus delicatus	*Polygnathus mehli - D. bouckaerti*	
	Polygnathus communis carina	
Lower *S. crenulata* ?	*Pseudopolygnathus multistriatus*	
S. lobata ?	*Bispathodus - Pseudopolygnathus*	
S. duplicata *S. sandbergi* ?	*Siphonodella – P. inornatus*	
Siphonodella sulcata ?	*Polygnathus spicatus*	
	P. variabilis – B. plumulus	

Figure 9. – Reprint from Austin and Davies, 1984, fig. 21. Summary of principal conodonts found in basinal and shelf faunas of the British Dinantian. The shelf faunas are particularly prone to facies control and some species, including ***Patrognathus variabilis*** and ***Polygnathus inornatus*** are much longer ranging than this chart would seem to imply. Other long ranging forms, such as ***Clydagnathus,*** are not shown on this figure. The sequence of shelf faunas shown, therefore, should not be used for correlation purposes. In particular, knowledge of Chadian-Asbian shelf faunas is especially limited.

EARLY CARBONIFEROUS CONODONT BIOFACIES MODELS

Sandberg & Gutschick (1979, 1980, 1984) indicated their concept of Osagean and early Meramecian conodont distribution with reference to a biofacies model, that extends from deep, starved-basin settings to the shoreline (fig. 11). This Mississippian biofacies scheme is similar to the worldwide Late Devonian biofacies

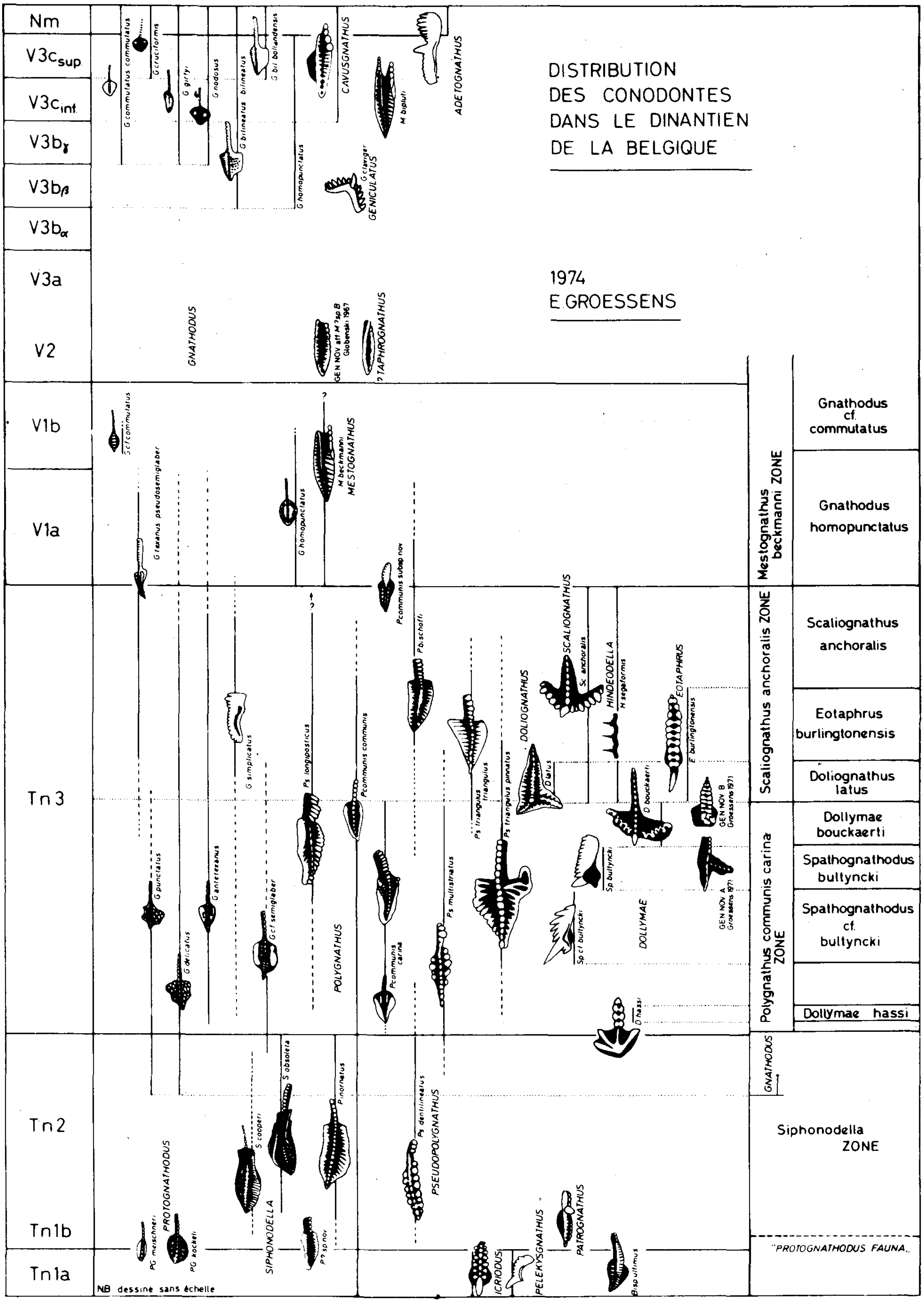


Figure 10. - Reprint from Groessens, 1974, plate 46

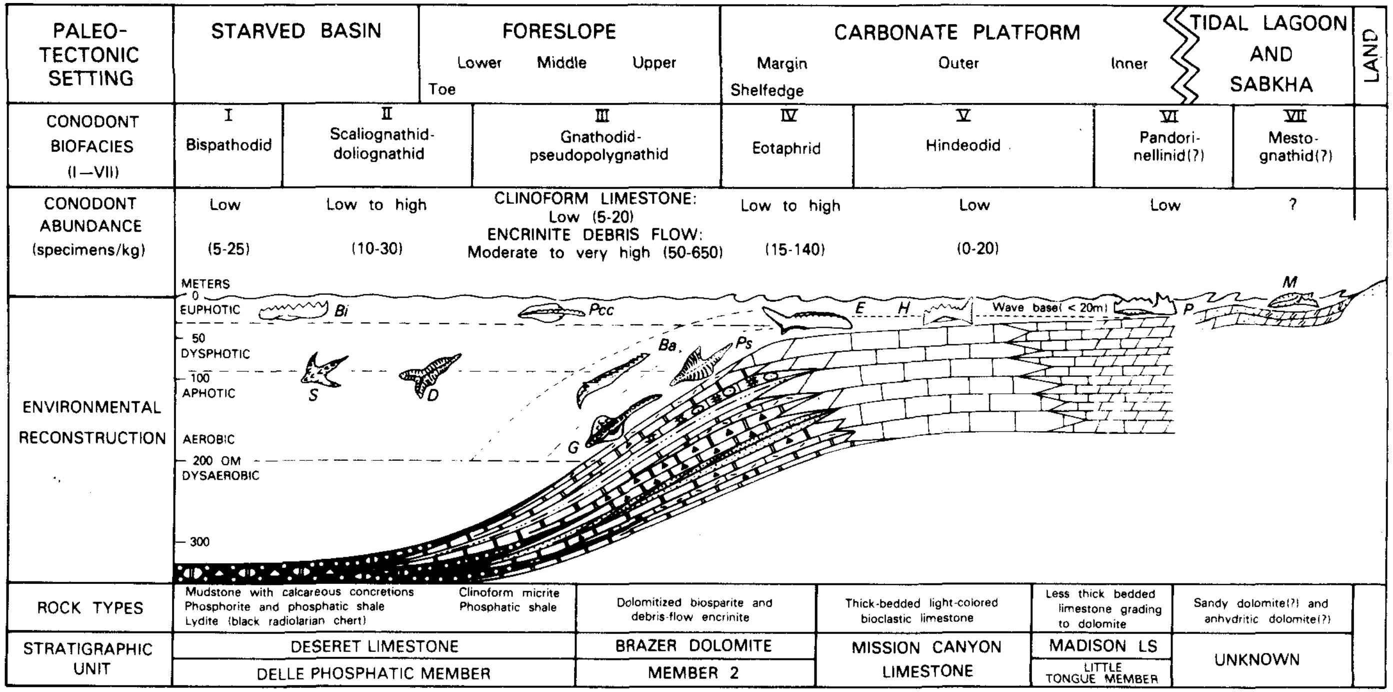


Figure 11. - Reprint from Sandberg and Gutschick, 1984, fig. 14.

scheme originally proposed by Sandberg (1976). The names of the seven Mississippian conodont biofacies (I-VII) are in most cases based on the one or two conodont genera that form the bulk of the faunas.

Although the distribution shown in figure 11 can be applied to British and Belgian Dinantian conodonts, the model does not extend across the platform. This region is one which is well developed through the British and Belgian Dinantian. Therefore it might be possible that additional shallow-platform, protected-shelf, and restricted-marine biofacies will be added to the Sandberg-Gutschick model in the future.

The presence of extensive oolite shoals on the platform, or of shooaling near the margin of the platform, has a pronounced effect on water depth, local energy conditions, salinity, and presumably, the supply of nutrients. Uncertainty concerning both the function and affinity of the organisms, which bore the conodont elements, makes judgements concerning the distribution of elements within the aerobic or photic zone extremely tentative (Austin & Davies, 1984). Nevertheless, such conodont biofacies models and interpreted paleoecology of platform conodonts are of the greatest importance in paleogeographic reconstructions. Classical concepts concerning the paleobathymetric evolution of enigmatic carbonate buildups such as the Waulsortian reefs of Belgium may have to be revised, or at least updated, in the light of recent conodont paleoecologic models.

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