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Detecting the late Frasnian *semichatovae* Event on the deep shelf of North Gondwana

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Short Title: The *semichatovae* transgression on North-Gondwana

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Abstract

The *semichatovae* Event is a mid-late Frasnian (Late Devonian) episode of a major marine transgression that coincides with the spread of the conodont *Palmatolepis semichatovae*. The occurrence of this species and the associated event were therefore proposed to define the Middle-Late Frasnian boundary. As this species is not found on the north Gondwana platforms, this event is only documented on the Laurussia marine outer-shelves. As such, it is not known in the Frasnian reference section within the Upper Quarry Coumiac, located in the Montagne Noire (southern France). In this contribution, we have used a multidisciplinary approach that combines sedimentology, conodont assemblages, magnetic susceptibility, and concentrations of certain elements that are indicative of detrital components to precisely date this event in the absence of *Palmatolepis semichatovae* by means of global scale correlations. We found that a significant part of the environmental signal has been preserved in the strata, and we could locate the *semichatovae* transgressive event in the cross-section in the lower part of Zone FZ 11. During this period of recurrent environmental perturbations, conodonts responded to sea-level changes only above a certain depth threshold which is reached only with the *semichatovae* event.

Keywords: *semichatovae* event, Late Devonian, conodonts, magnetic susceptibility, facies, detrital proxies, Montagne Noire

1. Introduction

Several global events in Earth history have long drawn the attention of researchers due to their multifaceted interactions within the global system: the lithosphere, biosphere, atmosphere, and hydrosphere (Walliser 1996). Of these, the environmental change at the Frasnian-Famennian (F-F) boundary during the Late Devonian and the associated Kellwasser extinction crisis is the most studied among the Devonian events, whereas several other Devonian severe perturbations remain rather poorly known. House (2002) emphasized the overvalued significance of this terminal Frasnian Kellwasser event and urged that study of other events was required to adequately place the F-F mass extinction in its global Devonian context.

Within the Frasnian, the *semichatovae* Event has been described as a major transgression (Ziegler & Sandberg 2000), during the most pronounced Devonian eustatic rise, the T-R cycle IId *sensu* Johnson et al. (1985), near the base of the Frasnian Zone 11 (Biozone FZ11 of Klapper 1989). It is characterized by the sudden spread of the conodont *Palmatolepis semichatovae*. This major eustatic rise was followed by a generally falling Famennian sea level related to the onset of glaciations in the Southern Hemisphere (Isaacson et al. 2008).

Palmatolepis semichatovae is widely known in equatorial latitudes (~0- 30°S) throughout Laurussia in shallow shelf environments during the Devonian (Sandberg et al. 1988, 1992; Ziegler & Sandberg 1990). However, it has not yet been found on the North-Gondwana deep shelf (e.g., Saupe & Becker 2022 for the review of the occurrence of the species and of the *semichatovae* transgression), except one doubted occurrence in Central Morocco (Lazreq 1999). Although *Palmatolepis semichatovae* is not found in Gondwana, the occurrence of *semichatovae* and the accompanying transgression data from Laurussia are still utilized to establish the lower boundary of the upper Frasnian substage base (Ziegler & Sandberg 2000; Saupe & Becker 2022). Consequently, defining the base of this substage on Gondwana is challenging, and other proxies are needed to identify the corresponding significant transgression event (Johnson et al. 1985).

Dopieralska et al. (2016) used neodymium (Nd) isotopes to reconstruct sea-level changes in Moroccan monotonous sections, allowing them to pinpoint the *semichatovae* transgression on the north Gondwanan shelf. Using changes in lithologies and facies, Mahboubi et al. (2018) observed an obvious transgressive episode recorded within the FZ11, which may also correspond to the *semichatovae* event on the Algerian platform.

Trends in conodont biofacies over time may allow evaluating sea-level variations and, as such, locating the *semichatovae* event. Indeed, since the pioneering work on conodont paleoecology by Seddon & Sweet (1971), conodonts have been considered to be water-depth dependent and changes in the composition of conodont assemblages reflect sea-level fluctuations (e.g., Girard & Feist 1997; Morrow 2000; Girard et al. 2021). On the other hand, trends in magnetic susceptibility (MS) can also be relevant, as an increase in magnetic susceptibility often correlates with regression and a decrease in magnetic susceptibility with transgression (e.g. Crick et al. 1997; Ellwood et al. 1999) depending on depositional settings, ramp vs. rimmed platform (e.g. da Silva et al. 2009a). Variations in MS trend records may rely on various factors, such as changes in paleoclimate and paleogeography, and can be modified during the diagenesis, but their correlation with conodont biofacies emphasizes the consistency of their relationship regarding sea level fluctuations (Girard et al. 2021).

Here we analyze the section of Coumiac, the stratotype of the F-F boundary deposited in an area located on a terrane separated from the north-Gondwana supercontinent (Stampfli et al. 2013), and where the FZ zonation was defined (Klapper 1989; Girard et al. 2005; Klapper & Kirchgasser 2016). As discussed below, in this section, the *semichatovae* event cannot be identified by the occurrence of the index species or by obvious sedimentological changes.

The aim of this contribution is to locate the *semichatovae* transgressive event in North Gondwana deep water carbonates, integrating data of micro- and biofacies with MS trends. In this regard, we analyze the late Frasnian section at Coumiac, southern France, where the Frasnian conodont Zones (Klapper 1989) and the F-F boundary GSSP (Becker et al. 1989) were defined, and as such constitutes a reference to both the North Gondwana outer shelf and worldwide other sections.

This study aims to (1) establish a detailed lithostratigraphic succession through the FZ10 and FZ11 zones, (2) generate both a high-resolution magnetic susceptibility profile and conodont biofacies trends, (3) investigate the general reliability of magnetic susceptibility and (bio)facies analyses as potential for identifying a major transgression in a monotonous deep-water sequence, and (4) propose alternative methods that may be applied to locate eustatic events when biostratigraphy and / or facies.

2. Geological context

2.a. Geological context and biostratigraphy

The outer shelf domain of the North Gondwana margin (i.e. Franke 2020) is characterized by pelagic deposits in the Late Devonian along the southern edge of the French Massif Central. In this area, the Coumiac site is located in the southeastern Montagne Noire (Fig. 1) on the south-facing inverted limb of the Hercynian Mt. Peyroux nappe (Arthaud 1970; Engel et al. 1982). The investigated Frasnian section is situated at the northern wall of the upper quarry (CUQ), which contains at its top the GSSP of the Frasnian-Famennian boundary (Becker et al. 1989). This section was first investigated for conodonts by Klapper in the early eighties of last century (*in* Feist 1983). This investigation led to the establishment of a continuous conodont zonation from the early Frasnian to the F-F boundary, namely MN zones 6 to 13 as described by Klapper (1989). First considered as a local zonation, it has been recognized worldwide and as such integrates the formal Frasnian Zonation (FZ, Klapper & Kirchgasser 2016). In this context, the Coumiac section constitutes not only a reference of most of the Frasnian conodont biozones but also is representative of the North Gondwana outer shelf. Whereas many fine-scaled biostratigraphical work had been devoted to the Frasnian/Famennian transition motivated by the definition of the F-F stratotype (i.e. Klapper 1989; Becker et al. 1989; Girard et al. 2005), the middle part of the Frasnian succession, i.e. the transition from the late FZ10 to the lower part of FZ11, remained less investigated. In particular, the position of the *semichatovae* event, in FZ11, cannot directly be identified as the index form was not found (Saupe & Becker 2022).

Furthermore, graphic correlations conducted by Klapper et al. (1995) suggested that, at Coumiac, there were two hiatuses (Fig. 2), within the FZ10 and FZ11, and this could be one reason for the absence of the conodont *Palmatolepis semichatovae* (Klapper, pers. com.). The overall Devonian transgressive episode was punctuated by transgressive-regressive (T-R) fluctuations. As the *semichatovae* event is related to a transgressive part of one of these T-R cycles, and is known to occur after the base of the FZ11, the analyses focused on the part of the section dating from the top of the FZ10 to the base of the FZ12 zones (Fig. 3). In the Coumiac Upper Quarry, the FZ10 begins in level CUQ14, and finishes with the start of FZ11 in level CUQ16a where *Pa. feisti* first occurs. FZ11 ends just before level CUQ20 (beginning of the FZ12) when the conodont *Palmatolepis winchelli* is present for the first time (Klapper 1989; Klapper & Kirchgasser 2016). Saupe & Becker (2022) subdivided the FZ11 into a lower (FZ11a = *feisti* Subzone) and an upper (FZ11b = *nasuta* Subzone) parts, the second one being defined by the conodont index *Pa. nasuta*, which occurs approximately at the same time as *Pa. semichatovae* (Saupe & Becker 2022). Bed numbers in blue of the new sampling mostly coincide with those in red formerly published in Klapper (1989) (Fig. 2-3).

3. Material & Methods

3.a. Sampling

Different approaches were used to depict the *semichatovae* transgression in the Montagne Noire Coumiac section (N43°28.168' E003°03.514): sedimentological facies, conodonts (biostratigraphy and biofacies), magnetic susceptibility, and trace element concentrations.

3.b. Facies

A first detailed microfacies profile of all the section at Coumiac (CUQ) had been established by Pr at et al. (1998). Here we focus on the interval corresponding to FZ10 and FZ11. Rock samples from this part of the outcrops were taken in place for analyses of thin-sections. Thin-sections were cut for microfacies analysis spanning the sequence studied for conodont and MS (Fig. 3). Based on field and

microscopic observations (semi-quantitative estimate of the relative abundance of bioclasts) and paleontological qualitative results, different facies types could be distinguished (Flügel 2004) and interpreted into sea-level fluctuations (Girard et al. 2014). All facies are related to a depositional environment according to the zonations proposed by Wright & Burchette (1996) and Flügel (2004).

3.c. Conodonts and biofacies

Samples of 500 g to 1 kg were collected from the field (Fig. 2-3). They were dissolved with formic acid, rinsed through two sieves and the residues (fraction between 100 µm and 1 mm) were picked for conodonts. All platform conodont elements were picked for stratigraphy and biofacies analyses. Based on the morphology of these platform elements, several genera can be identified that seem to have different environmental preferences. Some genera such as *Icriodus* are considered as shallow sea-surface dwellers because they occur in larger proportion in shallow marine sediments deposited near the coast. Their increase in proportion within the conodont assemblage may be interpreted as a sea-level fall (Morrow 2000; Sandberg et al. 1988; Sandberg et al. 2002). Other genera like *Palmatolepis* seem to be rather characteristic of deep sea-surface dwellers, far from the coast in areas with greater depth (Seddon & Sweet 1971; Sandberg 1976). Hence, the variations of the relative proportion of the different genera provide an indirect environmental proxy that may be related to sea-level fluctuations. Such an approach is called a biofacies analysis (Seddon & Sweet 1971).

3.d. Magnetic susceptibility (MS)

Da Silva et al. (2009a, b) suggested that during low stands of sea level, larger surface areas are subject to weathering and erosion, and that the detrital influx to the ocean are higher (Davies et al. 1977; Worsley & Davies 1979). Thus, Crick et al. (1997) had proposed that the highest MS magnitudes theoretically represent maximum low stand in sea level and that the MS signal increases during a sea level fall. Magnetic susceptibility has therefore been used as a proxy for sea level variations (da Silva & Boulvain 2002, 2006; Racki et al. 2002; Hladil et al. 2003). To tentatively study the sea-level variations

through the FZ10-FZ11 part of the Coumiac section, low field magnetic susceptibility (χ_{LF} , thereafter called MS) was directly measured *in situ* with a Bartington MS2E probe connected to the MS3 meter. The probe has an operating frequency of 2 kHz. Its sensitivity area, defined as the region yielding 50% of the maximal response, is of 3.8x 10.5 mm, facilitating high spatial resolution surface measurements. The measurement period was fixed to 10 seconds. Magnetic susceptibility measurements were measured at regular interval along each stratigraphic level (Figs. 2-3). To ensure a representative result, three to ten measurements were performed for each of the 35 successive sampled levels. Data were obtained in SI Units (Système International d'unités) and were transformed in m^3/kg using a theoretical value of 2600 kg/m^3 for carbonates.

3.e. Geochemical detrital proxies from XRF

Variations in element concentrations of carbonate rocks offer a wealth of information that can be used not only as a proxy for the diagenetic history but also for the redox, salinity, or productivity of the studied rocks. The elements that are commonly interpreted as proxies for detrital input are Al, Si, Ti, K, Zr (Sageman et al. 2003; Tribovillard et al. 2005; Riquier et al. 2006). In the laboratory of Geoscience (Montpellier), the Niton XL3t GOLDD+ portable analyzer was used for XRF non-destructive elemental analysis. Based on the Energy Dispersive X-ray Fluorescence principle, this device generates a complete fluorescence energy spectrum that is processed and interpreted to give qualitative and quantitative analysis of elements ranging from ^{12}Mg to ^{92}U . Flattened surfaces of the same samples as for MS were analyzed for 120 seconds using 30-second analysis times per filter that are the light filter for Al, K, and Si, the main filter for Fe, Zr, and the low filter for Ti. In this procedure the limit of detection ranges from a few ppm (mg/kg) to a few tens of ppm, depending on the element analyzed. The means and standard deviations of reproducibility were calculated based on 5 to 7 repeated measurements. Correlations between major element contents and MS values were calculated.

4. Results

4.a. Facies description and evolution

The deposits of the FZ11 are 3.30 m-thick. The facies of the FZ10 and the base of the FZ11 are represented by dm-bedded pink mudstones to wackestones with tentaculites and pelagic molluscs ("filaments"), and rare benthic organisms. Above, the facies throughout FZ11 is a homogeneous dm-bedded pink wackestone with tentaculites, entomozoans, some goniatites, and some benthic organisms (ostracods, rare trilobites).

Red-colored rocks with iron-coatings of bioclasts may indicate microbial activity as suggested by Pr at et al. (1999). The sediments are evenly fine-grained without lamination nor indicators of gravitational transport. Composition of conodont assemblages does not indicate preferential percentages between juvenile and adult elements. Among rare trilobites only very small sized specimens occur. These exhibit reduction of the visual complex, and, in particular blind morphs occur for the first time in the *Pterocoryphe-Pteroparia* evolutionary lineage (Feist 1995).

Facies and fauna consequently indicate deep-water, oligotrophic outer shelf (outer ramp) depositional setting, below both the lower limit of storm-wave action and penetration of light (50 – 100 m). We did not find any sedimentological indication to localize the *semichatovae* transgression.

De Vleeschouwer et al. (2017) estimated that FZ11 lasted 1.179 Myrs, indicating that the accumulation rate was about 0.0036 cm/year at Coumiac, like in deep sea settings. For the FZ12, sedimentation rate in Coumiac was estimated at 0.0038 cm/year. Such rates are very low, indicative of condensed sedimentation and possibly sedimentary hiatuses (Fig. 2-3). Consequently, sedimentary hiatuses cannot be excluded in such condensed sections, all the more so since stratification surfaces with discrete iron coatings occur, possibly indicative of hard-grounds and incomplete sedimentary record. That is the case 15 cm above the base of the bed 16 in the upper part of FZ 10 and within bed 17 in lower part of FZ 11 where the *semichatovae* transgression is expected (Fig. 3).

4.b. Conodont assemblages

Conodont species indicators of the FZ10, ~~and~~ FZ11a, and FZ12 zones were recognized. In agreement with Klapper (1989), we found *Palmatolepis plana*, *Palmatolepis feisti*, and *Pa. winchelli* in level CUQ15a, CUQ16a, and CUQ20, respectively. The new sampling did not recover specimens of the *Palmatolepis nasuta*, species that defines the base of the FZ11b, nor specimens of *Palmatolepis semichatovae* that occurs approximately at the same time, and defined the *semichatovae* transgression event. However, *Icriodus alternatus*, that occurs in bed CUQ17-3, can be used as an indicator of the base of the FZ11b, as it evolved during the *semichatovae* transgression (*nasuta* Zone) after Ziegler & Sandberg (2000).

Four genera are present during the time interval of interest (Fig. 3): *Ancyrodella*, *Icriodus*, *Polygnathus*, and *Palmatolepis*. Most variations in relative abundance are due to the balance between the shallow water *Icriodus* vs the deeper-water *Palmatolepis*. Notably, the *Icriodus* percentage increases around the FZ10/FZ11 boundary being relatively high, around 40% for samples on both sides of the first ~~terrace~~ hiatus (Fig. 3). When the *Icriodus* percentage decreases, the deep-water genus *Palmatolepis* increases and becomes dominant just after the second terrace reaching ~60% of the assemblage.

4.c. Variations in magnetic susceptibility

The MS at CUQ is based on 35 contiguous levels sampled over 250 cm and spans the Frasnian Zones FZ10 and FZ11. Trends in MS begin with very low values in the level CUQ13, then two excursions in MS are successively observed (Fig. 3). The maximum of these shifts occurs respectively in the levels CUQ16-4 to CUQ16-6, just after the first hiatus and in the levels CUQ17-1 to CUQ18-1 around the second hiatus. Thereafter the MS slightly decreases, reaching values comparable to previous ones observed in the FZ10 zone.

4.d. Variations in the detrital proxies

Values are very variable within a same level. The elements (Mg, Al, and Th) are not abundant in the rock samples and present very low values or not detectable. The first peak in MS coincides with peaks of detrital proxies (Fig. 4). This is not the case for the second MS peak that is not characterized by any obvious shifts in any detrital elements. Considering all the data, correlations with MS are significant for Zr ($p < 0.012$), and K 0.048, Ti ($p < 0.038$). Correlations doesn't exist for Si 0.12, Fe 0.45 and Al 0.29. For elements Th ($p < 0.105$) and Mg ($p < 0.712$) that are not abundant and can't be detectable, there is no correlation with the MS.

5. Discussion

5.a. Consistent trends in detrital inputs and MS

Because the MS signal can be altered due to numerous diagenetic phenomena such as clay mineralization (Katz et al., 1998) or dolomitization, Whalen & Day (2010) proposed to use different proxies to discriminate diagenetic and sedimentary MS signals. Major element content analyses do not record alteration of magnetic carriers. Indeed, considering the entire record and the mean values of the elements, all the values of detrital elements are correlated with MS mean values for the studied levels, except for the Th and Mg values that are not easily detectable in the rocks. Consequently, the contents of elements which are commonly interpreted as proxies for detrital input are correlated with MS values and display enrichment associated with MS peaks, in particular with the first increase after the first hiatus (base of FZ11a) (Fig. 4). On contrast, Mg content is not correlated with MS value, suggesting that dolomitization did not play a role in significantly altering the MS signal (Whalen & Day 2008; 2010). The conodont alteration index is low, CAI around 2.5 -3, suggesting that the strata were exposed to temperatures less than 250°C. Finally, the MS peaks can be correlated between sections separated by thousands of kilometers, even if their magnitudes vary. Indeed, the MS peaks occur at the same time in different geographic areas on both Laurussia and Gondwana margins (this study; da Silva & Boulvain 2006; Riquier et al. 2010; Whalen & Day 2008; 2010) (see below). Consequently, the

MS shifts are interpreted to reflect paleoenvironmental changes along the outer-shelf Gondwana margin.

5.b. Consistent global trends in magnetic susceptibility

In the absence of typical fauna to precisely define biostratigraphy and establish fine temporal-scale correlations worldwide, other proxies have to be used. Correlations rely on an integrated approach, consistency in the trends of each proxy, and recognizable trends from areas of different origins. For example, such an approach is now widely used by geochemists to correlate events in different locations or to correlate trends in different proxies that are indicators of the similar environmental parameters in the same place (Babek et al. 2016; Girard & Renaud 2007; Girard et al. 2021; Joachimski & Buggisch 2002). The most obvious result of the present study is the trends in the MS signal through the FZ10 and FZ11 that correlate with the increase in MS already observed in Coumiac (Riquier et al. 2010) and observed elsewhere around the world at that time (Belgium: da Silva & Boulvain 2002; Morocco: Ellwood et al. 1999; Algeria: Mahboubi et al. 2018; Canada: Whalen & Day 2008; Whalen & Day 2010). Such a consistent worldwide pattern in MS data implies that it can be used as a good correlation proxy (Crick et al. 2002; Whalen & Day 2008). More precisely, in Namur-Dinant Basin (Belgium) and in the Alberta basin (Canada), the MS signature displays a major bimodal MS increase in the middle to upper Frasnian (FZ11–12) (Fig. 5). MS values return to generally lower levels during the upper Frasnian (FZ12–13). The same patterns characterize the MS curve in Montagne Noire, with the occurrence of two shifts, the first, during the FZ10 just before the start of the FZ11, the second during the Zone FZ11. Both observed peaks are comparable in amplitude in Coumiac, compared to Canada where the second peak is always stronger than the first one (Whalen & Day 2008, 2010) (Fig. 5). The MS record of the peaks, particularly the second one, might be incomplete and the maximum of the MS signal could be missed in the Coumiac section. This incompleteness could partly explain the absence of any shifts in detrital elements associated with the second hiatus. Another explanation could be that this significant MS peak is not reflected in the detrital values that may reflect rather carbonate/clastic dilution more

than an increased input of clastics. However, Klapper et al. (1995) made graphic correlations that indicate sedimentary hiatuses that interrupt the sequence in Coumiac, which aligns with the observed micro-hardgrounds and deposit condensation (Préat et al. 1998). Consequently, the MS record of the peaks, particularly the second one, might be incomplete and a large part of the MS signal and the shift in detrital elements are probably missing in the Coumiac section. However, these gaps are not significant as the accumulation rate remains stable during the uppermost Frasnian, and very similar in FZ11 and FZ12. Thus, a significant part of the signal is recorded and can be correlated at a global scale.

5.c. Conodont biofacies, magnetic susceptibility and environmental changes

Saupe & Becker (2022) suggested that the Frasnian Subzone 11a (*feisti* Subzone) begins just before the regression that preceded the *semichatovae* transgression. The shallowing trend observed in the Coumiac levels of the FZ11a (increase in MS), and the following transgressive trend just after the second hiatus when *Palmatolepis* abundance increases and MS values decrease, are in accordance with this scenario (Fig. 3). This second MS peak can then be correlated with the base of the FZ11b (*nasuta* zone), when the *semichatovae* transgression is known to start in Laurussia (Sandberg et al. 1992; Saupe & Becker 2022). Despite not recorded lithologically, and without the presence of the index species, part of the *semichatovae* transgression is finally in evidence based on integrating changes in conodont assemblages and MS trends. The consistency of the results in both MS and conodont biofacies confirms that they are good proxies to identify events related to eustatic changes. This is a promising way to find events which are not identifiable in monotonous carbonate sections as at Coumiac and a powerful alternative to the traditional biostratigraphy.

The MS trends show that the environmental changes at that time are more complex. At first order, the sequence is characterized by a slight shallowing trend from FZ10 to FZ12 interrupted by two strong MS peaks indicators of abrupt regressive incursions. The biofacies data through the FZ11 appear simpler, when considering the trends based on the percentage of *Icriodus* vs *Palmatolepis*. At the base of the FZ11a, an overall shallowing is evidenced by an increasing of MS as well as by an increase of *Icriodus*-

The obvious increase in *Palmatolepis*, associated with the decrease in MS at the base of the proposed FZ11b, is consistent with the transgressive trend interpreted as the *semichatovae* event. In between, the *Icriodus* frequency remains high during all the FZ11a, even when MS returns to lower values suggesting a transgressive trend. Sandberg et al. (1992) already stated that *Icriodus* was perhaps a deep-water form, as they found the greatest percentages of *Icriodus* in the most offshore older deep shelf and older intermound settings in Belgium. Consequently, the occurrence pattern of *Icriodus* casts doubt on its uncritical application as an indicator of shallow-marine nearshore habitats. Differences in sampling, very close in MS, more spaced for conodont study, cannot alone explain the discrepancies. Indeed, the proportions of *Icriodus* remain high (between 20 and 45 %) during most all the FZ11a. A possible explanation for the discrepancies between MS and biofacies trends would be that conodonts responded to sea-level changes only above a certain threshold as expected in ecosystem responses to climate and extreme environmental changes (Smith 2011). The transgressive change in sea-level (transgression) at the FZ10-FZ11 boundary registered by MS could be not be of high enough magnitude to induce deep changes in the conodont assemblages. On the contrary, the threshold of water depth tolerance might have been crossed at the FZ11a-FZ11b in CUQ, explaining why biofacies are in accordance with MS trends. Such a scenario would have to be tested in more continuous sections.

6. Conclusions

In the Frasnian-Famennian stratotype Coumiac section, pelagic deposits during the FZ10-11 interval did not provide the index conodont *Palmatolepis semichatovae* nor sedimentological information for the associated major transgression. The combination of concomitant variations in MS, element detrital proxies and conodont biofacies allows to localize the *semichatovae* event in the Montagne Noire on the North Gondwana margin, consistently with the results in Laurussia. The combined use of these methods opens new perspectives to find eustatic events when they cannot be identified on the basis of biostratigraphic and / or facies data. The momentary discrepancies in MS and biofacies fluctuations

could be explained by the threshold to water depth tolerance of the conodonts, with an absence of clear response when the variation in depth is not of significant magnitude.

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Figure captions

Figure 1. **a-b.** Geographic location of the studied area near Bédarieux in the Montagne Noire in the south of France. **c.** Location of the Coumiac Upper Quarry.

Figure 2. **a.** General view of the middle - upper Frasnian beds in the Coumiac Upper Quarry (Montagne Noire, France). In red: position of Klapper (1989) samples, and red arrows: two hiatuses after Klapper et al. (1995). Dashed blue lines: boundaries between new samples (new samples in blue), blue circles: samples for conodonts, and in white: location of MS and XRF samplings. On the floor, the black box is about 20-25cm wide. **b.** Position of the Frasnian Zones (FZ) after Klapper (1989), and position of the studied beds in blue (drawing after Becker et al. 1989).

Figure 3. From left to right: Ages after De Vleeschouwer et al. (2017), and Percival et al. (2018). Frasnian Zones (FZ) after Klapper (1989) and this study with the facies succession observed, and position of the samples (MS and XRF). Black dashed line: proposed position of the FZ11b base. In red, bed numbers after Klapper (1989). **a.** Curve of magnetic susceptibility (MS) in $10^{-8} \text{ m}^3/\text{kg}$. The smoothing applied on MS values is a local non-parametric regression (loess) with a smoothing coefficient of 0.4 on all measurements. **b.** Conodont biofacies succession with position of the samples (CUQ).

Figure 4. Trends in magnetic susceptibility (MS in $10^{-8} \text{ m}^3/\text{kg}$) and element concentrations (in ppm) indicators of detrital input. Red boxes, position of the two hiatuses after Klapper et al. (1995).

Figure 5. Schematic magnetic susceptibility trends through the FZ10 to FZ12 for sections of Laurussia and N-Gondwana. Canada after Whalen & Day (2008; 2010); Belgium after da Silva & Boulvain (2002). Note that the observed interval of the Canadian and Belgian sections is approximately 50 m thick and the studied Coumiac section event interval is only 4 m.

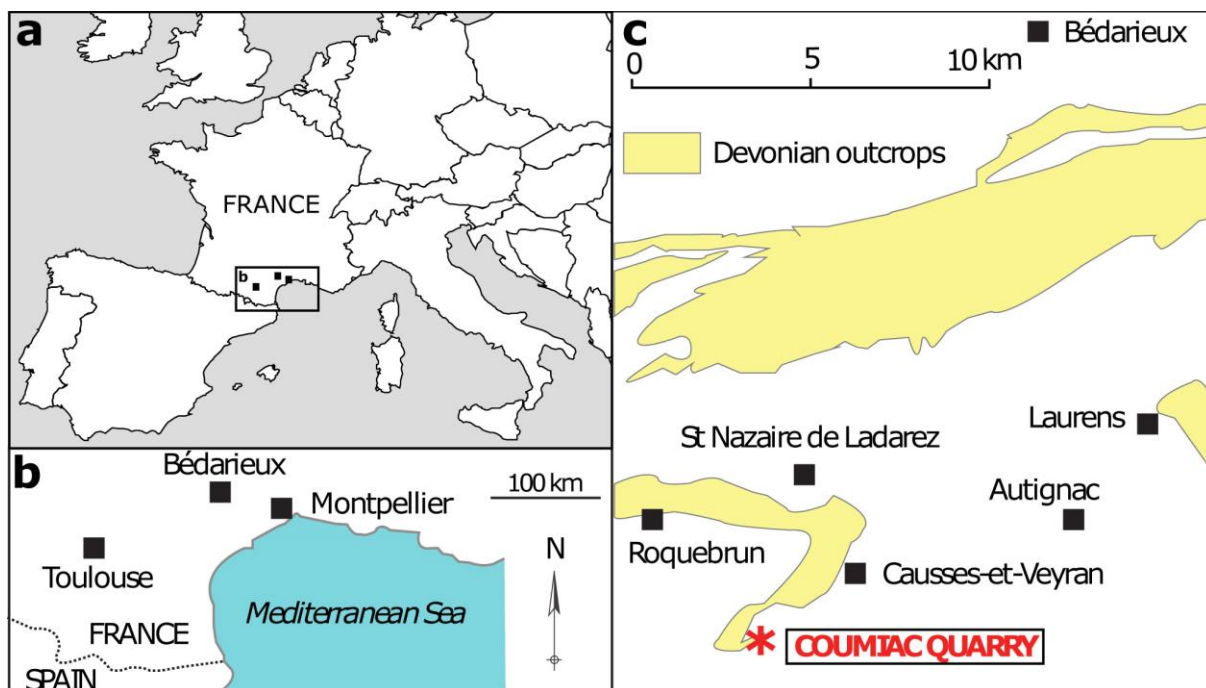


Figure 1

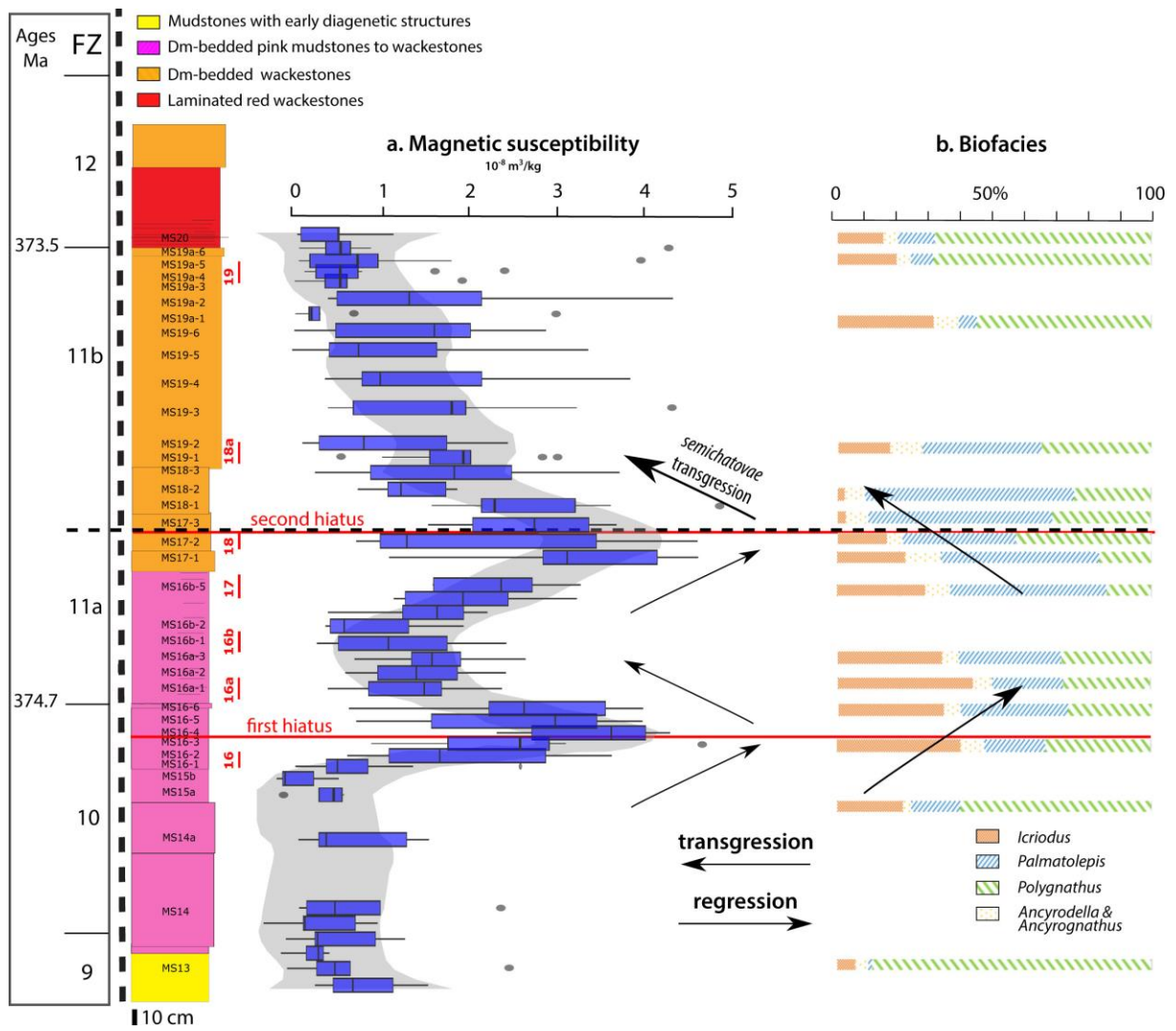


Figure 3

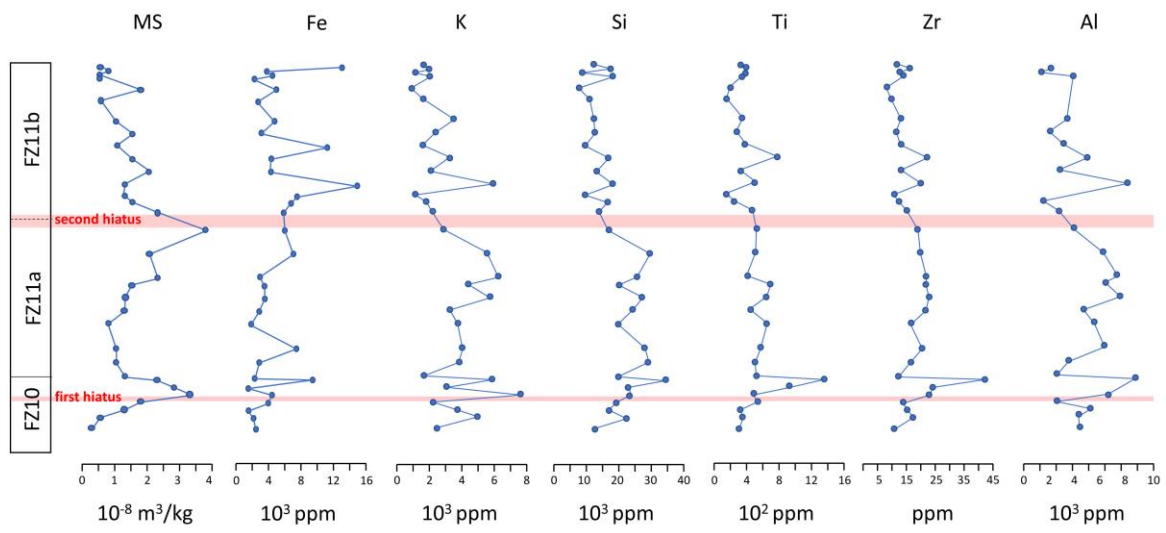


Figure 4

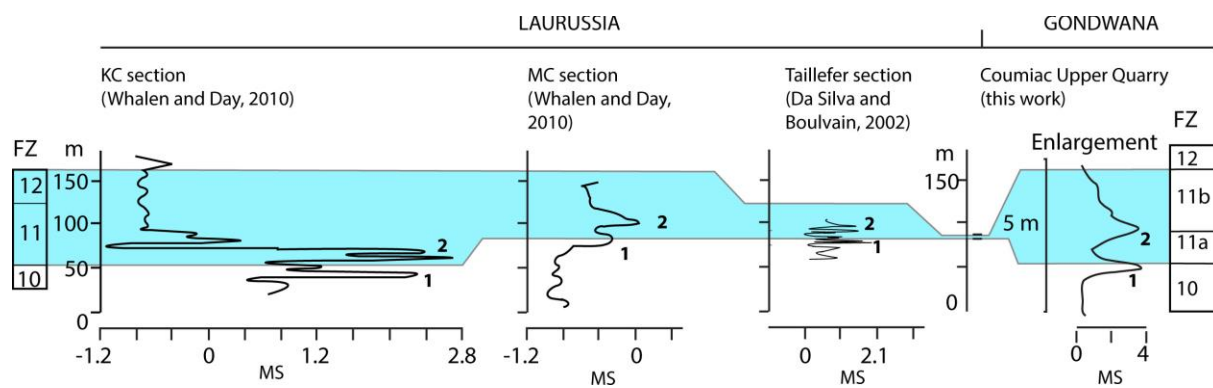


Figure 5