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LATE DEVONIAN EUSTATIC CYCLES AROUND MARGIN OF OLD RED CONTINENT

by

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(2 figures)

ABSTRACT.- A mainly Late Devonian (late Givetian to Early Carboniferous) major transgressive-regressive cycle, or depophase, is represented in the sedimentary succession of western Canada, western United States, New York, Belgium, and Germany. This major cycle comprises six smaller cycles characterized by initial abrupt deepening events followed by upward shallowing. Correlation of these cycles interregionally is supported by conodont zonal biostratigraphy.

The major and smaller cycles are concluded to be of eustatic origin in response to the growth and decay of oceanic ridge systems plus mid-plate thermal uplift and volcanism in ocean basins.

Repeated deepening events and cumulative onlap probably caused extinction of Frasnian faunas by reduction in the number of provinces and by drowning of carbonate platforms and organic reefs. •

Although the Late Devonian eustatic events were worldwide, they affected sedimentation mainly on platforms and not in the interior of Gondwana.

RESUME. - Un cycle de transgression-régression ou dépophase principalement d'âge Dévonien supérieur (du Givetien tardif au début du Carbonifère) est reconnu dans la séquence sédimentaire de l'ouest du Canada, de l'ouest des Etats-Unis, de l'Etat de New York, de Belgique et d'Allemagne. Ce cycle majeur comprend six cycles plus petits caractérisés par des changements de profondeur d'eau d'abord s'accroissant brutalement, ensuite diminuant. Des corrélations interrégionales de ces cycles sont possibles grâce à l'usage de la zonation biostratigraphique à conodontes.

Le cycle majeur comme les cycles plus petits sont attribués à un phénomène eustatique qui répond à la croissance et à la destruction de systèmes de crêtes océaniques auxquels s'ajoutent un soulèvement des parties centrales des plaques et le volcanisme des bassins océaniques.

Des approfondissements et des enfouissements répétés ont probablement été la cause de l'extinction de faunes frasniennes par réduction du nombre de provinces et par l'ennoyage des plateformes carbonatées et des récifs organiques.

Bien que les phénomènes eustatiques du Dévonien supérieur furent mondiaux, ils ont affecté la sédimentation principalement sur les plateformes et non à l'intérieur du Gondwana.

INTRODUCTION

In a recent paper (Johnson *et al.,* 1985a) we tested the following hypothesis : Devonian sea-level fluctuations occurred and were of a magnitude to affect sedimentation simultaneously in disjunct regions that had different rates and patterns of subsidence and uplift. This test was accomplished by identifying sedimentary events in five marine regions of Euramerica around the Old Red Continent, and by comparing their timing with reference to the Devonian standard conodont zonation (fig. 1). Our test supported the original hypothesis and led to the recognition, description, and naming of 12 transgressive-regressive (T-R) cycles arranged in two groups or depophases. In the present paper, we reiterate our observations and our classification of the Devonian sedimentary events of the se-

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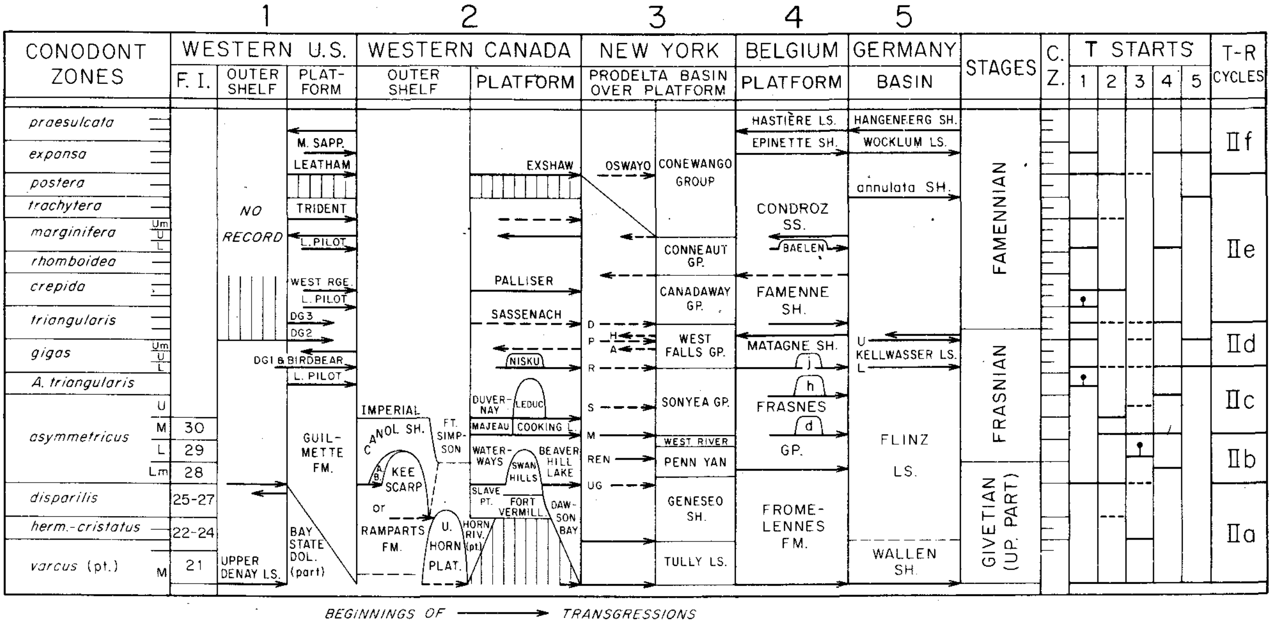

Figure 1. - Time-rock chart for five regions around the Old Red Continent, showing the principal deepening events of depophase II with arrows pointing to the right. Dashed arrows are inadequately dated in the conodont zonation. Arrows are drawn less than column width for the purpose of labeling or because they are within named units. A graphic summary of deepening events is given on the right. Depophases are labeled with Roman numerals and T-R cycles are indicated in lower case letters. F. I. indicates Faunal Intervals (Johnson and others, 1980). T starts with attached black dot are judged to be of tectonic origin. In the western Canada column, A.B. refers to the Allochthonous Beds at the base of the Canol Shale. In the column for New York, some units are listed by their first initial : UG is upper Geneseo Shale; REN is Renwick Shale; M is Middlesex Shale; S is Sawmill Creek Shale; R is Rhinestreet Shale; A is Angola Shale; P is Pipe Creek Shale; H is Hanover Shale; D is Dunkirk Shale. Some names or ranks of stratigraphic units used here for rocks in the United States may differ from those accepted by the U.S. Geological Survey. Modified from Johnson *et al.* (1985a, fig. 2).

cond depophase, which encompasses upper Givetian to Lower Carboniferous rocks. Because we define depophases as ending at the start of a new major transgression, the second depophase corresponds to the lower major cycle (events 1-12) plus the overlying stillstand phase (events 13-14) of Sandberg and others (1983, 1986).

Brief attention is given to biologic events of the same time interval, particularly to the Frasnian extinctions. In addition, we discuss the most likely causes of long-time and short-time sea-level fluctuations during the Late Devonian.

LATE DEVONIAN GEOLOGIC SETTING

Events of rifting and subsequent spreading away from the high-heat-flow zone of a ridge system involve rapid initial subsidence and continuing subsidence at a declining rate (Parsons & Sclater, 1977). Rifting events along platforms examined here preceded the Devonian by at least 200 m.y. so the Parsons-Sclater effect on subsidence should have been inoperative. Therefore, sea-level fluctuations should have been relatively important in the Devonian. Furthermore, by Late Devonian time, the facies progression had resulted in widespread, shallow platform seas where bottom gradients were low, and in which small sea-level fluctuations would be magnified in the sedimentary (and biologic) record.

In contrast to this setting, which would seem especially susceptible to eustatic changes, was the presence of foreland tectonic activity; all five studied regions were affected in this way during the Late Devonian. The western United States was in the Antler foreland (Johnson & Murphy, 1984); western Canada was in the Ellesmerian foreland; New York was in the Acadian foreland; Belgium and Germany were in the Variscan foreland (Krebs, 1979, fig. 1) where volcanism was more active than in the other regions.

The coincidence in timing of Late Devonian orogenesis in the geosynclines and widespread transgression on continental platforms is an example of the Haug effect (Johnson, 1971b, 1972).

EVIDENCE OF FLUCTUATION IN RELATIVE SEA LEVEL

Evidence for changes in apparent sea level of epicontinental seas can be obtained from lithologic changes upsection at single outcrops, from facies shifts as seen in reconstructed cross-sections, and from strand-line shifts (Vail and others, 1977). In practice, evidence from single outcrops must be integrated into a regional model (time rock transect) to be of any use. Facies shifts, detectable in multiple outcrops, provide the basic information about fluctuations in relative sea level. Deepening events are interpreted by comparing beds at any level with the underlying beds. Thus, almost unlimited amounts of data are potentially usable. The interpretive problem is one of determining which deepening events had the most far-reaching and significant effects on the regional stratigraphy. Deepening events found to be common enough in the Devonian record to be useful are indicated by the bases of black shales, inceptions of reef growth, drownings of platforms (subtidal shales over platform carbonate rocks), and sedimentary rocks above unconformities.

The cycles most commonly and readily observed in Devonian marine strata begin with deepening events that appear abrupt or sharp, followed inevitably by an upward-shallowing sequence of beds (fig. 2). We define the cycles we recognize in this way, so that the top of a cycle is determined by the base of the next-succeeding cycle. This necessitates the inclusion of hiatal space at cycle tops (e.g. Sandberg and others, 1983, events 13 and 14), a practice that eliminates many hard-to-make decisions about the continuity or lack of continuity of sedimentation in shallow-water lithotopes. Such decisions are unnecessary in our scheme and it can therefore be based entirely on inceptions, which are deepening events.

SECOND DEVONIAN CYCLE

Johnson *et al.* (1985a) documented two groups (or depophases) of T-R cycles in the Devonian. The first began in the Early Devonian, at the base of the Pragian, and extended through the middle Givetian. The second began in the late Givetian and extended into the Early Carboniferous, including beds below the Lower *crenulata* conodont Zone, which began a third, Early Carboniferous depophase. The sedimentary events of the second depophase are briefly characterized below. These compare favorably with events recognized by House (1983).

T-R CYCLE IIa

This cycle is represented by the Taghanic Stage of eastern North America, where it began as a widespread onlap (Johnson, 1970); in Belgium it is represented by the Fromelennes Formation (Bultynck, 1975). The inception of this cycle, where it is best dated, is within the Middle *varcus* Subzone. Within the limits of available accuracy the initial deepening event is evident in all five study areas.

Cycle IIa appears to be a sustained transgression rather than a cluster of separate events. Rock units of IIa include the basinal upper member of the Denay Limestone in Nevada, the upper Horn Plateau reefs and Dawson Bay Formation in western Canada, the Tully Limestone and Geneseo Shale of New York, the Fromelennes Formation of Belgium, and the Wallen Shale of Germany.

Although cycle IIa had very significant onlap effects, or because of them, the initial deepening event is either diachronous or obscured in some offshore sequences. An example of the former is the retarded onlap of the Keg River barrier in western Canada. Examples of the latter include shale on shale in the Hare Indian Formation, Canada, and in the Wallen Shale-Flinz Limestone sequence, Germany.

T-R CYCLE IIb

This cycle is represented by rocks in the Lowermost to Middle *asymmetricus* Zones; all were deposited following initial deepening events. The time encompassing the plotted inceptions may be very short- - i.e., the interval between the entry of *Polygnathus asymmetricus, P. norrisi,* or *Pandorinellina insita* and the entry of *Ancyrodella rotundiloba* (fig. 1). Basinal rocks below *A. rotundiloba* are less than 1.5 m thick in the northern Antelope Range of Nevada (Johnson *et al.,* 1985b). In Canada, the Waterways transgression, including parts of the Swan Hills and Kee Scarp reefs, is in the Lowermost *asymmetricus* Zone. In New York, the upper Geneseo Shale is probably in the Lowermost *asymmetricus* Zone (see appendix). In Belgium, the basal Frasnian transgression begins just below the Lower *asymmetricus* Zone (Bultynck, 1982).

T-R CYCLE IIc

This cycle begins above the base of the Middle *asymmetricus* Zone and continues through the *A. triangularis* Zone. It is represented by the Sonyea Group of New York and encompasses times of significant mudmound and reef growth (d and h bioherms) in Belgium and the Leduc reefs in Canada. The cyclic nature of IIc events is exemplified by numerous carbonate-evaporite cycles in the lower Duperow Formation of Canada (Wilson, 1967) and in the United States. Maywood Formation onlap occurred at the base of the cycle in the western United States (Johnson & Sandberg, 1977, fig. 8).

T-R CYCLE IId

Rocks of this cycle represent the greatest of the Devonian transgressions, beginning in the Lower *gigas* Zone and extending into the Lower *triangularis* Zone. Cycle IId coincides with the West Falls Group of New York and encompasses the black shales of the Kellwasser Limestone of Germany and the Matagne Shale of Belgium. The youngest Devonian reefs with colonial corals and common stromatoporids are in IId. The cyclic nature of IId events is evidenced by the numerous black shales at the bottom of upward-shallowing sequences in New York (Kirchgasser & House, 1981, figs. 1, 8, 9). T-R cycle IId comprises a pair of widely recognized transgressions (fig. 1).

T-R CYCLE IIe

This cycle begins with a deepening event represented by the Dunkirk Shale of New York and the probably correlative Famenne Shale transgression of Belgium, beginning in the Middle *triangularis* Zone. Following initial transgression, IIe shows prominent regressive tendencies over a prolonged period of time during which the Condroz Sandstone of Belgium was deposited (Dreesen & Thorez, 1980). In New York, this regression correlates with parts of the Canadaway, Conneaut, and Conewango Groups, from the Gowanda Shale to the base of the Oswayo Formation (Rickard, 1975).

The prolonged IIe regression was reversed twice by significant transgressions. The first was in the Lower *marginifera* Zone and the second was in the Lower *trachytera* Zone; these transgressions produced the Baelen mudmounds of Belgium and the *annulata* Shale of Germany, respectively. These pulses are also recognizable on the western United States platform (Johnson and others, 1985a, fig. 4).

T-R CYCLE IIf

This cycle began at the base of the Lower *expansa* Zone with a strong transgression that ultimately reversed the regression that dominated cycle IIe. The black shales at the bases of the Leatham Formation, Sappington Member of the Three Forks Formation, and Exshaw Formation, and probably the Oswayo Formation, represent IIf deepening in North America. In Europe, the inception of IIf is represented by the Epinette Shale and Wocklum Limestone. Upper IIf regression began in the Middle *praesulcata* Zone followed by stillstand or minor onlaps through the lower four conodont zones of the Carboniferous. Previously (Johnson and others, 1985a), our definition of cycle IIf was ambiguous in its exclusion of events 13–14 of Sandberg and others (1983). The cited upper IIf minor onlaps include Hannibal Shale over Louisiana Limestone in Illinois and Indiana, and deep-water *Gattendorfia* Limestone over shallower Hangenberg Shale in Germany. The next major transgressive cycle began in the Lower *crenulata* Zone (Sandberg and others, 1983, p. 707), corresponding to Tn2a in Europe.

CAUSES OF SEA-LEVEL FLUCTUATIONS

We suppose that long-term rises and falls in sea level during the Devonian resulted primarily from the growth and decay of oceanic ridge systems (Armstrong, 1969; Pitman, 1978). Sandberg *et al.* (1983) estimated that depophase II spanned about 21 m.y., a figure we judged to be long term.

In addition, we suggest that mid-plate thermal uplift and volcanism in ocean basins (Schlanger *et al.*, 1981) may have affected sea level repeatedly over long time periods. This process would have been capable of producing small but geologically instantaneous rises in sea level such as initiated the T-R cycles within depophase II and would have worked in conjunction with changes in volume of the mid-oceanic ridge system.

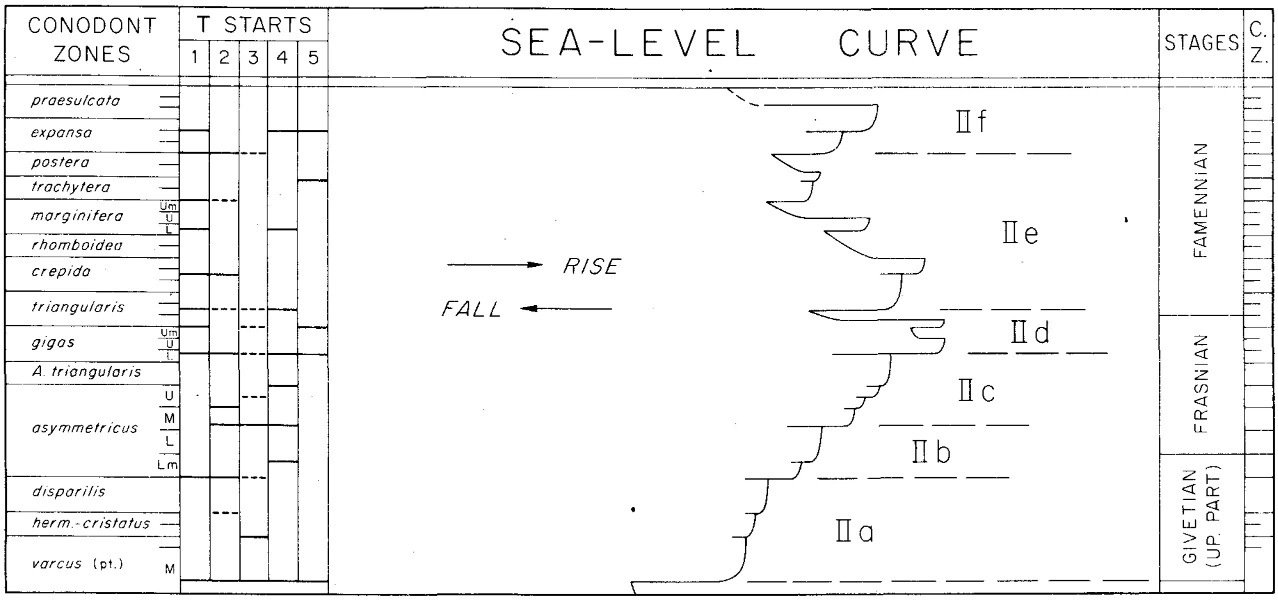

Figure 2. - Eustatic curve for the Devonian, showing T-R cycles of depophase II and their relationship to Devonian conodont zones. Deepening events, plotted inside the eustatic curve, are from fig, 1, Modified from Johnson *et al.* (1985a, fig. 12).

Episodes of continental glaciation could also have large effects on sea level. Glacigenic sediments of reported Famennian age in South America were recently reviewed by Caputo & Crowell (1985). Principal evidence for glaciation is widespread diamictites in the Solimões, Amazonas, and Parnaiba basins of Brazil. In the Amazonas basin, diamictite-bearing strata are in the Curiri and Oriximiná Formations (Curuá Group). Palynological data, including the presence of *Spelaeotriletes lepidophytus* (Kedo) Streel, indicate a late Famennian age (*preasulcata* Zone, fig. 2) for part of the Curiri Formation (McGregor, 1979, fig. 10). In the Parnaiba basin, the upper part of the Cabecas Formation includes persistent diamictite beds dated at the same level as in the Amazonas basin (Andrade & Daemon, 1974).

If South American glaciation occurred in mid-Famennian time it could have caused regression that characterizes T-R cycle IIe (fig. 2). The limited evidence for Devonian glaciation, however, cannot explain the numerous T-R cycles, nor could it have caused the Devonian facies progression.

FRASNIAN EXTINCTIONS

Important groups of brachiopods, colonial corals, stromatoporids, and other organisms present in the Frasnian died out in the late Frasnian; however, the lack of high resolution range data makes it impossible at present to verify that extinction occurred as a single event. In addition, a significant number of extinctions occurred during Frasnian time because of competition when the Appalachian province was lost as a separate entity. This is because Taghanic and early Frasnian onlap provided paths of communication across former barriers (Johnson, 1970). Quantitative documentation of the loss of diversity that resulted from these T-R II onlaps has been given (Johnson, 1971a).

House (1975, 1979, p. A203) pointed out that a succession of Frasnian transgressions first restricted the area of carbonate reefs and then caused the disappearance of those reefs. The result was diminution and extinction of various specilaized reef and associated carbonate organisms. Eder and Franke (1982) suported the hypothesis of drowning by showing that conodont-dated reef growth terminations were coincident with the blach shale events (IId) recorded in the Kellwasser Limestone (fig. 1). Black shales of the type common in some regions in T-R cycles IIa-IId, are interpreted as products of anoxic bottom waters. Balck-shale-producing anoxic events reduced living space in basinal areas while drowning killed shallow water and reef benthos. Both kinds of events resulted from sea-level rise.

Our compilation of the Frasnian-early Famennian transgressive history (fig. 2) supports an interpretation that a succession of three rapid deepening events within and above IId caused many of the Frasnian extinctions. Other extinctions were surely due to reduction in the number of provinces as transgression eliminated barriers to migration. No single extinction event is indicated.

ARE LATE DEVONIAN EVENTS WORLDWIDE ?

We have made only superficial comparisons between Devonian T-R cycles in Gondwana and around the Old Red Continent. Devonian stratigraphy (and faunas) of the northern Africa platform (Hollard, 1968) seem in general accord with the European record, but we have not analyzed them. Likewise, the shelf-basin history of western Australie (e.g., canning basin) seems in accord with depophase II onlap (Playford, 1980).

The interior of Gondwana was not the site of large epicontinental seas, and because of its high southern latitude position, it lacked carbonate rocks. Instead, it was the site of narrow and broad seaways and basins receiving detrital sediments. These were widespread in the Early Devonian, less so in the Middle Devonian (Johnson, 1979, figs 6, 7), and mainly the sites of terrestrial deposition in the Late Devonian. This is not the pattern of the Euramerican platforms, except perhaps during the Early Devonian.

The Gondwana pattern does not contradict a hypothesis that sea-level fluctuations have controlled Devonian sedimentation in an important way. The apparent lack of harmony with Euramerican cycles may be because the interior of Gondwana had undergone earlier cratonization, perhaps as long as 250-300 m.y. prior to when Euramerica reached the same stage of development. Consequently, by Devonian time much of Gondwana was well above sea-level and could not be flooded by wide-spread epicontinental seas. Apparently, the marine seaways that did cross parts of Gondwana during the Devonian followed epeirogenic downwarpings (Johnson, 1979, p. 300). In summary, Devonian sedimentation in Gondwana provides a diverse array of settings and patterns; some of the larger patterns are not in harmony with those described by us in Euramerica and most are still to be evaluated.

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APPENDIX

A significant revision of the New York succession in the interval Geneseo Shale to Renwick Shale, as reported by Johnson and others (1985a), is necessitated by recent fossil finds (*Kirchgasser and others, 1985*). DeWitt & Colton (1978, Pl. 2) showed that the thick Geneseo Shale at Abbey Gulf, and to the east, divides into a pair of thinner black shales westward (as at Jaycox Creek, Fall Brook, Beards Creek, and Taunton Gully). At Fall Brook and Beards Creek the nodular limestone beds, identified as Lodi Limestone, on top of the upper Geneseo black shale (UG on Fig. 1) have *Polygnathus norrisi,* a fossil that appears first in the Lowermost *asymmetricus* Zone (Feist and Klapper, 1985, p. 12-13; Kirchgasser and others, 1985). Kirchgasser and others (1985) also report *Ancyrodella rotundiloba* 2 m above the Lodi horizon at Abbey Gulf, well below the level of the Renwick Shale (REN on fig. 1).

From this evidence we plot an upper Geneseo deepening event at the base of the Lowermost *asymmetricus* Zone, corresponding to the base of cycle IIb. The Renwick deepening event is replotted within the Lower *asymmetricus* Zone where it is synchronous with no others known elsewhere. For this reason and because the Renwick is enclosed by Sherburne and Ithaca turbidites, it is judged to be of tectonic origin.