Miocene stable isotopes ($\delta^{18}O$, $\delta^{13}C$), biostratigraphy and environments in the southern limb of the Albufeira syncline (Setúbal Peninsula, Portugal)

Isótopos estables, biostratigrafía, y paleoambientes del Mioceno del flanco Sur del sinclinal de Albufeira (Península de Setúbal, Portugal)

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RESUMEN

Se estudia el contenido paleontológico (moluscos, ostrácodos, foraminíferos, vertebrados y palinofloras) de dos secciones del Mioceno marino (Burdigaliense al ?Tortoniense inferior) de la cuenca inferior del Tajo (proximidades de Lisboa — Penedo Norte y Ribeira da Lage). Se presenta una biostratigrafía basada en foraminíferos planctónicos, y se interpretan paleoambientes circa e infralitorales a partir de las asociaciones paleontológicas.

Los primero datos de isótopos estables (C y O), realizados sobre Ostreidos y Pectínidos, sugieren en Ribeira da Lage un cambio a una mayor influencia continental o ambientes de fondo más oxigenados, y un posible calentamiento en Serravalliense superior.

Palabras clave: *Isótopos estables, biostratigrafía, paleoambientes, Burdigaliense-?Tortoniense inferior, Cuenca del bajo Tajo, Península de Setúbal, Portugal*

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Introduction

In Lisbon and Setúbal Peninsula region seven transgressive events separated by regressive ones (with continental or brackish deposits) had been characterized during Miocene (Antunes *et al.*, 1973). At the western coast of the Setúbal Peninsula, Lower Burdigalian to Lower Tortonian deposits outcrop. Several studies have been published (Romariz *et al.*, 1961; Zbyszewski *et al.*, 1965; Zbyszewski, 1967; Nascimento, 1988; Antunes *et al.*, 1992; Sen *et al.*, 1992; Legoinha, 1993; Antunes *et al.*, 1995; Antunes *et al.*, 1996). In continuity with other works concerning high resolution stratigraphy on the Miocene units from the southern limb of the Albufeira syncline (Setúbal Peninsula), mollusks (oysters and pectinids) have been collected (Penedo and Ribeira da Lage sections, Fig. 1) for stable isotopes analysis ($\delta^{13}C$, $\delta^{18}O$) and $^{87}Sr/^{86}Sr$ ages. The stratigraphic and environmental frame is mainly based on data concerning foraminifera, ostracoda, vertebrates and palinomorphs from the Penedo Norte and

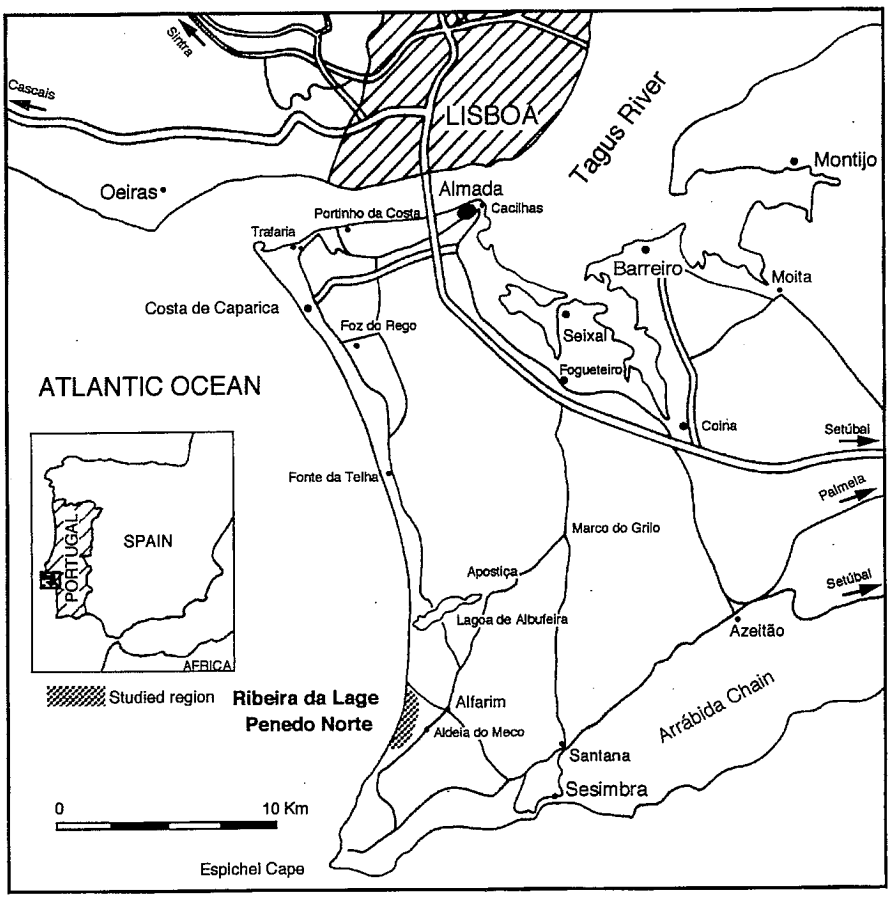

Fig. 1.- Lisbon and Setúbal Peninsula region. Penedo Norte and Ribeira da Lage sections.

Fig. 1.- Lisboa y Península de Setúbal. Mapa de situación de las secciones estudiadas.

Ribeira da Lage sections (Antunes *et al.*, 1995). In this work we present the first $\delta^{13}C$, $\delta^{18}O$ results. The analysis have been made at the "Servicio General de Analisis de isotopos estables, Facultad de Ciencias, Universidad de Salamanca".

Stratigraphy (Fig. 4)

Penedo Norte (Figs. 2, 4)

This section is about 1 Km North of Penedo (coordinates according to sheet 464/Sesimbra from the 1:25 000 military Map of Portugal: M-107 650Km, P-167 200Km). Zbyszewski (1967) correlates the section with the Lisbon region classical units "Helvetian" VI_{a-b}.

The lower beds (1 to 5) yielded among others *Globigerinoides* cf. *altiapertura*, *G. subquadratus*, *G. triloba*, *Globoquadrina dehiscens*, *Globorotalia mayeri* and *G. praescitula* which point out to N7, Upper Burdigalian.

No typical Lower Miocene ostracod species were found. As for bed 1, the environment was infralittoral. In bed 5 (sample 31) *Bosquetina carinella* is plentiful; the association of ostracods suggests 50 to 100 meters depth (circalittoral); *Olimfalunia costata*, common in the Middle Miocene, occurs too. Ostracoda suggest the Langhian eustatic maximum (cycle 2.3, Haq *et al.*, 1987).

There is an erosion surface between beds 5 and 6. On this surface there is a conglomerate whose elements are mainly very abraded bivalve casts with a black, phosphate-rich patina (L. Gaspar, Marine Geology Lab., Portuguese Geological Survey). Sample 25 yielded *Orbulina suturalis*, *Praeorbulina* cf. *glomerosa* and *P. transitoria*. These species point out to N9, Langhian. However, the evolutive line *G. sicanus* › *P. glomerosa* remains unknown; this suggests there is a gap corresponding to part of N8.

A rich association from the lowermost part of bed 7 (sample 32) indicates N10: *Globorotalia peripheroronda*, *Orbulina suturalis*, *O. universa*, *Praeorbulina transitoria*. The top of bed 7 is marked by *Globigerinoides subquadratus* and frequent *Globorotalia* cf. *menardii* that point out to N11, Lower Serravalian.

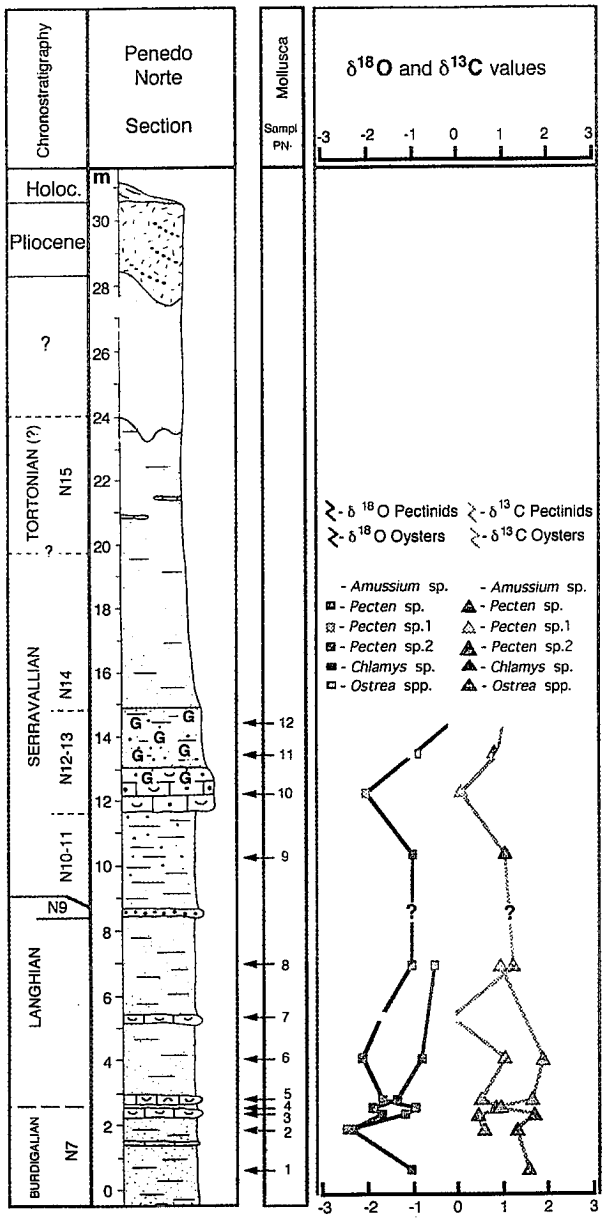

Fig. 2.- Penedo Norte section.

Fig. 2.- Sección de Penedo Norte.

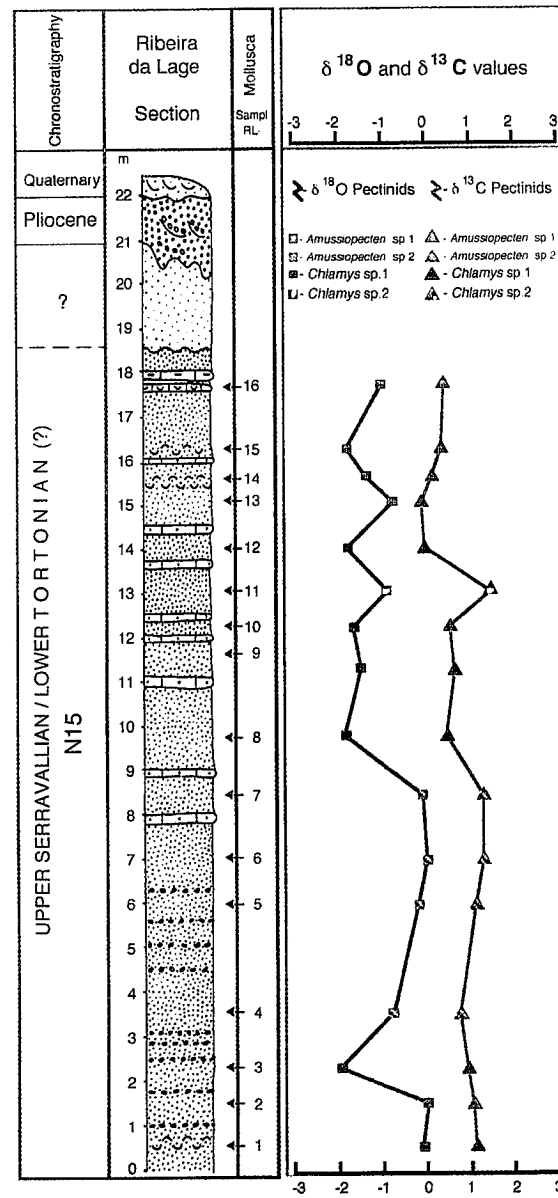

Fig. 3.- Ribeira da Lage section.

Fig. 3.- Sección de Ribeira da Lage.

The overlying conglomerate (bed 8) is unsuitable for the study of the microfauna. It contains glauconite and fragments of phosphate crusts. Pectinid shells from bed 8 were $^{87}Sr/^{86}Sr$ dated (H. Elderfield, Cambridge University): 11.5 to 13Ma.

Bed 9 is a middle-grained glauconite rich sandstone. K-Ar age (C. Regêncio Macedo, Coimbra University) is 10.97±0.25 Ma, Lower Tortonian.

Vertebrate remnants are common (mainly in bed 8). Among sharks, the most frequent are Carcharhinids as *Hemipristis*, *Galeocerdo* and *Negaprion* — stenotherm, warm water forms that predominate here, as they do in Lisbon Va and Vb units. They disappear later, either entirely (as *Negaprion* after VIa division) or nearly so. Lamniform sharks are also very common, specially *Isurus*. This genus essentially indicates temperate waters; their presence is nearly (Va, Late Burdigalian) or totally unknown (Vb, Langhian) in Lisbon, where they occur commonly after VIa. As it could be expected, the above referred Carcharhinids vary in the opposite sense as *Isurus*. There is also a contrasting variation among marine mammals, irenians being frequent until the early Middle Miocene (but nearly disappearing afterwards), while cetaceans (*i. e.* delphinids) and even a seal occur in later units. The seal means non tropical environments and a post-14Ma age. A land mammal (a Cervid) was also recognized. As a whole, remnants whose ages range since Late Burdigalian-Langhian to Serravallian did accumulate in marine environments that changed from tropical to temperate ones. There were not far away emerged lands.

As far as bed 10 is concerned, an association of *Globorotalia* cf. *menardii*, *G. mayeri*, *G. scitula*, *Neogloboquadrina continuosa* and *Globigerina druryi*, as well as the absence of *Globigerinoides subquadratus* indicateS N14.

Ostracods point out to Serravallian age for beds 6 to 10, and to the 2.4 and 2.5 (or 2.6?) cycles (Haq *et al.*, 1987). The association *Loxoconcha (L.) ducasseae*, *Pterigocythereis (P.) jonesi*, *Ruggieria nuda*, *Ruggieria tetraptera tetraptera* and *Bythocythere* sp. from beds 7 (sample 24) and 10 (sample 34) show that circalittoral stage environments were attained.

The commonest dinoflagellata (*Lingulodinium*, *Operculodinium*, *Polysphaeridium zoharyi*, *Spiniferites* spp.) point out to warm, high salinity waters. On other hand, *Homotryblium*, *Lingulodinium machaerophorum*, *Operculodinium israelianum* and *Tuberculodinium vancampoae* (samples 22 and 21, beds 8 and 9) suggest a depth decrease. The richest sample (25) (bed 5) corresponds to open sea waters.

Spores are scarce. The Polypodiaceae are the best represented family (samples 22 and 25). Gymnosperms predominate. Angiosperms have been found only in sample 25: Oleaceae in association with *Ephedra*, Compositae and grasses may point out to dry environments.

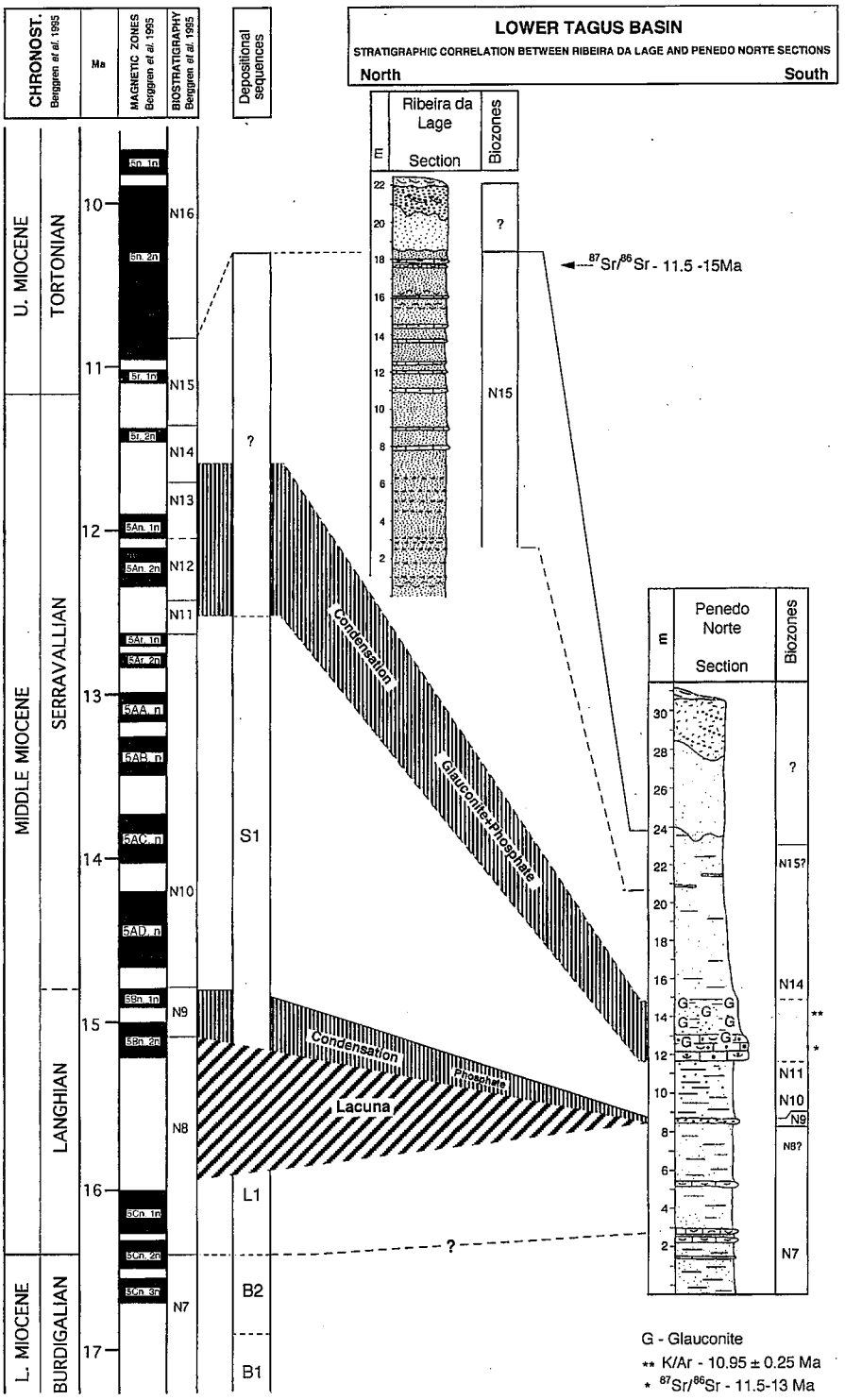

Fig. 4.- Stratigraphic frame of Penedo Norte and Ribeira da Lage sections.

Fig. 4.- Correlación estratigráfica entre las secciones de Penedo Norte y Ribeira da Lege

Ribeira da Lage (Figs. 3, 4)

Observation was carried on the cliffs at the Moinho de Baixo beach (coordinates, sheet n° 464/Sesimbra from the 1:25 000 military Map of Portugal, M-108,320Km, P-169,425Km). Zbyszewski (1967) correlated the section to the Tortonian VIIa-b. The outcrops show medium to fine grained, micaceous sands ("areolas") with frequent decimeter thickness beds. *Chlamys macrotis* is very common towards the top.

The planktonic foraminifera association is marked by *Globorotalia* cf. *menardii* with 5 to 51/2 chambers at the last spire in ventral view (at

Penedo Norte section only forms with 4 to 4 1/2 chambers are common), *Neogloboquadrina continuosa*, *Globigerina apertura*, *G. druryi*, *Globigerinopsis aguasayensis*, *Orbulina suturalis* and *O. universa*. No *Globorotalia mayeri* nor *Neogloboquadrina acostaensis* were observed. This association indicates the N15 zone.

There is a sharp contrast between the Ostracod associations from Ribeira da Lage and Penedo Norte sections. At Ribeira da Lage, *Bosquetina carinella*, *Bythocypris arcuata*, *Cytherella* aff. *compressa*, *Echinocythereis* gr. *scabra* and *Incongruellina (L.) marginata* were never found; however, *Aurila* sp., *Neocytherideis linearis*, *Ponthocythere* sp. and *Urocythereis* sp. are present. The species regarded as typical for Tortonian are lacking; these beds may be ascribed to Serravallian. Corresponding environments are infralittoral. The Ribeira da Lage beds may be related to 2.6 and/or 3.1 cycle (Haq *et al.*, 1987).

Dinoflagellates are rare and scarcely diversified. *Lingulodinium*, *Polysphaeridium* and *Spiriferites pseudofurcatus* predominate.

Spores are always scant. However some hepathics (*Anthoceros*) and ferns (Polypodiaceae) are present (samp. 2 and 6).

Pollens are commoner than at Penedo Norte. Bialate pollens still predominate. At the lower part of Ribeira da Lage section Compositae, Amaranthaceae/Chaenopodiaceae and *Ephedra* are frequent. This association is related to the close-by littoral. Otherwise, *Ulmus*, *Myrica*, *Castanea* and *Ilex* point out to a temperate and humid climate. As for the upper part of the section, the pollen assemblage comprises *Quercus* and Compositae associated to *Cathaya* and *Keteleeria*, which indicate a rather warm and humid climate (*Cathaya* and *Keteleeria* still live in evergreen chinese forests).

Chlamys shells from sample 16 were dated $^{87}Sr/^{86}Sr$ (H. Elderfield, Cambridge University): 11.5 to 15Ma.

C and O isotope analysis

Sample preparation

After ultrasonic cleaning the outside of the *Ostrea* shells has been microperforated along the umbo-paleal diameter in order to obtain several years average with season variations. Shell fragments obtained in the umbo-paleal sense of pectinids have been smashed in an agata mortar.

The organic matter was destroyed by heating up to 400°C under vacuum during two hours. The samples were then introduced in the Sira-II (VG) spectrophotometer with orthophosphoric acid at 25°C. The results are expressed in PDB (Pee Dee Belemnite standard).

$\delta^{18}O$ and $\delta^{13}C$ analysis from Penedo and Ribeira da Lage

All the isotopic values obtained from mollusks are in close agreement to the central field of "shallow-water mollusks and foraminifera" of Milliman (1974).

Oxygene values are more changeable (more variable conditions) at Penedo Norte (2,30δ range for pectinids, Fig. 2) than at Ribeira da Lage (1,21δ range for *Chlamys* and 0,26δ for *Amussiopecten*, Fig. 3). At Penedo Norte section the isotopic values for pectinids show more variation than those for *Ostrea*. The same for Carbon isotopes. At Penedo Norte section depth variation cannot be clearly correlated to the isotope distribution. Contradictory data from pectinids and oysters (PN-2 and PN-5 samples) may be related to re-sedimentation.

Vazquez *et al.*, (1991) have studied the isotopic composition of *Amussiopecten baranensis* from shallow Langhian (N8, Blow) deposits of the Penedés basin (Catalonia, Spain). The obtained values are similar, their range being intermediate between those of Penedo Norte and Ribeira da Lage.

At the Ribeira da Lage section, $\delta^{18}O$ curve points out to open marine environments and, from RL-8 sample upwards, to higher temperatures. The $\delta^{13}C$ decrease, also from RL-8 sample upwards, may be related to growing continental influence or to sea bottom more oxydizing environments. These facts also correspond to a colour sediment change from grey to yellowish. This may perhaps be correlated to the beginning of the 3.1 cycle of the eustatic sea level change (Haq *et al.*, 1987).

Conclusions

1. Biostratigraphy, palaeoecology, chronostratigraphy and isotopic knowledge of Miocene units from the western litoral area of the southern limb of Albufeira sincline was improved.

2. The lower beds of Penedo Norte section correspond to the terminal part of depositional sequence (DS) B2, 3d order eustatic cycle (EC) 2.2 (Haq *et al.*, 1987) and to the DS L1 (EC 2.3) that have been characterized for the Miocene in the distal part of the Lower Tagus basin (Antunes *et al.*, 1996). The beds 6 and 7 correspond to the upper part of the DS S1 (EC 2.4). Beds 8 and 9 correspond to N12-N13 and represent condensation levels; these may be correlated to EC 2.5.

3. The Ribeira da Lage section yielded faunas that indicate N15 (Upper Serravallian) and may correspond to part of CE 2.6 and/or CE 3.1.

4. At the Ribeira da Lage section, the $\delta^{13}C$ decrease points out to either the increase of continental environments influence, or to more oxygenated sea bottom environments. It is stressed by colour change (grey to yellowish) of the concerned sediments, and may also be related to the beginning of EC 3.1.

5. $\delta^{18}O$ decrease observed at Ribeira da Lage section suggests higher water temperatures by the end of Serravallian times.

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