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Devonian basin-fill histories of the Spanish Cantabrian Mountains and the Belgian Ardennes; a comparison

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Abstract

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The evolution of the Pre-Devonian and the Devonian sedimentary basin in the Cantabrian Mountains (N.W. Spain) and in part of the Belgian Ardennes is traced and compared. Emphasis is on the palaeogeography reflected by lithofacies in the carbonate platforms in both basins. Lithofacies from the Devonian system have been chosen because the Devonian is the Period of relative tectonic quiescence between the Caledonian and the Variscan orogenies. It could be attempted for such a Period to characterise sediment patterns and the nature of carbonate in terms of the megatectonic and geodynamic frame within which they are formed. For Iberia a geodynamic mobile model has been proposed in the literature, whereas the tectonically imbricated Belgian Ardennes are geodynamically a stable area. The Belgian carbonate platforms appear to have a Pacific faunal/particle affinity, and they evolved from rimmed margin to knoll-reef rimmed ramp platforms. The Spanish carbonate platforms appear to have an Atlantic faunal/particle affinity and evolved from ramp type to reef-rimmed carbonate platforms.

Introduction

The late Cambrian to late Ordovician convergence of the Arctic and the North Atlantic Caledonides is marked by the lapetus suture; it gave rise to the formation of Laurasia. Convergence of this super-continent and the proto-Tethys plate led perhaps to a steeply dipping, north plunging subduction zone (Ziegler 1982). Microcontents could have been broken off from Gondwana and rafted individually to the North. Iberia has been explained as such a microcontinent (Bard et al. 1980, Ziegler 1982). Throughout the Devonian and early Carboniferous an overall compressional regime prevailed although tensional intervals are known to have existed locally and temporally. The early to middle Devonian megatectonic framework of Central Europe, being the result of these movements, shows Variscan foredeep-basins rimming the northern continental Caledonian landmasses. The southern parts of these basins were folded and imbricated in thin-skinned thrust sheets during the late Carboniferous and now from the mid-European Variscan externides. Similarly, and at approximately the same time, thin-skinned folding and thrusting in a northward direction characterised

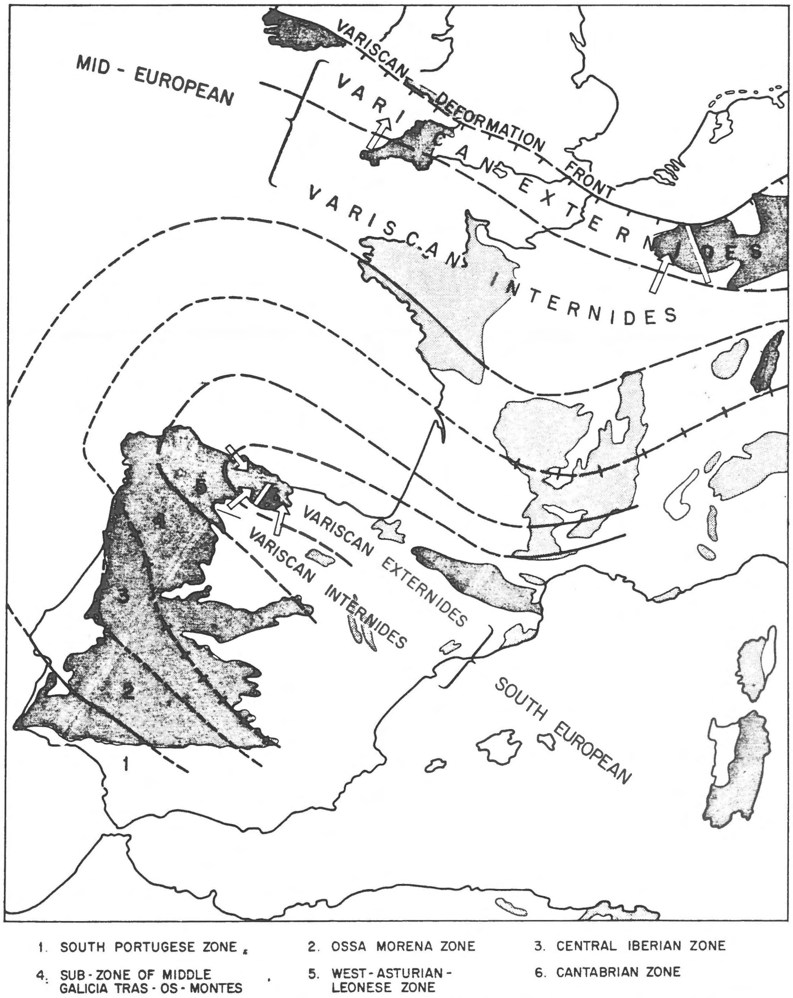


Fig. 1. Outcrops of the European Variscides. Arrows indicate general direction of transport of structural elements.

the south-European Variscan externides in the Cantabrian Mountains. (Fig. 1).

For a comparison of sedimentary characteristics of the two studied areas, of which one might be situated on a rafting microcontinent, it is helpful to have a geodynamically assuredly stationary area available as reference. Although the Belgian Ardennes are tectonically imbricated, it is such an area. It is also an area with which the author is well acquainted. The same is true of the Cantabrian Mountains in NW Spain which, however, represents the possible geodynamically mobile area.

Sedimentary characteristics in geodynamically contrasting areas are best compared when sediments are considered, deposited during an anorogenetic time interval. Such a Period is the Devonian. It is the Period of relative structural quiescence, following the North-European Caledonian orogeny and preceding the Central- and South European Variscan orogeny.

Thus, the main topic of the present paper is an inventarisation and a comparison of Devonian sediment patterns and characteristics of the Cantabrian Mountains with those of the Dinant Nappe area in the Belgian Ardennes. More comparisons are needed between elements of the Variscan orogeny in order to ultimately arrive at a detailed reconstruction of the palaeo-geodynamic position of the various elements of the Variscan orogeny; here the two areas mentioned have been taken as a starting point for such comparisons.

Basin evolution Cantabrian Mountains

Pre-Devonian

In the Cantabrian Mountains the Palaeozoic up to the Carboniferous is characterised by the occurence of two lithostratigraphic groups. The Luna Group (Figures 2, 3) is predominantly siliciclastic; only at the base we find interbedded shallow marine carbonates. It reflects a slowly sudsiding shelf, bordered to the North and East during the late Cambrian and early Ordovician by a linear seaward-prograding coastline that gradually evolved into a number of high-destructive delta comple-

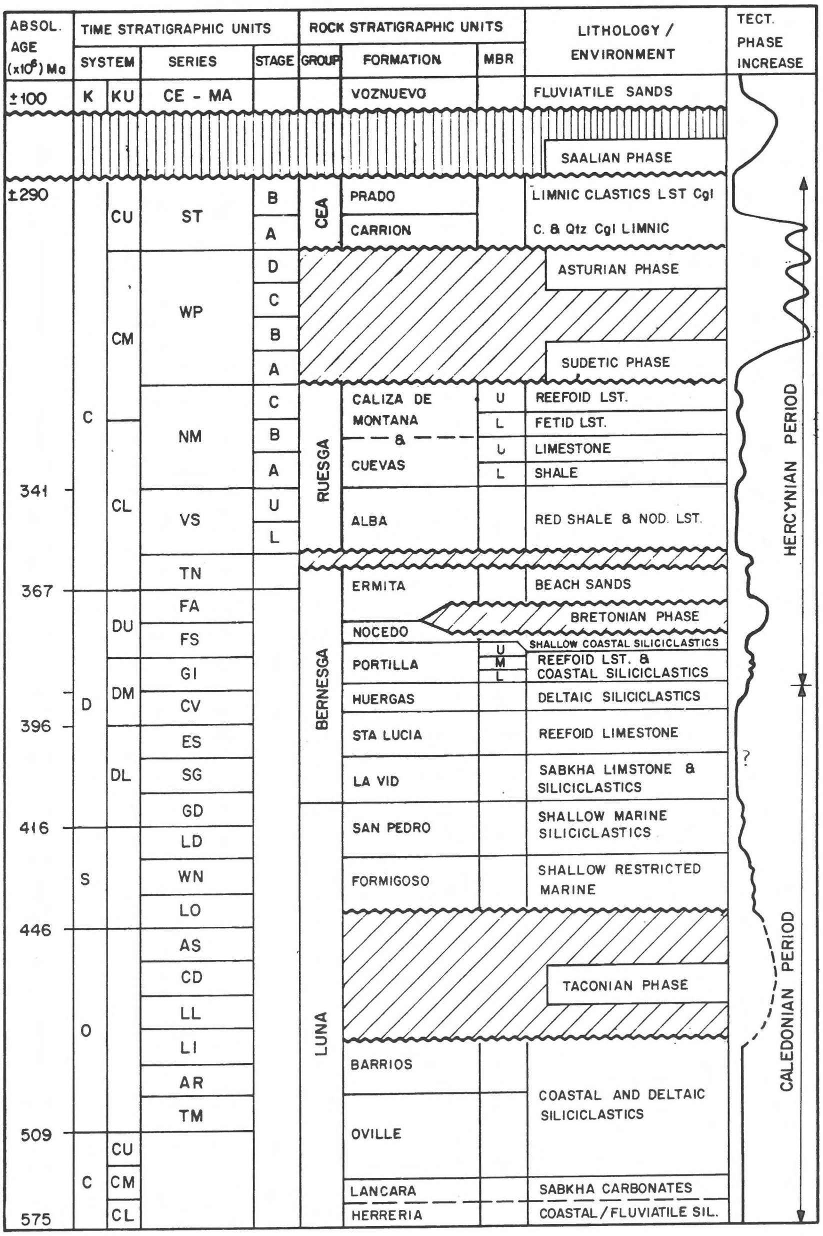


Fig. 2. Lithostratigraphic synopsis S. Cantabrian Mountains, NW. Spain.

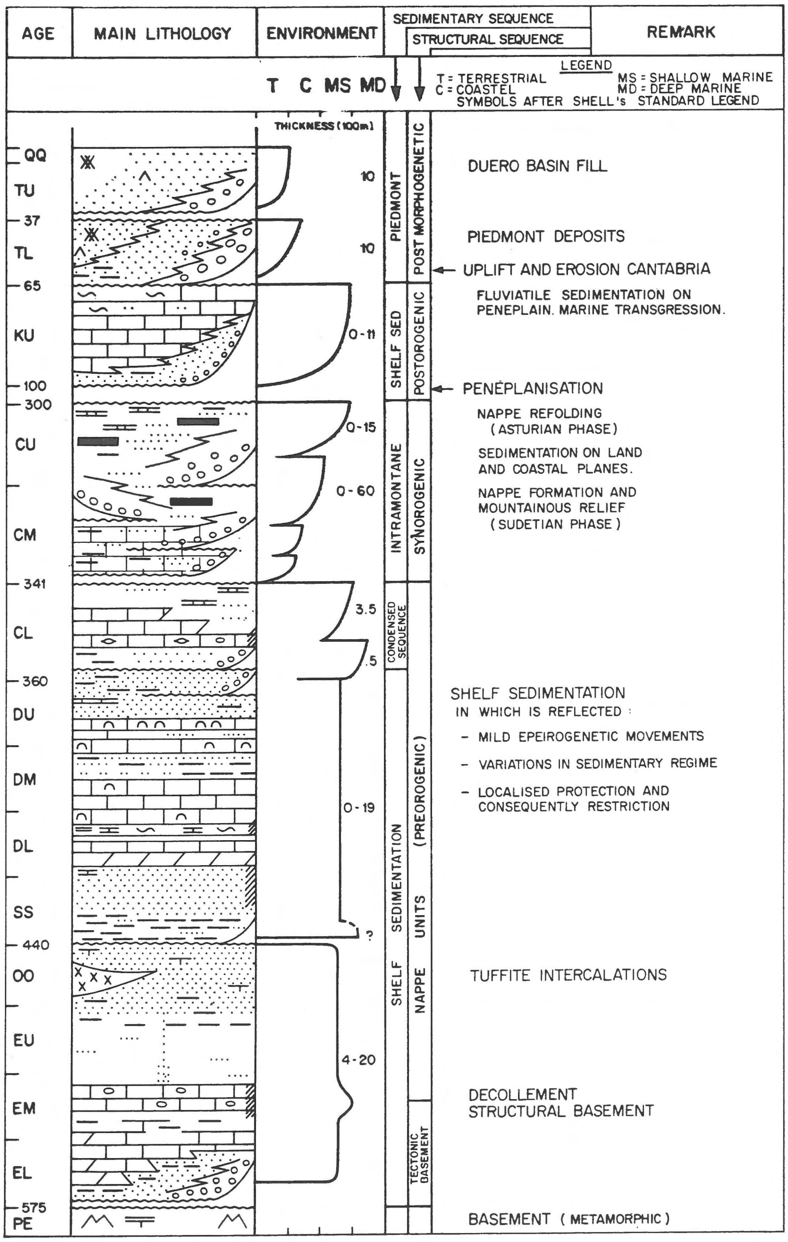


Fig. 3. Geological Synopsis S. Cantabrian Mountains, NW. Spain.

xes (Gietelink 1973). Effusive rocks and tuffite intercalations, occasionally deposited within these coastal environments, testify to magmatic activity in the hinterland. Uplift produced an unconformity; following this, subsidence occured and shales were deposited in a somewhat deeper environment but still on the shelf. The shales are succeeded by an ironoxide-stained, shallow marine, red sandstone unit with volcanic fragments included. Palynofacies studies (Rodriguez 1982) show this sandstone to be partially formed close to the coast, partially under outer neritic conditions. A phase of basin instability and a regression towards the top of this unit is suggested.

Devonian

The regressive sequence at the end of the Silurian and during the early Devonian favoured the formation of carbonate platforms. A number of them, alternating with siliciclastics intercalations, form the Bernesga Group (Figs. 2, 3). The areal distribution of the carbonate platforms (Fig. 4) appears to decrease in time. A diagrammatic N-S cross-section through the Devonian Basin (Fig. 5) depicts the nature and distribution of the sediments deposited, up to the Bretonian phase (Asturian doming). Map (Fig. 4) and cross-section (Fig. 5) demonstrate the mechanism of basin-fill which was regular reactivation of source areas for siliciclastics and gradually infilling of the basin by carbonates that became areally more and more confined. The areal confinement of sediments is further accentuated by the Late Devonian erosion phase that followed the Asturian doming. In Asturias an area-wide regression is seen due to the doming, superimposed on more localised tilting and erosion (Julivert 1981). In León it is thought that sea level fluctuations acted alternatingly in and out of phase to the movement of individual blocks (Krans 1982).

Trends in lithological units

A very apparent trend in the Devonian basin is the increase in reefoid character of the carbonate platforms, and a change in platform margin nature towards younger carbonate units (Figs. 3, 5).

From NE to SW the Gedinnian-Siegenian La Vid carbonate facies reflects environments ranging from supratidal (Sabkha-like) to intertidal and shallow (protected?) marine. The most interior facies zones are dominated by stromatolitic dolomites. Nearer the platform-rim wind or storm-swept banks of bioclastic matter occur (Ruhrman

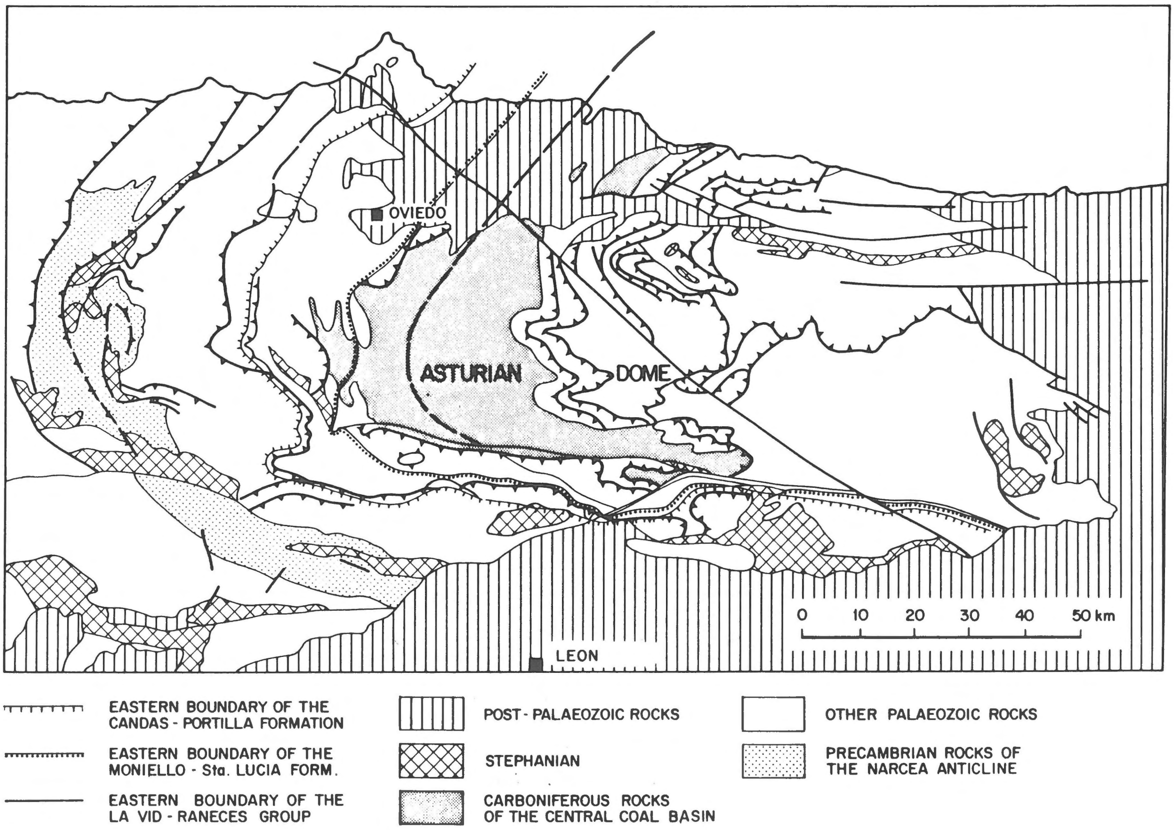


Fig. 4. Cantabrian Mountains, NW. Spain. Extend of distribution of La Vid, Sta. Lucia and Portilla formations. (consistent met Fig. 3)

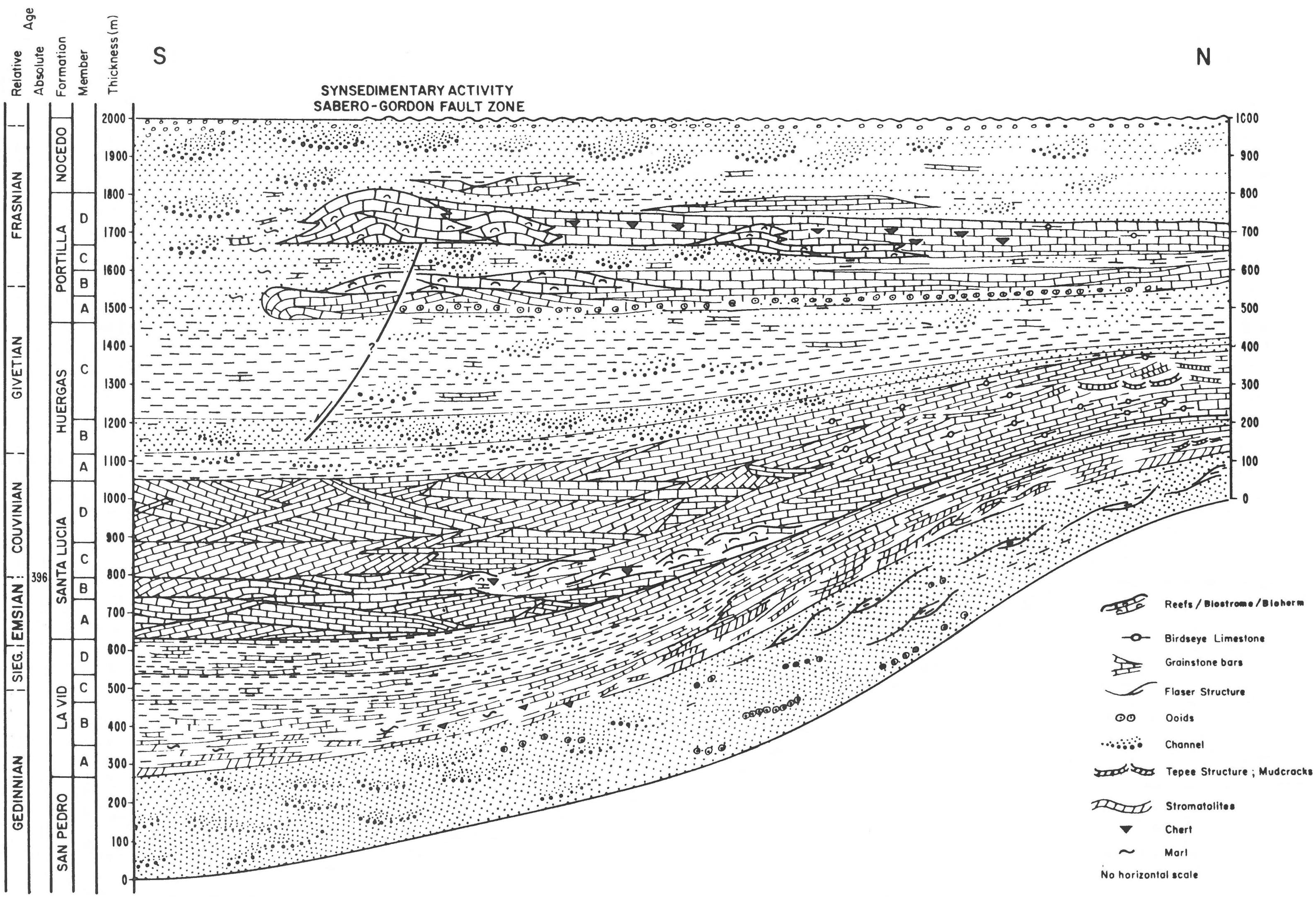
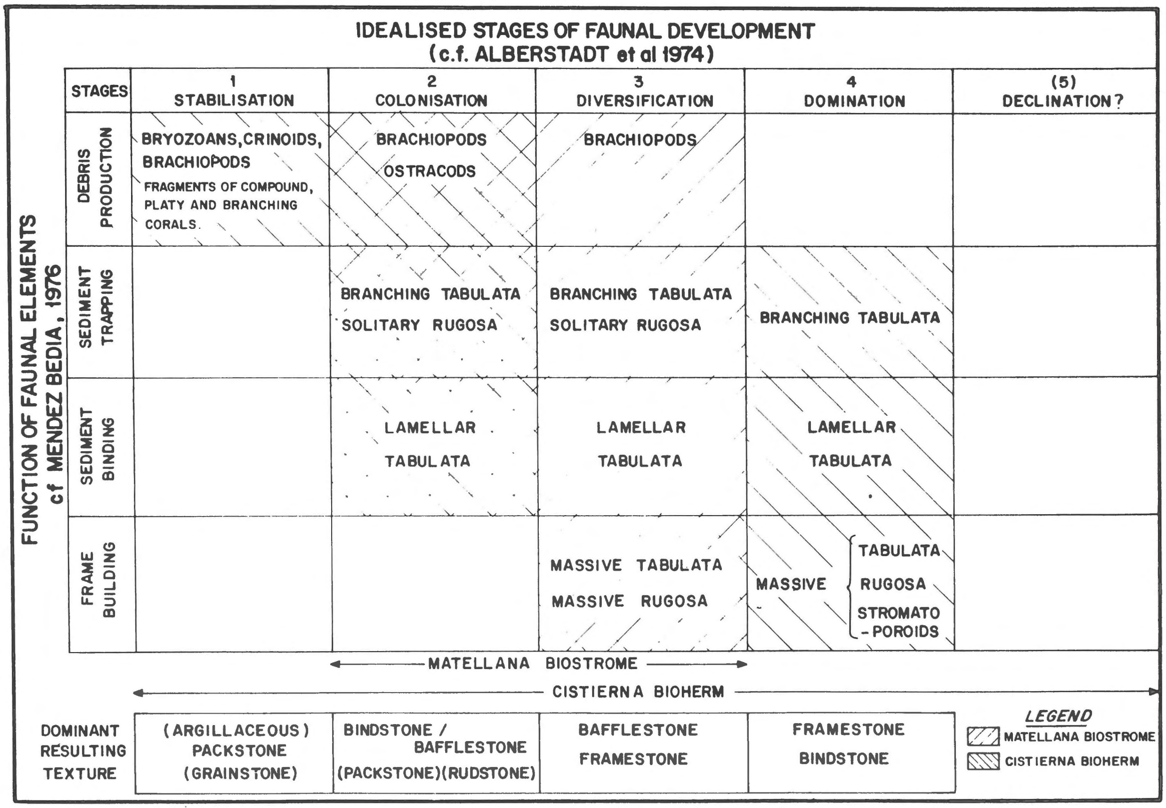


Fig. 5. Diagrammatic representation of N-S cross-section through Devonian basin, S slope Cantabrian Mountains, NW Spain, up to Famennian Hiatus.

1971, Stel 1975). Sparse biostromes (Brouwer 1964) could have been formed by pioneering faunas on such bioclastic banks and in the basinal shales in front of the carbonate platform (e.g. near Colle). The carbonate platform has the aspect of a ramp on which no clear margin-edge buildups formed.

The Emsian-Couvinian Sta. Lucia carbonates have a number of similarities with the La Vid carbonates. From NE to SW three facies-zones occur. The most interior facies is characterised by an abundance of mud-cracked supratidal to intertidal lime mudstone with palaeosoil indications and dissecting erosive tidal channels. This belt of peritidal deposits continues in Asturias (Mendez-Bedia 1976). To the south and the west of this facies belt a zone is present, characterised by encrinitic/bioclastic grainstone bars. It straddles a fundamental basement fault (The Sabero-Gordón-line) and is prominent south of it. It has no regionally extensive equivalent in Asturias (Mendez-Bedia 1976, p. 86). However, in the Arnao region (Asturias), Mendez-Bedia (1976) described a true bioherm which locally acts as the barrier zone, functionally replacing the bioclastic grainstone bars of the Sta. Lucia Formation in León. Biostromal coral-stromatoporoidal accumulations in back-barrier position (just N of the Sabero-Gordón line, behind grainstone bars) surpass both in dimension and regional distribution the La Vid biostromes. The Asturian lagoonal packstones, wackestones and mudstones with birdseyes and scarce laminations are reminiscent of the La Vid platform interior sediments. The Sta. Lucia carbonate platform has distinct characteristics of a rimmed margin platform of which the margin development is controlled by a fundamental fault.

Part of the northern and eastern facies of the Portilla carbonates are removed by the late Devonian erosion. Thus no peritidal depositional facies remained (Reijers 1972). Shallow, restricted back-reef environments with bioclastic grainstones and packstones, but also with considerable amounts of lime-mudstones are present. Patch reefs are com-



mon and ooid bars point to a tidal influence towards the exterior part of the platform. The rim of the carbonate platform is characterised by reef track deposits (Reijers 1972, 1980; Reijers & ten Have 1983, Reijers et al. in prep.) including biostromes and bioherms. The nature and internal architecture of these reefoid bodies (Fig. 6) are demonstrated by contrasting a well developed biostrome (near Matallana) and a well developed bioherm (N. of Cistierna) (Reijers 1972, 1980). The bodies are internally zoned (Alberstadt et al. 1974) and the zonation reflects various environ-

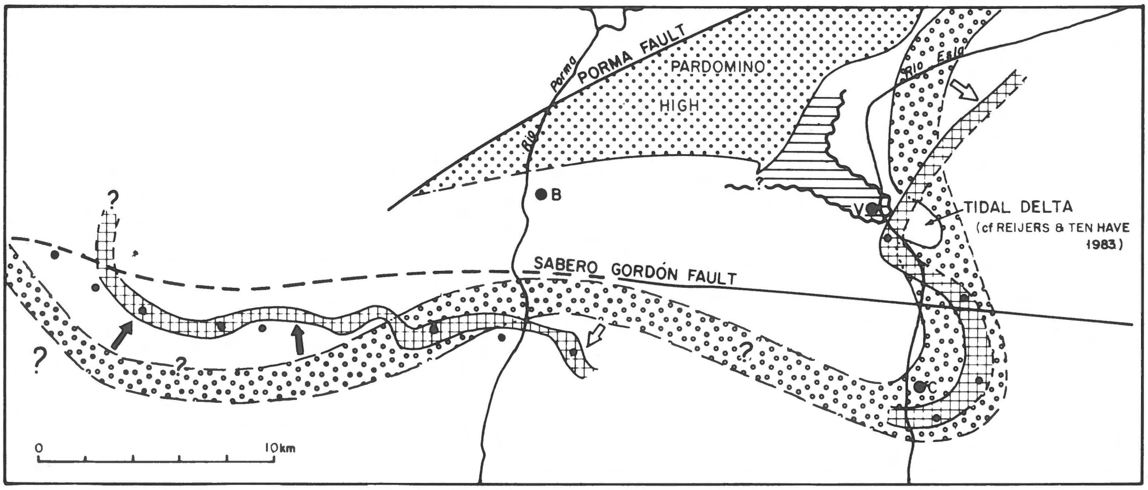


Fig. 7a. Palaeogeography at the transition Givetian – Frasnian.

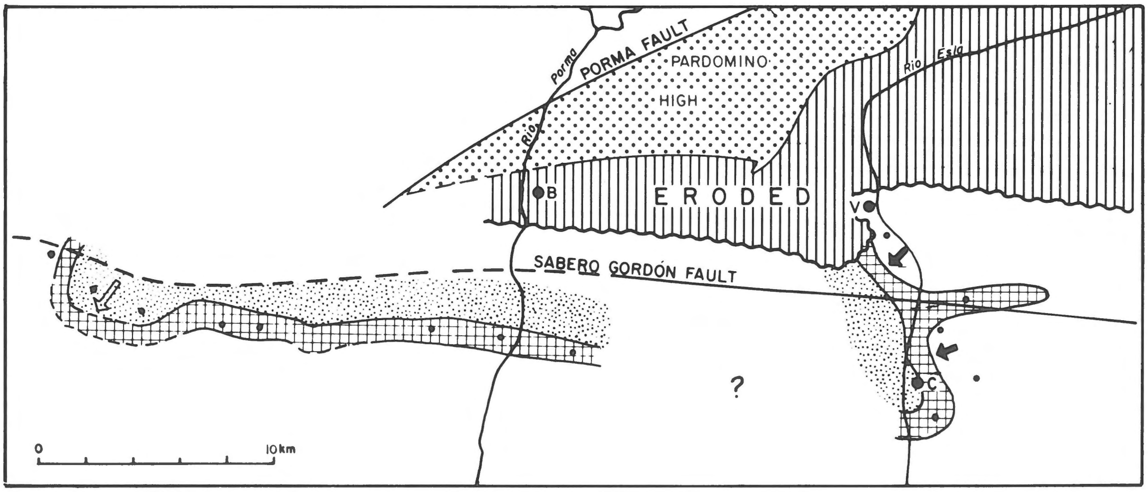
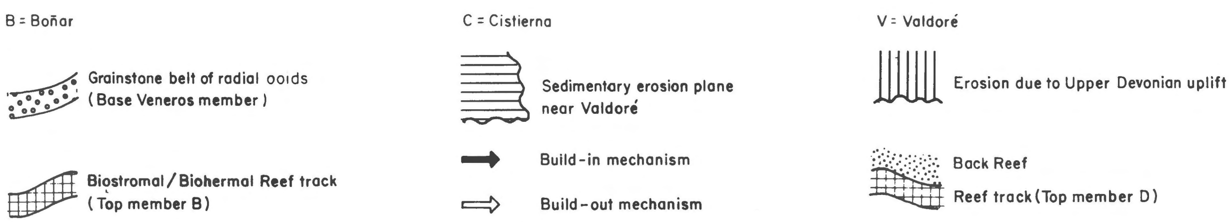


Fig. 7b. Palaeogeography at approximately end Portilla deposition.



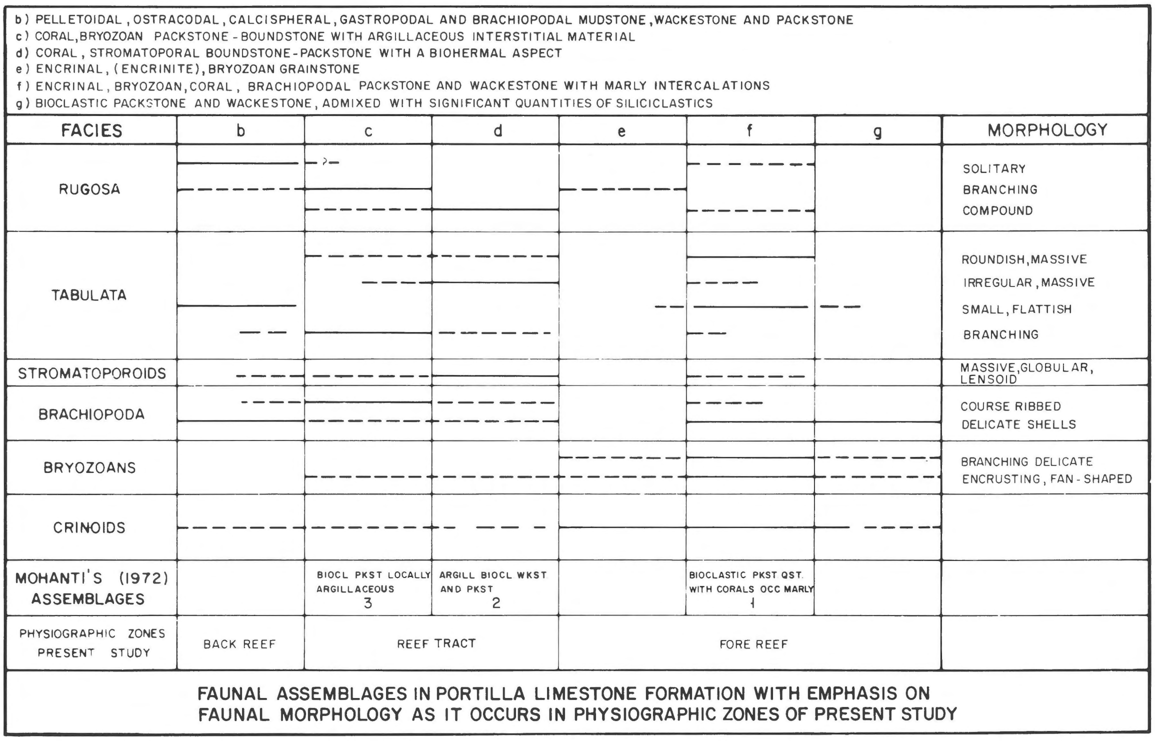


Fig. 8.

mental conditions as a result of the active growth of the carbonate bodies and of the onset of the late Devonian world-wide transgression that eventually drowned the carbonate platform.

Two levels in the Portilla carbonates show an explosive development of reef builders of the types depicted in figure 6; i.e. at the Givetian-Frasnian boundary and in the early Frasnian. At the lower level an incipient, discontinuous and at the higher level a mature, continuous barrier reef developed, rimming the carbonate platform. These reefs are depicted in figures 7a, b respectively in a palinspastic reconstruction (see Reijers et al. in prep.). Both reefs follow the Sabero-Gordón fault zone over approximately 100 km EW and in time they build out into adjacent areas. Cross-bedded fore-reef bioclastic grainstone bars assume the protecting function in front of gaps in the barrier reef. Based on the work of Mohanti (1972) and of Reijers (1972, 1980) it is possible to characterise the back-reef, the reef and the fore-reef zones in the Portilla Formation in terms of faunal assemblages with an emphasis on faunal morphology (Fig. 8). Because of Walther's (1893-1894) Law it is clear that a number of aspects shown laterally in figure 8, are also present vertically in figure 6. Of the three carbonate units discussed it can be stated that the amount of individual species is variable and often very high, and the diversity in species and genera is generally high, but not exceptionally high.

The described carbonate units are alternating with siliciclastic internals (Fig. 5) which are of shallow marine origin. The regional facies distribution follows that of the described carbonate units; the most restricted conditions prevail to the N and the E whilst in a southerly and a westerly direction more open and deeper marine conditions predominate. The introduction of siliciclastics onto the carbonate platform marks a first order cyclicity (Reijers 1980), which is partially triggered by activity of the Asturian Dome, and partially by the relative level of the sea.

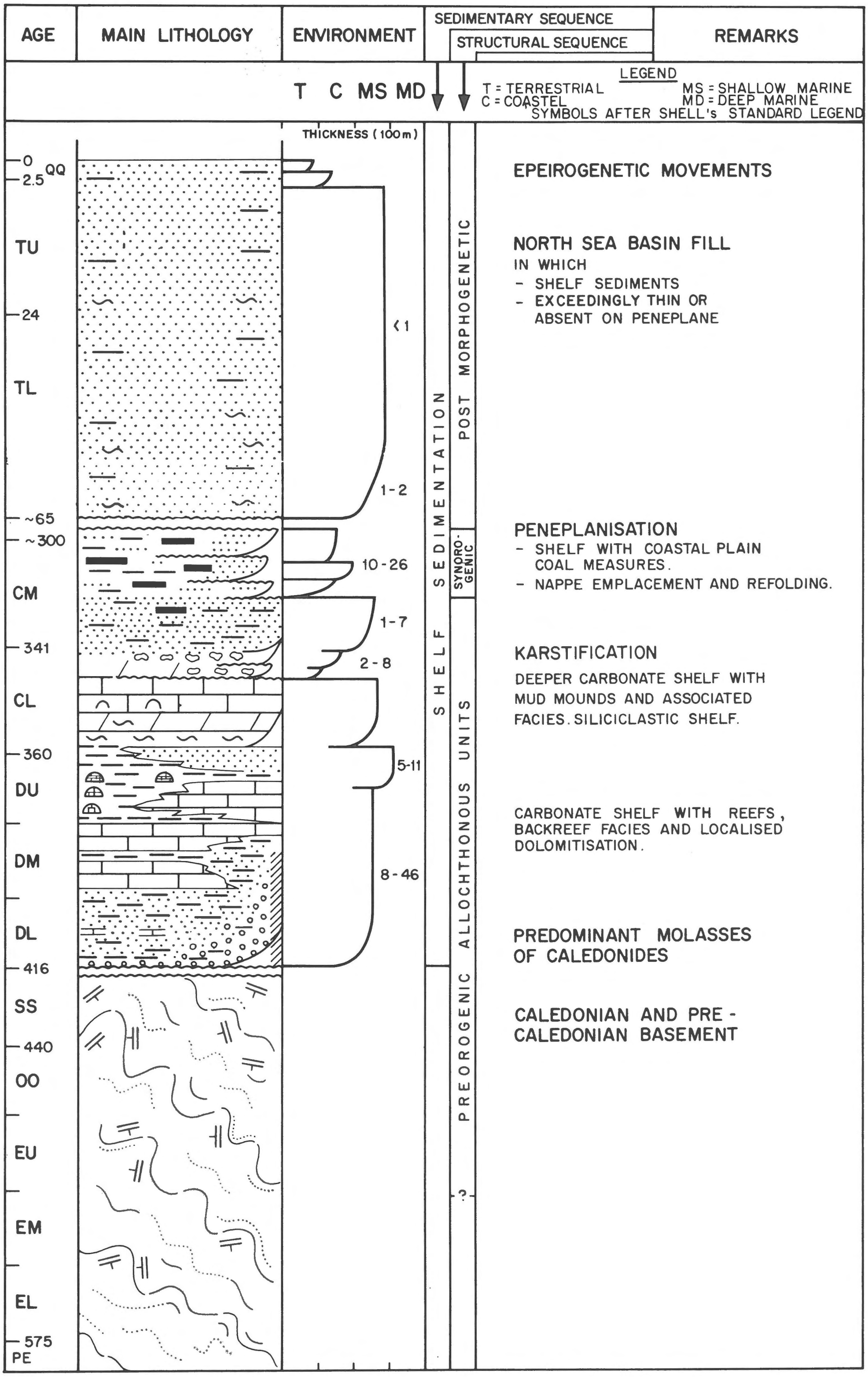


Fig. 9. Geological synopsis Dinant Nappe, Ardennes – Belgium.

Basin evolution Ardennes (Dinant area)

Pre-Devonian

In Belgium the early Cambrian Cadomian orogeny supplied siliciclastics throughout the Cambrian. This northerly source diminished in importance towards the end of the Cambrian, and during the Ordovician and Silurian clastics were brought from the south into the depositional basin. The Stavelot-Venn and Rocrol-massifs were uplifted, due to the Caledonian orogeny, and supplied some material, including reworked Ordovician acritarchs, to the Silurian deposits of the Condroz area (Bless et al. 1983). Here Silurian strata are absent due to erosion and a gap exists in the sedimentary record around the Silurian-Devonian junction (Fig. 9).

More regional results of the Caledonian orogeny are:
- a foldbelt from Norway into Great Britain. In depressions of this belt, formed by subsequent rifting and subsidence, Old Red Sandstone accumulated during the Devonian;
- the Cornwall-Rhenish basin which crosses from W. Germany through the Belgian Ardennes, N. France and S. England;
- the Belgo-Dutch platform (Bless et al. 1983), localised in between the other two elements.

Devonian

The succesion of Devonian strata is given in figures 9, 10 and 11. The early Devonian is characterised by deposition on a shelf rimming the Cornwall-Rhenish basin, of breakdown products mainly of the Old Red continent. Only from the middle Devonian onward carbonates do form (Figs. 9, 10) and in time the southern boundary of the various carbonate units shifts to the north. The Devonian carbonate units are preceded, interrupted and followed by siliciclastic units.

During the early Devonian the depocentre in the Cornwall-Rhenish basin was situated in the south of the present-day Belgian Ardennes (Ziegler 1982). A terrigenous regime prevailed and large quantities of siliciclastic material were derived from the Old Red Continent in the North as well as from the southerly Normanian – Mid German land areas. Some positive areas (Rocroi, Stavelot-Venn) continued to deliver material. High-energy rapid stream and sheetflood deposition dominated. Generally the coarsest material is oldest and occurs more to the north, reflecting an active Caledonian hinterland. With time material generally became finer, although pulses of coarser and very unsorted material remain a characteristic element. Towards the end of the early Devonian, sedimentation decreased and more shaly lenses occur together with limestone streaks.

The Couvinian heralds a pronounced differentiation between shelf carbonates and siliciclastics realms (Reijers 1984, fig. 4). At some distance from the Old Red Continent carbonate sediments replace siliciclastics. Carbonates predominate towards the shelf edge from where they interfinger with basinal fine siliciclastics, and with shelf siliciclastics of an increasingly coarser nature to the North. During the Couvinian, Givetian and Frasnian the sea transgressed in a northerly direction from the Dinant area over the positive Condroz-zone (Figs. 11, 12) towards the Namur area. Via a graben in the Belgo-Dutch platform the transgression reached deep into the Old Red Continent, as testified by open-marine Devonian carbonates with a Frasnian flora and Middle- to Upper Devonian ostracods that have been encountered in the central part of the North Sea. Anhydrite occurs intercalated with these carbonates.

During the Givetian and the Frasnian the northern shelf of the Cornwall-Rhenish basin was an extensive shallow-marine carbonate platform. Some siliciclastic influxes from the positive Condroz swell in the north and restriction in the interior part of the platform caused carbonate production to be less prolific away from the platform edge. However, close to the edge of the carbonate platforms, near the towns Givet and Couvin (Fig. 12), impressive stromatoporoid bioherms occur (Fig. 13 and Reijers 1984, fig. 7a, b), thus making the Givetian carbonate platform a rimmed one. The faunal diversity is generally very great. From the middle Frasnian onwards there is a distinct separation between a northerly shallow-marine carbonate platform and a southerly deeper-marine offbank

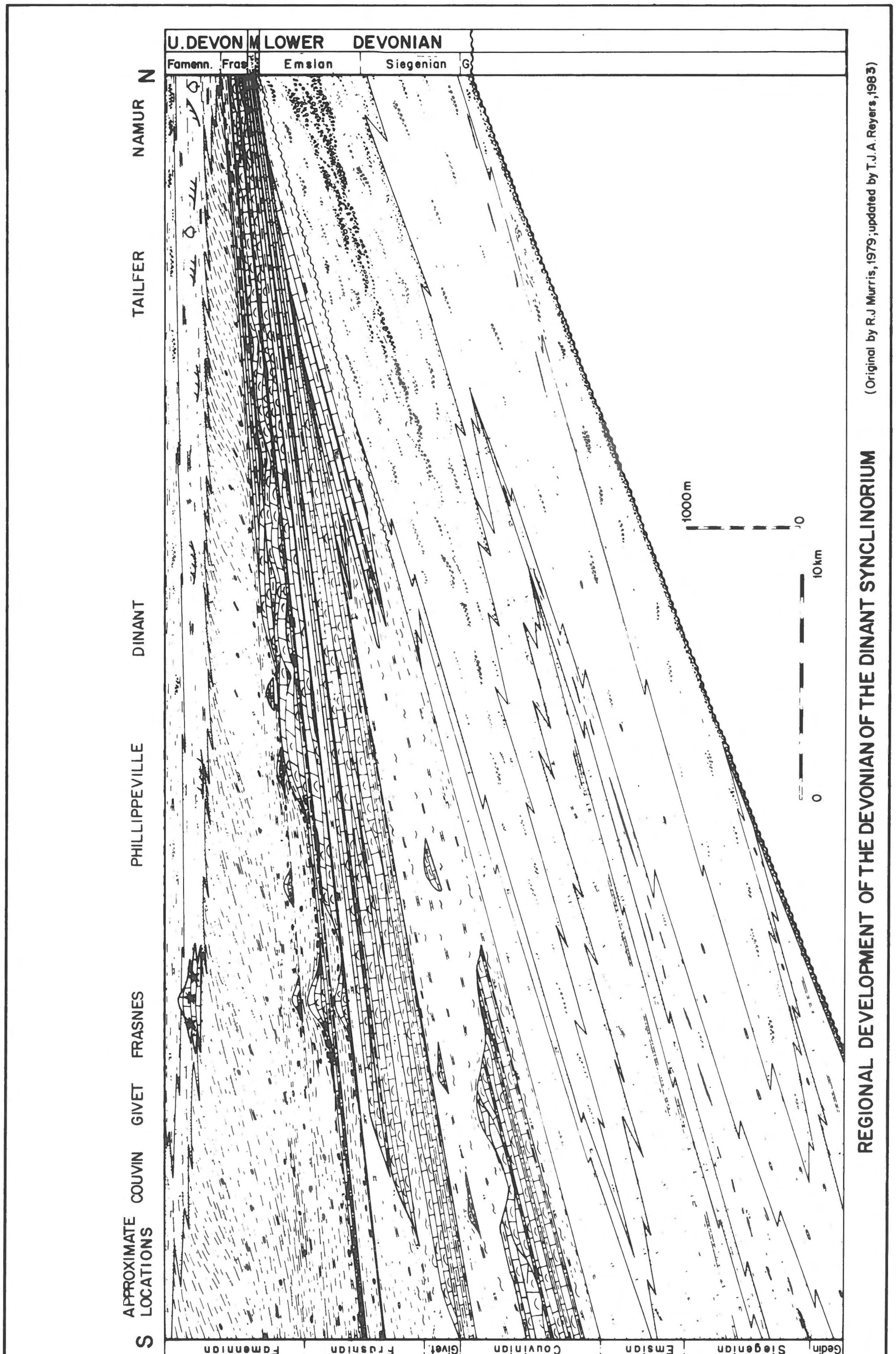
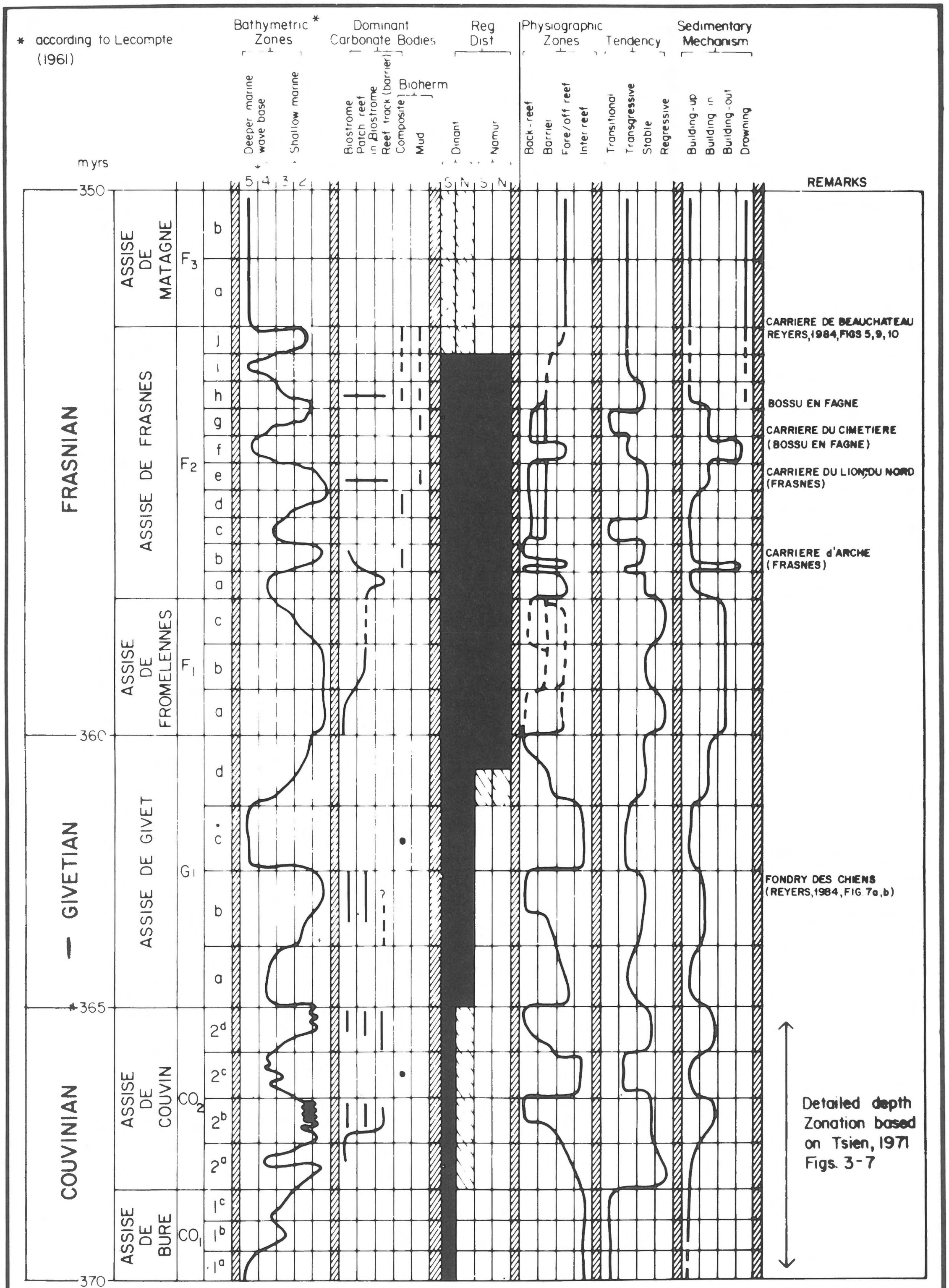

REGIONAL DEVELOPMENT OF THE DEVONIAN OF THE DINANT SYNCLINORIUM
(Original by R.J Murris, 1979; updated by T.J.A. Reyers, 1983)
S
APPROXIMATE LOCATIONS
COUVIN
GIVET
FRASNES
PHILLIPPEVILLE
DINANT
TAILFER
NAMUR
N
U.DEVON
M
LOWER DEVONIAN
Famenn.
Fras
Emsian
Siegenian
G
UPPER DEVONIAN
MID. DEVONIAN
LOWER DEVONIAN
Famennian
Frasnian
Givet.
Couvinian
Emsian
Siegenian
Gedin
1000m
0
10km
0

Fig. 10.



Summary of depth-zones of carbonate bodies, and their regional distribution. This is interpreted in terms of physiographic zone, tendency and sedimentary mechanism

Fig. 11.

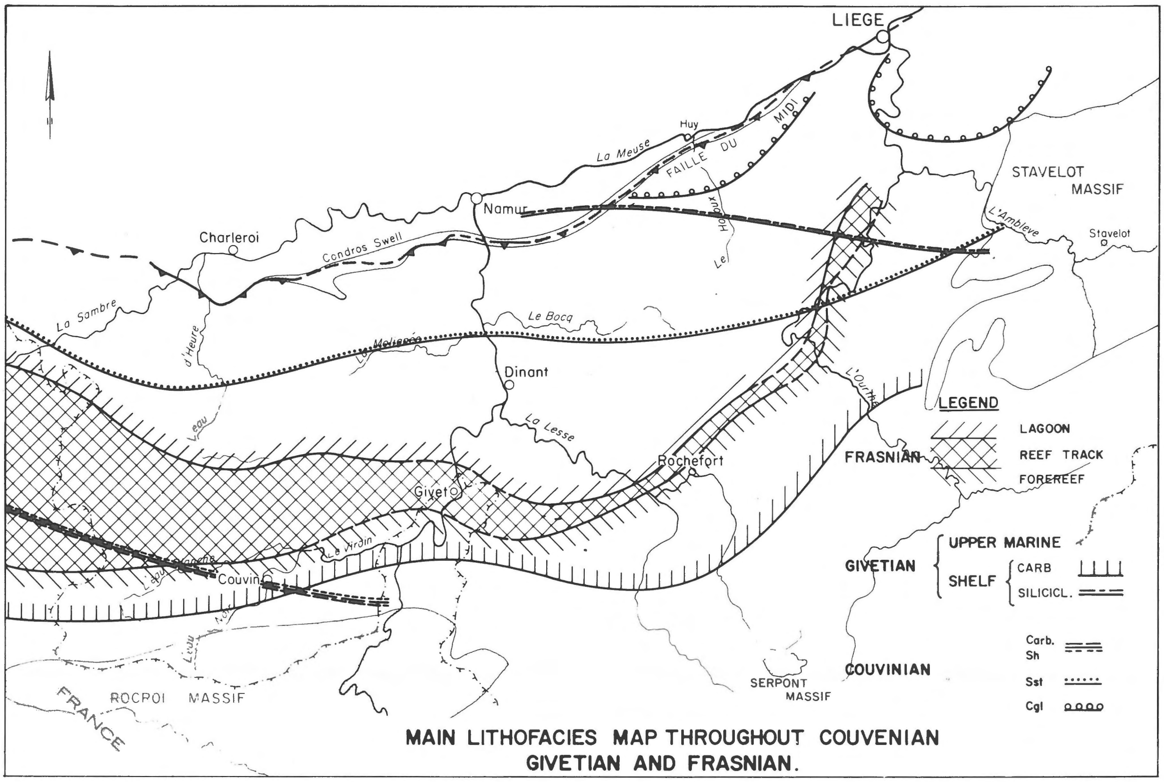


Fig. 12.

environment. The position of the boundary between these two areas is not stable in time. It runs E – W through Philippeville and Merlemont and tends to shift in a northerly direction throughout the Frasnian. The position of this line is characterised by extensive dolomitisation, although dolomite is confined to areas between subsiding N – S trending blocks that cross the platform edge. No clear biohermal accumulation or reefs characterise the rim of the carbonate platform which is best referred to as a ramp. The offbank, deeper-marine setting is characterised by prolific development of individual knoll-reef-like carbonate build-up structures in certain places. It is possible to contrast the biohermal accumulations that characterise the southern edge of the Givetian carbonate platform (e.g. at Fondry des Chiens), with the knoll-reef-like 'mud mounds' of the zone in front of (south of) the continuous Frasnian carbonate platform (e.g. 'Beauchateau' at Senzeille) (Fig. 13).

A number of facies gradients are apparent within the Frasnian:

(1) There is a distinct zone crossing the village of Frasnes in an E – W direction, where knoll-reef-like bioherms and mud mounds occur 'stacked' on top of each other. This feature characterises the southern-most belt of carbonate bodies and this zone lies in front of the dolomitised edge of the ramp-like carbonate platform.
(2) Further to the north this facies belt is followed by a zone in which isolated reddish mud mounds of late Frasnian age occur. Some of such carbonate bodies overstep the dolomitised edge of the middle Frasnian ramp but they never form part of it. They 'float' in shale.
(3) Reddish carbonate mud mounds get younger to the north (Tsien 1971, 1974, 1979, 1980). This reflects the ongoing Frasnian transgression of the sea which has flooded the porous, dolomitised southern zone of the carbonate ramp.
(4) The 'stacked' and the 'floating' bioherms are always present over the earlier Givetian rim-

FUNCTION OF FAUNAL ELEMENTS (cf Mendez Bedia, 1976) — PROCESS \ STAGES	1. STABILISATION	2. COLONISATION	3. DIVERSIFICATION	4. DOMINATION
Debris Production	CRINOIDS, CORAL FRAGMENTS	CORAL AND STROMATOPOROID FRAGMENTS		
Sediment Trapping	- BRANCHING TABULATE CORALS - BRACHIOPODS - CRINOIDS	BRANCHING TABULATE CORAL	BULBOUS STROMATOPOROIDS AND STROM FRAGMENTS MASSIVE CORALS	
Sediment Binding		- PLATY TABULATE CORALS - PLATY STROMATOPOROIDS - ALGAE	- PLATY AND MASSIVE TABULATE CORALS - PLATY STROMATOPOROIDS - ALGAE	
Frame Building				BULBOUS STROMATOPOROIDS SOME CORALS
Lecompte's (1961) Depth zones	5 – 4	3	2 – 1	1
Dominant resulting texture	Grainstone (Givetian) Bafflestone (Frasnian)	Bindstone (Frasnian) Packstone, Rudstone (Givetian)	Bindstone (Givetian) Framestone (Frasnian)	Framestone Bindstone

1 HIGH HYDRAULIC ENERGY, CLEAR WATER
2 HIGH HYDRAULIC ENERGY, TURBID WATER
3 MODERATE HYDRAULIC ENERGY
4 AROUND WAVE BASE
5 QUIET ZONE, BELOW WAVE BASE
} Le Compte's 1961 DEPTH ZONES

Idealised stages of faunal development (c f Alberstadt et al 1974)

[/] Givetian Bioherms
[\] Frasnian Mudmounds

Fig. 13. Contrast Givetian bioherms and Frasnian mud mounds, Dinant Synclinorium, Belgium.

med carbonate platform, and it is thought that pre-existing topographic relief on that platform, only partly draped by shales, triggers such mud mounds.

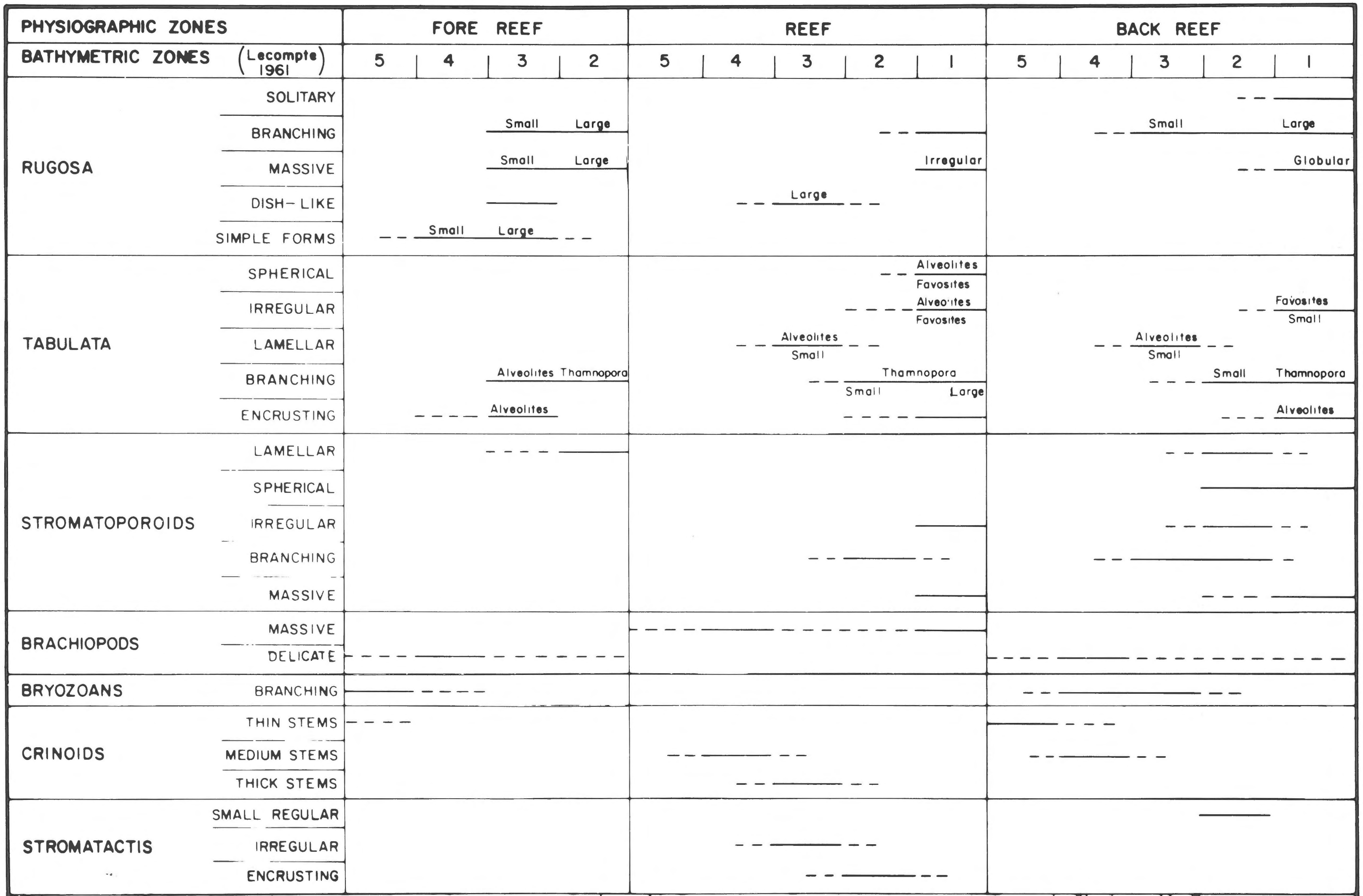
The red mud mounds and the 'stacked' bioherms further south, although rather different in naturel, are collectively included in a 'reef track zone' as has been done in figure 12. But this reeftrack does not form a rim of the continuous ramp-like Frasnian carbonate platform, nor is it in any way similar to the Spanish continuous barrier reef. To the north of this reef track zone and within the carbonate ramp there is a lagoon in which bioclastic limestones alternate with interbedded siliciclastics. Occasionally stromatolitic dolomite is found. The back reef lagoon (= platform interior) and the zone with bioherms and mud mounds (= the reef track) and their fore-reef facies can be characterised in terms of faunal assemblage and of predominant faunal morphology. A lot of detailed work in this respect has been carried out by Tsien (1971, 1974, 1979, 1980) on which figure 14 is mainly based. A striking faunal diversity, next to a great amount of species, is apparent.

Following the Frasnian reefoid development a rapid deepening due to a world-wide transgression kills reefgrowth. This deepening gave rise to deposition of the Matagne shales (Fig. 11) which throughout the Famennian were gradually replaced by fine sandstone and calcareous sandstone.

Discussion and comparison

Comparison of some geological parameters (Table 1) brings to light the contrasts between the Devonian depositional settings in the Ardennes and in the Cantabrian Mountains.

Provided the right environmental conditions are present, and an overall high stand of sea level reduces the land area, then in clear tropical water in which carbonates are produced prolifically, carbonate platforms may form. They could build out (away from the coastline), if the seabottom in



Faunal Assemblages in Devonian of Dinant/Namur Basins, with Emphasis on Faunal Morphology as it Occurs in Physiographic Zones of Present Study. (Based on Tsien 1971)

Fig. 14.

Table 1. List of contrasts in sediment properties of the Devonian of the Cantabrian (N.W. Spain) and the Ardennes (Belgium).

		Variable	Spain	Belgium
Cyclicity of lithologies	1	Cyclicity	three siliciclastic units alternate with three carb. units	two siliciclastic units sandwich one carbonate unit in which siliciclastics occur interbedded
	2	Nature silicicl.	shallow marine lagoonal and deltaic	*lower unit:* shallow marine – continental (Old Red Sandstone) *upper unit:* interdeltaic, low energy environment; somewhat deeper than lower unit (Condroz sandstone)
	3	Nature carb.	shallow marine, reefoid with associated facies	shallow marine, reefoid with associated facies
	4	Dolomite and other evaporites	decreases in importance towards younger strata	increases in importance towards younger strata
	5	Red beds	exclusively at base Devonian (Gedinnian)	Old Red Sandstone from Gedinnian to Emsian and locally Couvinian
Lateral and vertical distribution	6	Lateral extent and nature carbonate units	zonal facies, facies belts 10 – 50 km wide	allochthonous (Dinant Nappe) but at least 30 km wide zonal facies
	7	Onset carb. production	U. Gedinnian – Siegenian	Couvinian
	8	Lateral extent silicicl. units	area wide	area wide. Note: off-bank siliciclastics occur associated with carb. platforms
	9	Sedimentary mechanism	vertically build-in and build-out depends on individual block movements	build-up and build-in
Nature and aspect of reefs	10	Nature reefs	biostromes and some bioherms arranged in barrier reef tracks	biostromes and mud mounds
	11	Relation reefs-substrate	fault controlled	irregularities on sea bottom perhaps induced by pre-existing carbonate build-ups
	12	Relation reef/ barrier – carbonate platform	Late Devonian: rimmed margin Middle „ : rimmed margin Early „ : ramp	reefs, mounds are developed away from edge carbonate platform. In off-bank shale basin occur: a) 'stacked' biohermal mud mounds b) 'floating' red mud mounds These have no equivalent in Spain. Continuous carbonate platforms are rimmed (Givetian) or ramp-type (Frasnian)
	13	Reefoid character through time	*Frasnian:* biostromal-biohermal barrier-reefs *Couvinian:* lagoonal patchreefs *Siegenian:* scarce biostromes	*Frasnian:* biostromes and mud mounds *Givetian:* biostromes and bioherms *Couvinian:* biostromes
Elements of carbonates	14	Main faunal elements	bioclasts, corals, stromatoporiods, bryozoans, crinoids, moderate faunal diversity	lime mud, bioclasts, algae, corals, stromatoporoids, crinoids, brachiopods, bryozoans. High faunal diversity.
	15	Non-skeletal particles	ooids in characteristic zones in Givetian	no ooids
Causes for cyclicity	16	Sea-tendency during Frasnian	transgressive	transgressive
	17	Epeirogenesis	updoming (Asturian dome)	rhythmic movements in backreef zone. Transversal zones of subsidence

front of them is very mildly sloping, or they could build up, following a rising sea level or a subsiding seabottom. These two situations generally give rise to shoaling sequences. The type of carbonate platform is not only dependent on the degree of slope of the seabottom, it is also controlled by a host of environmental parameters, such as temperature and water clarity.

Platforms and their margins are nowadays (Cook et al. 1983) classified according to their morphology as rimmed margins (reef-dominated or sand-shoal-dominated) and as non-rimmed margins. In terms of the predominant physical process, they can also be classified as windward, leeward or tidal carbonate platforms. Another way to classify carbonate platforms is by looking at the nature and abundance of carbonate particles present. Lees (1975) defined faunal/floral constituents in carbonate associations on the basis of the prevailing temperature in the depositional environment, and recognised a warm-water association which he named the chlorozoan association. This he further subdivided into skeletal and non-skeletal associations. Thus associations can be defined with an Atlantic and with a Pacific affinity. The former is characterised by a low diversity chlorozoan association and the presence of ooids/aggregate grains, the latter by a high diversity chlorozoan association and the absence of ooids/aggregate grains. These two classification methods are applied on the discussed Belgian and Spanish carbonate platforms.

From early to late Devonian the carbonate platforms in the Cantabrian Mountains evolved in a characteristic way. In the early Devonian La Vid Formation, crinoidal calcarenites and shales characterise the exterior shelf. The provenance of these shales must be found in the south. Enclosed in these shales are some low diversity coral biostromes with restricted areal dimensions (Brouwer 1964 and Stel 1975). The carbonate platform can be described as non-rimmed with mixed siliciclastics and carbonates, wind influence and an Atlantic affinity.

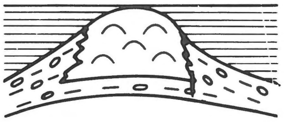
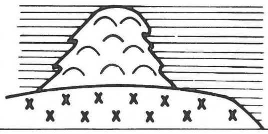
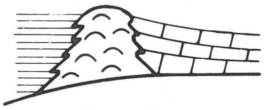
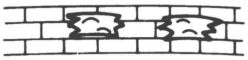
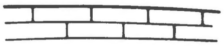
The exterior part of the carbonate platform of the Middle Devonian Sta. Lucia Formation is characterised by cross-bedded crinoidal grainstone bars. Thus this platform is a sand-shoal dominated rimmed margin platform with wind domination and an Atlantic affinity.

During deposition of the Portilla carbonates active local tectonic movements triggered coral-stromatoporoid barrier-reef type build-ups parallel to the coast. Tidal currents in an open shelf setting swept bioclastic material together and formed banks. Consequently the late Devonian carbonate platform can be classified as a reef dominated rimmed margin with wind and tidal influence and an Atlantic affinity.

An ongoing transgression throughout the middle-late Devonian characterises the Ardennes. The hinterland here, being eroded during the early Devonian, intermittently supplied modest amounts of siliciclastics over the platform interior carbonates. Such carbonates locally reflect a distinct shoaling and since this occurs in association with carbonate inbuilding tendencies in the platform frontal ranges it could be speculated that the entire carbonate platform was occasionally slightly tilted. This speculation is supported by the occurrence of platform interior cycles that frequently end in small diastems (Reijers 1984) and that can be correlated over great distances.

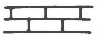
The discussed Givetian carbonate platform is classified as having a rimmed, reef-dominated margin with wind dominance. The high species diversity and the absence of coated grains suggests a Pacific affinity. The discussed Frasnian carbonate platform is classified as a knoll-reef rimmed ramp with no apparent wind or tide dominance. Here too, a Pacific affinity is found.

Sediments were deposited on the northern shelf of the Cornwall-Rhenish basin which was of a geosynclinal nature. The mild synsedimentary tilting of the carbonate platforms – which gave rise to the diastems in the platform interior areas, but also to the transgressive tendency in the platform frontal ranges – was the natural result of ongoing deepening of the geosynclinal trough. While this tilting went on along a hinge-line which perhaps coincided approximately with the edges of the various carbonate platforms, characteristic differences in carbonate build-ups developed. An example can be seen in figure 13 in which a bioherm

			CORNISH – RHENISH BASIN		CANT.-PYR. BASIN	
			BELGIUM (TSIEN 1974 REIJERS 1984)	GERMANY (KREBS 1969, 1974)	SPAIN (REIJERS 1972, 1980)	PRESENT USAGE
CARBONATE MASSES RELATED TO DEEPER BASIN		Mud mound	A	B-3		Mud mound
		Composite bioherm	B	B-3		Composite bioherm
		Isolated bioherm on vulcanics		A		Bioherm on vulcanic rise
SHALLOW PLATFORM		Barrier reef	D	B-1	D	Reef track
		Isolated bioherm reefs in lagoons	E	B-2	C+D	" Patch reefs in biostrome
		Bank in shelf lagoon	C	C	C	Biostrome

LEGEND

 Bioherm / mud mounds reef ss.

 Biostrome

 Shale

 Nodular shale

Main Organic Carbonate Bodies in Devonian in Western Europe

Fig. 15.

– on the rim of the carbonate platform in the Givetian – is contrasted with a knoll-reef type mud mound developed in the downthrown zone south of the carbonate platform in the Frasnian. In Belgium these features contrast dramatically with those of two carbonate bodies (Fig. 6) that represent the barrier reefs (Fig. 7) of the Cantabrian Mountains (see also Fig. 15).

Barrier reefs of the type found in Spain, can only form in structurally quiet areas and this reinforces the conclusion reached by Parga (1970) that the thick accumulations of Middle-Upper Palaeozoic sediments in the zones around the Central Iberian Zone (Fig. 1) lack geosynclinal characteristics, although they doubtless are persistent depocentres.

Interesting differences are noticeable with respect to the siliciclastics that intercalated within the carbonate platforms in Spain and Belgium.

In the foregoing discussion on the nature of the various carbonate platforms a transgressive situation (Belgium) and a high sea level stand (Spain) were assumed during carbonate production, as a result of which the source area for siliciclastics is reduced. In case of a prevailing low sea level, however, or emergence of the hinterland, siliciclastics from that source area could be brought onto the shallow marine carbonate platform and into the basin in front of this platform. Such alternation in high and low water levels and its effect on the sediment pattern has been recognised and described by Meisner (1972) and termed cyclic and reciprocal sedimentation. Reijers (1980) recognised such a first order cyclicity in the Cantabrian Mountains. When the seabottom in front of a carbonate platform slopes steeply, however, such as in a geosynclinal situation, an overall high sea level will not result in outbuilding of the carbonate platform. Neither will this happen if the seabottom is flat, but beyond the euphotic zone. In such cases the carbonate platform will essentially withdraw (build-in) towards the coastline and basinal shales will cover the most external parts of the previously existing carbonate platform. This also gives rise to cyclicity, but of an entirely different nature, which cannot be termed reciprocal sedimentation. It is this latter mechanism that is responsible for the pulses of holomarine siliciclastics that spill over the carbonate platform edges in the Belgian Devonian. The holomarine fines could laterally be brought into the basin by long-shore currents or they could have a southerly provenance, the exposed Normanian-Mid-German land areas (Ziegler 1982). Open marine sediments of a somewhat deeper nature mark the moments of maximum transgression during the Couvinian, Givetian and Frasnian. An example is found in the Matagne shales that immediately overly the uppermost Frasnian carbonates.

Throughout the Devonian a gradual climate change is reflected in the Spanish and Belgian sediments. The red beds and the stromatolitic dolomites in the Spanish early Devonian, and the palaeosols in the middle Devonian point to arid tropical conditions, whereas the vegetation in the siliciclastic lagoons of the Middle-Upper Devonian and the locally karstified carbonates in the Portilla could suggest more humid tropical conditions. In Belgium, dolomites and stromatolites in intertidal environments in Givetian and Frasnian carbonates in the Tailfer area suggest arid tropical conditions. Similar conditions are indicated by the Middle-Upper Devonian anhydrites that are associated with shallow-marine carbonates in the Devonian graben in the North Sea (Ziegler 1982), and by dolomitic cements, palaeosols and enterlithic structures in evaporites within the uppermost Famennian sands. Perhaps somewhat more humid tropical conditions could have preceded the arid conditions towards the end of the Devonian, but there is little certainty on this point.

Conclusions

– The Devonian carbonate platforms in Spain have evolved from ramp-types into rimmed margin types, whilst they maintained their Atlantic affinity. The platforms in Belgium evolved from rimmed margin types into a knoll-reef rimmed ramp both with a Pacific affinity.

– From this it appears that the carbonate platforms in Belgium were facing an ocean, and that deposition was likely taking place in a leeward position of the continent, adjacent to an actively subsiding geosynclinal trough. The carbonate platforms in Spain were formed in an intercratonic basin between the isolated Asturian Dome on the external shelf and a more internal but yet not active zone of the Hercynian orogeny to the south. These platforms were facing the palaeo-trade winds. Consequently they were tide-dominated.

– There are subtle palaeoclimatologic indications in Spain suggesting an increase in humidity throughout the Devonian, whereas in Belgium an increase in aridity seems to be indicated.

– The active subsidence of the geosyncline triggered the tilting of the Belgian carbonate platforms and the holomarine incursions of siliciclastics that now can be found sandwiched between the carbonates. The alternation carbonates-siliciclastic of the Spanish Bernesga group by contrast, is the result of relative sea level changes and of a reactivated source area, giving rise to reciprocal sedimentation. The continuous rimmed margin of the carbonate platform in Spain and the absence of such a continuous barrier in the Belgian carbonate platforms are controlling these siliciclastic sediment distribution patterns.

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