

## Answer to comment bdg-12-C5631-2015 by referee Jan Fischer

### Page 3, line 19

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#### 1) Referee comment:

"Primitive" sharks, compared with modern neoselachians, would be the Devonian Cladoselache or the symmoriid Stethacanthus. Hybodonts, the extinct sister group of the neoselachians, and especially the Late Jurassic species were advanced and already highly derived fishes of the extensive chondrichthyan stem group, from where the modern crown group (sharks and rays) derived.

#### 2) Author's response:

Accepted.

#### 3) Changes in the text:

~~Regular excursions into lower salinity waters can be linked to the age of the deposits and correspond to an ecological adaptation, most likely driven by the Kimmeridgian transgression and by the competition of the primitive shark *Asteracanthus* with the rapidly diversifying neoselachians (modern sharks).~~

Regular excursions into lower salinity waters can be linked to the age of the deposits and correspond to an ecological adaptation, most likely driven by the Kimmeridgian transgression and by the competition of the **hybodont shark** *Asteracanthus* with the rapidly diversifying neoselachians (modern sharks).

### Page 4, line 16

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#### 1) Referee Comment:

According to Ziegler 1990, during the Kimmeridgian, the Massif Central wasnt formed, but this land mass would be the American Massif? Is this correct or already outdated?

Ziegler, P. A. (1990): Geological Atlas of Western and Central Europe. Shell International Petroleum Maatschappij, The Hague: 239 p.

#### 2) Author's response:

In the works of Hug (2003) and Thierry et al. (2010), both terms, Armorican and Central Massifs, are used in the context of the Early Kimmeridgian already. However, the Central Massif mentioned in those studies and in our manuscript is not the equivalent to the extant Massif Central. Gely et al. (2014) use the "Central platform" to avoid any confusion. Since Massif Central is an expression commonly used in the literature, we will leave it as it is in our manuscript. Also, it allows a direct comparison with other works of the PAL A16 team on the Porrentruy region.

Gély, Jean-Pierre, F. Hanot, Francis Amédéo, Françoise Bergerat et al. (2014). Le Bassin Parisien - Un Nouveau Regard Sur La Géologie. Bulletin D'information Des Géologues Du Bassin de Paris, Mémoire hors-série Vol. 9.

Hug, W. A. 2003: Sequenzielle Faziesentwicklung der Karbonatplattform des Schweizer Jura im Späten Oxford und frühesten Kimmeridge. *Geofocus* 7, Fribourg, 1-155

Thierry, J. et al. (44 co-auteurs) 2000: Map 10: Early Kimmeridgian (146-144 Ma). In: Dercourt, J., Gaetani, M., Vrielynck, B., Barrier, E., Biju-Duval, B., Brunet, M. F., Cadet, J. P., Crasquin, S. & Sandulescu, M. (eds.), Atlas Peri-Tethys, Paris, palaeogeographical map

### 3) Changes in the text:

None.

Page 5, lines 6-9

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### 1) Referee Comment:

- What taxa have been found on genus level besides *Asterhacanthus*, *hybodus* and *Ischyodus*?
- hybodont sharks, the extinct sister group of modern sharks - Maisey 2004

Maisey, J. G., Naylor, J. P. & Ward, D. J. (2004): Mesozoic elasmobranchs, neoselachian phylogeny and the rise of modern elasmobranch diversity. - In: Arratia, G. & Tintori, A. (eds): Mesozoic Fishes 3 - Systematics, Paleoenvironments and Biodiversity. Proceeding of the international meeting Serpiano, 2001. Verlag Dr. Friedrich Pfeil, München, p. 17-56.

- subcohort Neoselachii or subdivision Selachii of the Subclass Elasmobranchii of the class Chondrichthyes. Confusing, I know. A superorder of the Selachii would be Squalomorphii or Galeomorphii (Cappetta 2012). Since you mention Heterodontiformes, Squatiniformes and Scyliorhinidae (Carcharhiniformes) (p. 8) taxa from both superorders are contained.

Cappetta, H. (2012): Chondrichthyes - Mesozoic and Cenozoic Elasmobranchii: Teeth. - In: Schultze, H.-P. (ed): Handbook of Paleichthyology 3E. Verlag Dr. Friedrich Pfeil, München: 512 p.

### 2) Author's response:

We agree that it needs more precision (a detailed publication on the fauna will follow).

### 3) Changes in the text:

~~Sharks and rays (subclass Elasmobranchii) are represented by the so-called "primitive sharks" or hybodonts (order Hybodontiformes), modern sharks (superorder Selachimorpha) and rays (suborder Rhinobatoidei). Chimaeras (superorder Holocephali, order Chimaeriformes) are also present.~~

Sharks and rays (subclass Elasmobranchii) are represented by the **hybodont sharks – the extinct sister group of modern sharks (Maisey et al., 2004) (order Hybodontiformes: "*Hybodus*", *Planohybodus*, *Asteracanthus*) –**, the modern sharks (subcohort Neoselachii, order Carcharhiniformes: *Palaeoscyllium*, *Corysodon*; order Heterodontiformes: *Heterodontus*, *Paracestracion*; order Protospinaciformes: *Protospinax* order Squatiniformes: *Pseudorhina*) and rays (superorder Batomorphii, order Rajiformes: *Belemnobatis*, *Spathobatis*). Chimaeras (superorder Holocephali, order Chimaeriformes: *Ischyodus*) are also present.

Added reference :

Maisey, J. G., Naylor, J. P. & Ward, D. J.: Mesozoic elasmobranchs, neoselachian phylogeny and the rise of modern elasmobranch diversity. - In: Arratia, G. & Tintori, A. (eds): Mesozoic Fishes 3 - Systematics, Paleoenvironments and Biodiversity. Proceeding of the international meeting Serpiano, 2001. Verlag Dr. Friedrich Pfeil, München, p. 17-56, 2004.

Page 5, line 22

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1) *Referee Comment:*

I would recommend using enameloid in the whole text instead of enamel since it describes the outer hypermineralized tissue of shark teeth as well as fish teeth that is distinct in its structure to mammal enamel. And enameloid is the used term in scientific publications.

Enax, J., Prymak, O., Raabe, D. & Epple, M. (2012): Structure, composition, and mechanical properties of shark teeth. *Journal of Structural Biology* 178 (3): p. 290-299.

Vennemann, T. W., Hegner, E., Cliff, G. & Benz, G. W. (2001): Isotopic composition of recent shark teeth as a proxy for environmental conditions. *Geochimica et Cosmochimica Acta* 65 (10): p. 1583-1599.

2) *Author's response:*

Accepted. Changed in the commented sentence and throughout the whole text, including figures. See comment Page 21, figure 3 for the new figure. We chose another adult *Asteracanthus* tooth than the previously figured one. The new one is better comparable to the juvenile specimen.

3) *Changes in the text:*

~~The best mineralised part (enamel *s.l.*, i.e. enamel and enameloid) was isolated from Pycnodontiformes and *Asteracanthus* teeth (Fig. 3).~~

The best mineralized part **of the teeth, the enameloid**, was isolated in Pycnodontiformes and *Asteracanthus* (Fig. 3).

Page 6, lines 1-2

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1) *Referee Comment:*

What were the criteria to decide what's unaltered and what's not?

2) *Author's response:*

Here we provide some more detail. Please see response to comment on Page 8, lines 21-25 for a more detailed discussion on the preservation, based on the results.

3) *Changes in the text:*

~~The visibly most unaltered and dentine-free teeth were selected~~

Due to its very small size, only the outer aspect of this material was considered to select visibly best-preserved specimens, *i.e.* not worn-out teeth and/or with ornamentation well defined. After manual removing of the largest part possible of the root, the most dentine-free teeth were selected.

Page 6, line 8

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1) *Referee Comment:*

How much material of enameloid or bulk sample was needed for a single sample?

2) *Author's response:*

The minimum quantity of powder sampled was 2mg.

3) *Changes in the text:*

~~The sample powders were pre-treated following the procedure of Koch et al. (1997), and the PO<sub>4</sub><sup>3-</sup> ion of the apatite was separated and precipitated as silver phosphate (e.g. Kocsis, 2011; O'Neil et al., 1994).~~

The sample powders (**at least 2mg per sample**) were pre-treated following the procedure of Koch et al. (1997), and the PO<sub>4</sub><sup>3-</sup> ion of the apatite was separated and precipitated as silver-phosphate (e.g. Kocsis, 2011; O'Neil et al., 1994).

Page 6, line 17

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1) *Referee Comment:*

explain in brackets

Vienna Standard mean Ocean Water

2) *Author's response:*

Accepted

3) *Changes in the text:*

~~The data are expressed in permil and reported as  $\delta^{18}\text{O}_p$  on the VSMOW scale.~~

The data are expressed in permil and reported as  $\delta^{18}\text{O}_p$  on the VSMOW scale (**Vienna Standard Mean Ocean Water**).

*1) Referee Comment:*

Were the data normalized to the NBS-120c value?

*2) Author's response:*

The data were not corrected to NBS-120c. It was only used for cross-checking preparation of the samples. As no accepted and real matrix match standard exist for bioapatite, the slightly lower NBS-120c (compare to other reported values) is thought to be related to heterogeneity in this reference material. Additionally, NBS120c is a sedimentary phosphorite therefore it could respond differently to pretreatments and also to dissolution compared to pure enamel. When very extreme values are obtained the samples are always re-prepared and re-run.

*3) Changes in the text:*

~~For the NBS-120c an average value of 21.3 ± 0.3‰ (n = 6) was obtained.~~

For the NBS-120c an average value of 21.3 ± 0.3‰ (n = 6) was obtained. This is somewhat lower than the mean reported value of 21.7 ‰ (e.g. Halas et al., 2011), still no correction was applied here as the small offset is thought to be due to heterogeneity in the sedimentary phosphorite and its different response to pretreatments than enameloid.

*Added reference:*

Halas, S., Skrzypek, G., Meier-Augenstein, W., Pelc, A., Kemp, H.F.: Inter-laboratory calibration of new silver orthophosphate comparison materials for the stable oxygen isotope analysis of phosphates. Rapid Commun. Mass Spectrom. 25, 579–584, 2011.

*1) Referee Comment:*

- d18O<sub>h20</sub> or d18O<sub>w</sub>?

See Fig. 4 figure caption as well as Supplement Table and Legend.

- (d18O<sub>w</sub>)

- for the ice-free

*2) Author's response:*

The text was modified accordingly to make it more consistent. Thank you.

*3) Changes in the text:*

~~The oxygen isotopic composition of unaltered fish teeth is function of both, water temperature and isotopic composition of ambient water during tooth growth (Kolodny et al., 1983; Lécuyer et al., 2013; Longinelli~~

and Nuti, 1973). Here below is the phosphate fractionation equation of Lécuyer et al. (2013) used for calculating the temperature of sea water:

$$T (^{\circ}\text{C}) = 117.4(\pm 9.5) - 4.50(\pm 0.43) \times (\delta^{18}\text{O}_{\text{PO}_4} - \delta^{18}\text{O}_{\text{H}_2\text{O}}) \quad (1)$$

For marine fauna, the global, average seawater isotopic composition can be used as an approximation that is assumed to be equal to  $-1\text{‰}$  for Late Jurassic seawater (e.g. Shackleton and Kennet, 1975).

The oxygen isotopic composition of unaltered fish teeth ( $\delta^{18}\text{O}_p$ ) is function of both, water temperature (T) and isotopic composition of ambient water ( $\delta^{18}\text{O}_w$ ) during tooth growth (Kolodny et al., 1983; Lécuyer et al., 2013; Longinelli and Nuti, 1973). Here below is the phosphate fractionation equation of Lécuyer et al. (2013) used for calculating the temperature of sea water:

$$T (^{\circ}\text{C}) = 117.4(\pm 9.5) - 4.50(\pm 0.43) \times (\delta^{18}\text{O}_p - \delta^{18}\text{O}_w) \quad (1)$$

For marine fauna, the global, average seawater isotopic composition ( $\delta^{18}\text{O}_w$ ) can be used as an approximation that is assumed to be equal to  $-1\text{‰}$  for the ice-free Late Jurassic seawater (e.g. Shackleton and Kennett, 1975).

*Reference corrected :*

Shackleton, N. and Kennett, J. P.: Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP sites 277, 279, and 281, Initial Rep. Deep Sea, 29, 743–756, 1975.

Page 7, line 10

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1) *Referee Comment:*

What does it mean?

2) *Author's response:*

**The statistics of Student's t-test shows a significant difference** between enamel and dentine, a difference already observed by several authors (Lécuyer et al., 2003; Sharp et al., 2000; Pucéat et al., 2003). That is a further argument for the better preservation of enamel compared to dentine and for the focus on enamel samples in the interpretation. However, since this is the Results section, these precisions will be given further in the text.

3) *Changes in the text:*

~~Dentine values of *Asteracanthus* average  $18.9 \pm 0.8\text{‰}$  ( $17.7 - 20.0\text{‰}$ ,  $n=11$ ), indicating a statistically significant difference to the equivalent enamel samples collected on the same teeth (student t test:  $t_{(20)} = 2.98$ ,  $p < 0.01$ ).~~

The average value of  $18.9 \pm 0.8\text{‰}$  ( $17.7 - 20.0\text{‰}$ ,  $n=11$ ) in the *Asteracanthus'* dentine is significantly different to the equivalent enameloid samples collected on the same teeth demonstrated by Student's t-test:  $t_{(20)} = 2.98$ ,  $p < 0.01$ .

*References added :*

Pucéat, E., Lécuyer, C., Sheppard, S. M. F., Dromart, G., Reboulet, S. and Grandjean, P.: Thermal evolution of Cretaceous Tethyan marine waters inferred from oxygen isotope composition of fish tooth enamels, *Paleoceanography*, 18(2), 1-12, doi:10.1029/2002PA000823, 2003.

Sharp, Z. D., Atudorei, V. and Furrer, H.: The effect of Diagenesis on oxygen isotope ratios of biogenic phosphates, *Am. J. Sci.*, 3000, 222–237, 2000.

**Page 7, line 19**

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*1) Referee Comment:*

(Schaefer, 2012)

*2) Author's response:*

Accepted, more consistent with the rest of the sentence.

*3) Changes in the text:*

~~Among vertebrates, coastal marine turtles (Plesiochelyidae) (Anquetin et al., 2014; Püntener et al., 2014) and crocodylians (Thalattosuchia) are common (Schaefer, 2012).~~

Among vertebrates, coastal marine turtles (Plesiochelyidae) (Anquetin et al., 2014; Püntener et al., 2014) and crocodylians (Thalattosuchia) (Schaefer, 2012) are common.

**Page 8, lines 2-3**

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*1) Referee Comment:*

- references for that fact?

- So far nothing has been said about conditions of reduced salinity in Porrentruy. Anticipating of the interpretation.

*2) Author's response:*

- A paper on the chondrichthyan fauna is in preparation. The genera now listed above (in response to your comment on Page 5, lines 6-9) are comparable to the references proposed (Duffin and Thies, 1997; Thies, 1995).

- Accepted. Here, the “also” is confusing and can be understood as both “also dominated by hybodonts”, and “also associated to conditions of reduced salinity”. The authors did not mean to inform on the salinity of Porrentruy at this point of the manuscript.

*3) Changes in the text:*

~~However, our chondrichthyan assemblage is similar to that in northern Germany (e.g. in Oker) (Duffin and Thies, 1997; Thies, 1995), also dominated by hybodonts and rays and associated to conditions of reduced salinity (Underwood and Rees, 2002; Underwood and Ward, 2004; Underwood, 2002, 2004).~~

Our chondrichthyan assemblage (**see section 2**) is rather similar to that in northern Germany (e.g. in Oker) (Duffin and Thies, 1997; Thies, 1995), also dominated by hybodonts and rays. **There, the fauna is** associated to conditions of reduced salinity (Underwood and Rees, 2002; Underwood and Ward, 2004; Underwood, 2002, 2004).

Page 8, line 9-12

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1) *Referee Comment:*

- "*Heterodontiformes*" is crossed out

- That kind of durophagous lifestyle can be also assumed for *Asteracanthus* with its clutching-crushing-grinding-dentition.

Cappetta, H. (2012): Chondrichthyes - Mesozoic and Cenozoic Elasmobranchii: Teeth. - In: Schultze, H.-P. (eds): Handbook of Paleichthyology 3E. Verlag Dr. Friedrich Pfeil, München: 512 p.

Cuny, G. (2012): Freshwater hybodont sharks in Early Cretaceous ecosystems : A review. - In: Godefroit, P. (eds): Bernissart dinosaurs and Early Cretaceous terrestrial ecosystems. Indiana University Press, Bloomington, p. 518-529.

- references for the lifestyles of these sharks?

2) *Author's response:*

- According to Cappetta (2012), Heterodontiformes are part of the Neoselachii and should not be crossed out. Here we added Neoselachii to make clearer what we mean about "modern sharks", which can be confusing.

- We agree about the durophagous diet for *Asteracanthus*, though a benthic lifestyle is more disputable. The possibility for the most grown-up individuals to feed on ammonites cannot be discarded, regarding their dentition (ammonites are abundant in the study area). In his book "Les requins sont-ils des fossiles vivants ? – L'évolution des poissons cartilagineux" (EDP Sciences, 2002), Gilles Cuny briefly mentions a possible relation between the large size reached by ammonites and *Asteracanthus*. Based on the quite stable isotopic composition of *Asteracanthus* teeth coming from deposits of different depths, Lécuyer et al. (2003, see references) consider *Asteracanthus* as a surface dweller.

A benthic lifestyle is more reasonable for the modern shark taxa we list: *Pseudorhina* and *Protospinax* show a dorso-ventral flattening; extant relatives of our *Heterodontus* and *Palaeoscyllium* (e.g. *Heterodontus francisci* and *Scyliorhinus stellaris*) live close to the sea floor. A benthic lifestyle is proposed for those taxa in the references we cite.

3) *Changes in the text:*

~~Interestingly, the few modern sharks of our assemblage (Heterodontiformes, Squatiniformes and Scyliorhinidae) are all thought to have had a benthic lifestyle, supporting a well-oxygenated bottom water, which is also indicated by the invertebrate fauna.~~

Interestingly, most of the few modern sharks (**Neoselachii**) of our assemblage (i.e. *Heterodontus*, *Palaeoscyllium*, *Protospinax*, *Pseudorhina*) are thought to have had a benthic lifestyle (**Underwood, 2002; Underwood and Ward, 2004**), supporting a well-oxygenated bottom water, which is also indicated by the invertebrate fauna.

Reference added:

Cappetta, H.: Chondrichthyes - Mesozoic and Cenozoic Elasmobranchii: Teeth. - In: Schultze, H.-P. (eds): Handbook of Paleoichthyology 3E. Verlag Dr. Friedrich Pfeil, München: 512 p., 2012.

Page 8, line 21-25

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1) Referee Comment:

- What kind of distinct range is this between *Asteracanthus* dentine (17.7-20 permil) and *Asteracanthus* enameloid (17.0-19.7 permil)? What points to alteration in the first one? The wider range?

- You examined cathodoluminescence on the material or how do you decided whats altered and whats not? What means original and how do you detect it?

- The stability of enameloid has been repeatedly questioned: e.g.:

Kohn, M. J., Schoeninger, M. J. & Barker, W. W. (1999): Altered states: Effects of diagenesis on fossil tooth chemistry. *Geochimica et Cosmochimica Acta* 63 (18): p. 2737-2747.

Sharp, Z. D., Atudorei, V. & Furrer, H. (2000): The effect of diagenesis on oxygen isotope ratios of biogenic phosphates. *American Journal of Science* 300: p. 222-237.

Zazzo, A., Lécuyer, C. & Mariotti, A. (2004): Experimentally-controlled carbon and oxygen isotope exchange between bioapatites and water under inorganic and microbially-mediated conditions. *Geochimica et Cosmochimica Acta* 68 (1): p. 1-12.

2) Author's response:

Here, apart from general aspect of the fossil material (well-defined ornamentation, absence of sign of transportation), microscopic observation of thin sections and CL analyses (revealing non-luminescence) were performed. As there is no way to be completely sure of the pristine quality of a fossil shark tooth, we also infer the good preservation of enamel samples using their isotopic value range. "Distinct range in value" refers here to the difference between *Asteracanthus* enamel and Pycnodontiformes enamel values only. However, here is more detail:

- Since all samples analyzed in this work come from the same deposits (always several taxa analyzed in a same bed), one would expect a uniform isotopic signature in all samples if the material was diagenetically altered.

- *Asteracanthus* and Pycnodontiformes enamel value ranges are distinct from each other, *Asteracanthus* ones being in average lower. This difference is most probably due to different original isotopic composition and not to diagenesis.

There is another way to explain those taxon-related differences in the isotopic value, but it seems very unlikely: teeth from one taxon could have been deposited in an environment different to the study environment, suffered different alteration, then been reworked and redeposited in the study area, together with autochthonous material from the other taxon. Preliminary trace element study (i.e., rare earth element distribution) did not support mixed-reworked fauna.

- *Asteracanthus* and Pycnodontiformes enamel values are also distinct from the ones of dentine-bearing samples of other taxa (i.e. bulk samples of *Hybodus* and rays, dentine of *Ischyodus*).

- *Asteracanthus* dentine isotopic values are all higher than their enamel counterpart measured on the same tooth, except one that is slightly below (sample BSY008-579). As a less resistant, more porous tissue, the dentine seemingly suffered alteration to some extent. The *Asteracanthus* dentine values *tend* to values similar to dentine-bearing samples of other taxa and this is also why dentine-bearing samples in general are ruled out from the final interpretation, since they are more likely to be diagenetically altered than enamel samples.

- About the stability of enameloid, Zazzo et al. (2004) showed that even under organic conditions (bacterium mediated – which may change the PO<sub>4</sub> and δ<sup>18</sup>O too) enamel retains the original isotopic composition.

### 3) Changes in the text:

~~In contrast, the isotopic compositions of Pycnodontiformes and *Asteracanthus* enamel samples are considered not to have been altered, because of their distinct range in values, their original histological structure when examined with a microscope and the generally good preservation potential for enamel/enameloid when not recrystallised (e.g. Kohn and Cerling, 2002). The significant differences in δ<sup>18</sup>O<sub>p</sub> values of *Asteracanthus* and Pycnodontiformes enamel from Porrentruy (Student *t* test,  $t(38) = 6.36$ ,  $p < 0.01$ ) hence indicate different living environments (Fig. 4).~~

In contrast, the isotopic compositions of Pycnodontiformes and *Asteracanthus* enameloid samples are considered not to have been altered, **partly because** of their original histological structure when examined with a microscope, **their non-luminescent character when subjected to cathodoluminescence**, and the generally good preservation potential for enameloid (e.g. Kohn and Cerling, 2002). **Still, the distinct range in values of *Asteracanthus* and Pycnodontiformes enameloid, both when compared to one another and to dentine-bearing samples, is the best indicator of their good preservation. Indeed, *Asteracanthus* enameloid values measured on a tooth always differ from their dentine counterpart from the same specimen – the dentine being higher, except in one case. This shows that the enameloid did not suffer the same level of alteration that the dentine underwent. The same can be inferred from the isotopic difference between *Asteracanthus* and Pycnodontiformes enameloid values, which would be expected to result in similar values if they would have undergone the same diagenetic alteration (see Fischer et al., 2012). Because of these reasons, the significant differences in δ<sup>18</sup>O<sub>p</sub> values of *Asteracanthus* and Pycnodontiformes enameloid from Porrentruy (Student *t*-test,  $t_{(38)} = 6.36$ ,  $p < 0.01$ ) are interpreted as reflecting actual differences in the living conditions rather than in the alteration process (Fig. 4). We will focus on those values for the rest of the discussion.**

### Reference added :

Fischer, J., Voigt, S., Franz, M., Schneider, J. W., Joachimski, M. M., Tichomirowa, M., Götze, J. & Furrer, H. (2012): Palaeoenvironments of the late Triassic Rhaetian Sea: Implications from oxygen and strontium isotopes of hybodont shark teeth. *Palaeogeography, Palaeoclimatology, Palaeoecology* 353-355: p. 60-72.

Page 9, line 7-9

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### 1) Referee Comment:

What are the Late Jurassic comparative marine values for a "classical marine signal" based on what and who determined them? References?

2) *Author's response:*

We base on the papers we use as comparison isotopic compositions. Those papers are about Jurassic marine vertebrates from Western Europe. You can refer to Fig. 5 to look at the value ranges from those comparison studies. This is now clarified in the text.

3) *Changes in the text:*

~~Most of the Pycnodontiformes  $\delta^{18}\text{O}_p$  values are compatible with the marine conditions indicated by the associated fauna and the resulting average sea surface temperature is also consistent ( $23.9\pm 4.4$  °C, n=13).~~ Most of our Pycnodontiformes  $\delta^{18}\text{O}_p$  values (18.2-21.9‰) indicate marine conditions, **since they are comparable with the isotopic composition measured on several marine vertebrate taxa from the Late Jurassic of western Europe (18.5-22.8‰) (see Billon-Bruyat et al., 2005; Dromart et al., 2003; Lécuyer et al., 2003).** Those values are consistent with the marine conditions indicated by the associated fauna of Porrentruy. When used in the Eq. (1), the Pycnodontiformes  $\delta^{18}\text{O}_p$  values result in a mean temperature range that is consistent considering the paleogeographical settings of the study site ( $23.9\pm 4.4$  °C, n=13).

Page 9, line 18

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1) *Referee Comment:*

Why do hybodont fin spines preclude post mortem transport?

2) *Author's response:*

You are right, the presence of fin spines alone does not directly preclude transport. However, because of their size, fin spines are unlikely to be transported on large distances in our context of shallow and low-energy platform (as indicated by the sediment type where most shark remains are found, the marls). We agree this needs some precision.

3) *Changes in the text:*

~~Moreover, the record of *Asteracanthus* fin spines and several teeth still preserved with their root (see Fig. 3) an indication of post-mortem embedding rather than tooth loss in hybodonts (Underwood and Cumbaa, 2010) also precludes transport.~~

Also, the associated record of several large *Asteracanthus* fin spines in the Lower Virgula Marls (a lagoonal facies indicating a low-energy context) (see Waite et al., 2013) points out the absence of transport over long distances of those relatively large objects (up to 26.5 cm long) and supports hereby the autochthonous character of this genus. Moreover, the preservation of the root in several *Asteracanthus* teeth (see Fig. 3) – an indication of post-mortem embedding rather than tooth loss in hybodonts (Underwood and Cumbaa, 2010) – also precludes transport.

*1) Referee Comment:*

For your values an extant analogon - euryhaline bull sharks generally occupy brackish inshore and riverine environments with temperatures of 26–32 °C

Carlson, J. K., Ribera, M. M., Conrath, C. L., Heupel, M. R. & Burgess, G. H. (2010): Habitat use and movement patterns of bull sharks *Carcharhinus leucas* determined using pop-up satellite archival tags. *Journal of Fish Biology* 77 (3): p. 661-675.

Fischer, J., Voigt, S., Franz, M., Schneider, J. W., Joachimski, M. M., Tichomirowa, M., Götze, J. & Furrer, H. (2012): Palaeoenvironments of the late Triassic Rhaetian Sea: Implications from oxygen and strontium isotopes of hybodont shark teeth. *Palaeogeography, Palaeoclimatology, Palaeoecology* 353-355: p. 60-72.

*2) Author's response:*

Thank you for this very valuable information.

*3) Changes in the text:*

None directly at the place of the comment. The reference of Fischer et al. (2012) was added in the diagenesis part, see Comment on Page 8, lines 21-25.

*1) Referee Comment:*

Makes sense - Extant relatives with comparable ecological niches such as heterodontid sharks dwell in warm-temperate waters around 20 °C

White, W. T. & Sommerville, E. (2010): Elasmobranchs of Tropical Marine Ecosystems. - In: Carrier, J. C. et al. (eds): *Sharks and their relatives II - Biodiversity, adaptive Physiology, and Conservation*. CRC Press, London New York, p. 160-200.

*2) Author's response:*

Another valuable data, thank you.

*3) Changes in the text:*

*Sentence added:*

Extant elasmobranchs that occupy different environments during relatively long period of their lives (not necessarily with salinity variations) can do so for different reasons: seasonal environmental changes, reproduction, and development in distinct environment in first ontogenetic stages (White and Sommerville, 2010).

*Reference added:*

White, W. T. and Sommerville, E.: Elasmobranchs of Tropical Marine Ecosystems, in Sharks and their relatives II - Biodiversity, adaptive Physiology, and Conservation, edited by J. C. Carrier, J. A. Musick, and M. R. Heithaus., pp. 160-200, CRC Press, London New York, 2010.

**Page 10, line 4**

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*1) Referee Comment:*

I agree but there are still other opinions:

Botella, H., Valenzuela-Ríos, J. I. & Martínez-Pérez, C. (2009): Tooth replacement rates in early chondrichthyans: a qualitative approach. *Lethaia* 42 (3): p. 365-376.

*2) Author's response:*

Accepted. Changed for a more moderate declaration

*3) Changes in the text:*

~~Assessing the tooth replacement rate of an extinct shark is impossible.~~

Assessing the tooth replacement rate of an extinct shark is **difficult**, and studies in respect are scarce (e.g. Botella et al., 2009).

*Reference added :*

Botella, H., Valenzuela-Ríos, J. I. and Martínez-Perez, C.: Tooth replacement rates in early chondrichthyans: A qualitative approach, *Lethaia*, 42(3), 365–376, doi:10.1111/j.1502-3931.2009.00152.x, 2009.

**Page 10, line 5**

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*1) Referee Comment:*

... of rather few files of large teeth?

file according to Cappetta 2012 (p. 10) for a series of teeth perpendicular to the jaw edge

Cappetta, H. (2012): Chondrichthyes - Mesozoic and Cenozoic Elasmobranchii: Teeth. - In: Schultze, H.-P. (eds): *Handbook of Paleichthyology* 3E. Verlag Dr. Friedrich Pfeil, München: 512 p.

*2) Author's response:*

Both the files and lines are quite limited in *Asteracanthus*, compared to other sharks, e.g. with tearing-type dentition (see picture on p.136 in Rees & Underwood (2008): Hybodont sharks of the English Bathonian and Callovian (Middle Jurassic). *Palaeontology*, 51).

3) Changes in the text:

~~However, *Asteracanthus* possesses a crushing dentition composed of a rather small amount of large teeth (see Rees and Underwood, 2008); hence, a relatively slow replacement rate is likely, compared to other sharks with numerous slender, cuspidated teeth adapted to clutch and tear their prey.~~

However, *Asteracanthus* possesses a crushing dentition composed of a rather small amount of large teeth (see Rees and Underwood, 2008, p.136) **organized in a relatively low number of files and rows (*sensu* Cappetta, 2012)**; hence, a relatively slow replacement rate is likely, compared to other sharks with numerous slender, cuspidated teeth adapted to clutch and tear their prey.

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Page 10, lines 10-11

1) Referee Comment:

Please define it in 5.1 before for the Late Jurassic marine realm

2) Author's response:

See response to comment on Page 9, lines 7-9

3) Changes in the text:

~~The isotopically lower signature of *Asteracanthus*, compared to a classical marine signal, corresponds either to a constant brackish living environment or to a marine environment with regular excursions into fresh- or brackish waters (or vice-versa).~~

The isotopically lower signature of *Asteracanthus*, compared to a classical Late Jurassic marine signal (**see data from marine vertebrates of other studies in section 5.1**), corresponds either to a constant brackish living environment or to a marine environment with regular excursions into fresh- or brackish waters (or vice-versa).

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Page 10, lines 20-21

1) Referee Comment:

- What means middle sizes or large?

- If I understand it correctly, the determination of juvenile teeth is singly based on its size?

Why are these teeth not the extreme lateral teeth of the dentition that are distinctly reduced as shown in Cappetta 2012 and Rees and Underwood 2008?

Are there any morphological traits or hints for ontogenetic heterodonty, that allow such assignment? I know that it is very difficult to identify but your assignment need a little bit more substantiated.

Cappetta, H. (2012): Chondrichthyes - Mesozoic and Cenozoic Elasmobranchii: Teeth. - In: Schultze, H.-P. (eds): Handbook of Paleoichthyology 3E. Verlag Dr. Friedrich Pfeil, München: 512 p.

Fischer, J., Voigt, S., Schneider, J. W., Buchwitz, M. & Voigt, S. (2011): A selachian freshwater fauna from the Triassic of Kyrgyzstan and its implication for Mesozoic shark nurseries. Journal of Vertebrate Paleontology 31 (5): p. 937-953.

Rees, J. & Underwood, C. J. (2008): Hybodont sharks of the English Bathonian and Callovian (Middle Jurassic). *Palaeontology* 51 (1): p. 117-147.

2) *Author's response:*

We agree this needs more precision. Again compared to the picture on p.136 in Rees & Underwood (2008) (Hybodont sharks of the English Bathonian and Callovian (Middle Jurassic). *Palaeontology*, 51), the “small-scaled teeth” we mention are clearly undersized. Furthermore, the size difference between this small material and the other, larger teeth is much greater than the size difference between lingual-most and labial-most teeth in the figure of Rees & Underwood (2008).

A photograph of this small-sized material has been added in Figure 3 for a direct comparison with the normal adult size and we propose to moderate our assumptions in the text.

3) *Changes in the text:*

~~While more than 130 middle sized to large *Asteracanthus* teeth were found in the Porrentruy excavation sites, only 4 very small scaled (< 1 cm) and badly preserved teeth were discovered among hundreds of kilograms of sediment sieved and picked, which suggests a different living environment during the juvenile stage, and excursions of adult individuals for reproduction purposes. The record of hundreds of submillimetric fish remains such as dermal denticles exclude a taphonomic bias linked to the size of the teeth.~~

More than 130 *Asteracanthus* teeth were found in the Porrentruy excavation sites. Only 4 of them appeared to be clearly undersized (< 1 cm) (Figure 3). As illustrated in Rees & Underwood (2008, p.136), the size difference between lingual-most and labial-most teeth of any file is quite small in *Asteracanthus medius*. Even if a stronger heterodonty cannot be excluded for other species of the genus, it seems more likely that the clearly undersized dental material belonged to juvenile individuals. Their proportionally limited number suggests a different living environment during the juvenile stage. Therefore, excursions of adult individuals for reproduction purposes can be considered. The record of hundreds of submillimetric fish remains such as dermal denticles resulting from sieving of hundreds of kilograms of sediments exclude a taphonomic bias linked to the size of the teeth.

Page 11, lines 3-4

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1) *Referee Comment:*

The same problem.

The dentition of *Asteracanthus* is formed by small posterior teeth, followed by the large, up to 6 cm large lateral brick-like teeth and middle sized anterior ones in front.

I guess distinction of different morphotypes of a single dentition and different ontogenetic stages just works with the morphology of the teeth. If all teeth have more or less the same shape this might point to different sizes of the ancient shark. If the size difference is accompanied by different morphology (see Fig. 3 in Rees and Underwood 2008) different teeth of a heterodont dentition seems to be more realistic.

2) *Author's response:*

See comment above. Here, we propose to take out the assumptions made on “medium-scaled teeth” which represent an intermediate size, more difficult to define.

3) *Changes in the text:*

~~Middle-sized teeth potentially represent young individuals that had already colonised the marine realm. *Asteracanthus* individuals that have reached a considerable size were then a less easy prey and also able to feed on the large ammonites and bivalves living in the marine realm of the platform.~~

Page 11, line 20

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1) *Referee Comment:*

It is already written in the figure caption

2) *Author's response:*

Accepted.

3) *Changes in the text:*

~~All data given in this Figure are available in the Supplement.~~

Page 12, line 17

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1) *Referee Comment:*

Not necessary since you already cite Kriwet 2000 above

2) *Author's response:*

Accepted.

3) *Changes in the text:*

This is the first isotopic evidence of a euryhaline ecology for the large, durophagous shark *Asteracanthus*, classically considered as marine ~~for more than 150 years~~ (Agassiz, 1843; Rees and Underwood, 2006, 2008).

Page 12, line 20

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1) *Referee Comment:*

Most of the d18Op values....

Not all of them exceeding the tolerance limit for modern fishes of 38-40C as you even show in Fig. 4

2) *Author's response:*

You are right. Considering the excursions into lower salinity that we propose, all intermediates between the highest isotopic composition reflecting “normal marine” conditions and the lowest one representing a lower salinity are expectable.

3) *Changes in the text:*

*Rewriting the sentence:*

~~The  $\delta^{18}\text{O}_p$  values of enamel measured in the hybodont shark *Asteracanthus* are too low to reflect fully marine conditions.~~

Most of the  $\delta^{18}\text{O}_p$  values of enamel measured in the hybodont shark *Asteracanthus* are too low to reflect fully marine conditions.

Page 18, line 4

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1) *Referee Comment:*

Purbeck

2) *Author's response:*

Accepted.

3) *Changes in the text:*

~~Underwood, C. J. and Rees, J.: Selachian faunas from the earliest Cretaceous Purbeck groups of Dorset, Southern England, Spec. Pap. Palaeontol., 68, 107–19, 2002.~~

Underwood, C. J. and Rees, J.: Selachian faunas from the earliest Cretaceous Purbeck groups of Dorset, Southern England, Spec. Pap. Palaeontol., 68, 107–19, 2002.

Page 19, figure 1

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1) *Referee Comment:*

- According to Ziegler 1990, during the Kimmeridgian, the Massif Central wasn't formed, but this land mass would be the American Massif? Is this correct or already outdated?

Ziegler, P. A. (1990): Geological Atlas of Western and Central Europe. Shell International Petroleum Maatschappij, The Hague: 239 p.

- How could the paleoaltitude of Porrentry at about  $\sim 30^\circ\text{N}$  when in the small map is far above  $45^\circ\text{N}$ ?

2) *Author's response:*

About the Central Massif, see answer to the comment on Page 4, line 16.

The small square on the upper left represents a present geographical map, with the shaded area indicating the sample sites of other studies. This is not a paleogeographical map. As such, the latitudes on this part of the picture are also present latitudes. The large picture represents the paleogeographical setting.

We agree this can be misunderstood and changed the legend to make it clearer:

3) *Changes in the text:*

~~Figure 1. Geographical position of Porrentruy (\*) and other European sites (°) of previously published studies and providing geochemical data compared in Fig. 5. Paleogeographical map of the shaded square area (Late Kimmeridgian, modified from Comment et al. 2011). CH = Switzerland, paleolatitude of Porrentruy = ~ 30°N. Emerged land is outlined, darker grey corresponds to deeper water.~~

Figure 1. Paleogeographical map of the study site and surroundings (Late Kimmeridgian, modified from Comment et al., 2011). CH = Switzerland, paleolatitude of Porrentruy = ~ 30°N. Emerged land is outlined, darker grey corresponds to deeper water.

*Upper left corner:* **present-day geographical position** of Porrentruy (\*) and other European sites (°) of previously published studies and providing geochemical data compared in Fig. 5. **The shaded square delimits the area detailed in the palaeogeographical map.**

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Page 20, figure 2

1) *Referee Comment:*

- The orbital cycles are not mentioned or discussed in the text. Thus, this part of the figure seems to be unnecessary.
- Is there a reference for the used ammonite biozone available?

2) *Author's response:*

- The orbital cycles highlight the transgression of the Upper Kimmeridgian. The transgression is mentioned in the abstract in the 2nd point of the Concluding remarks. We added the reference to the figure at that point.
- Reference for the ammonite zone added in the figure (Comment et al. 2011)

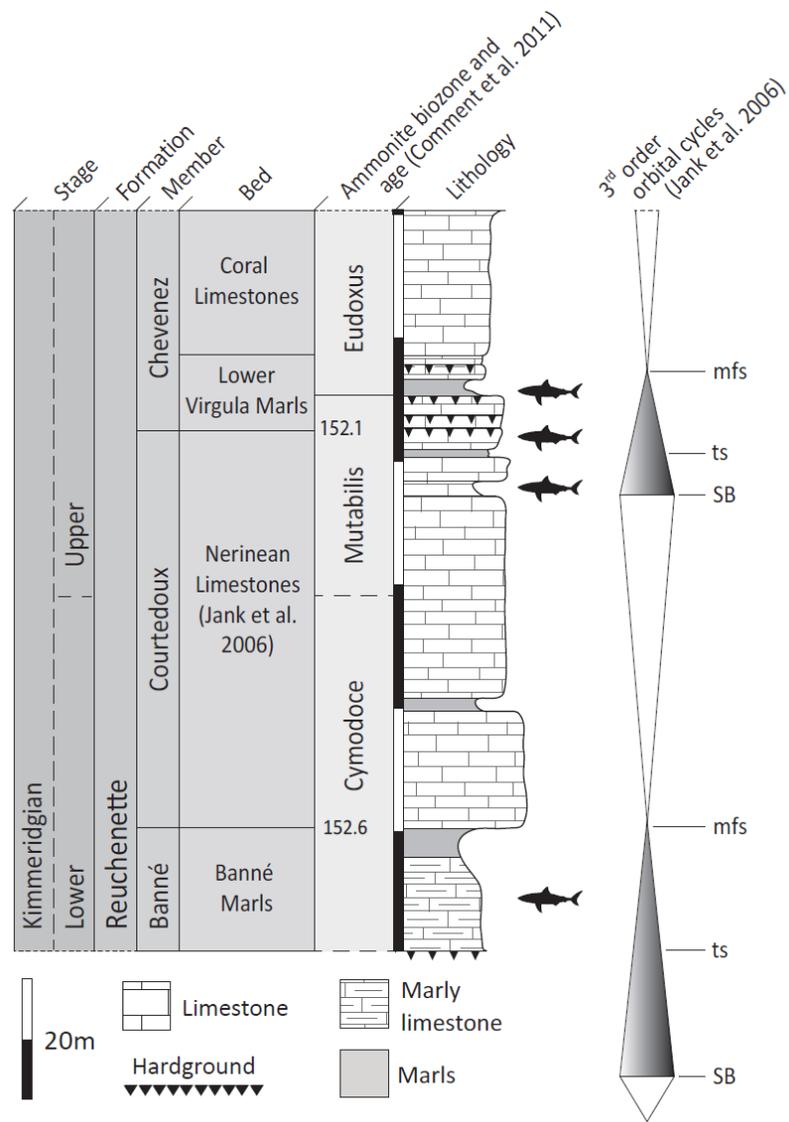
3) *Changes in the text:*

On Page 13, lines 1-4:

~~The Kimmeridgian transgression (i.e. opening of new shallow water niches) and probably competing stress from quickly diversifying neoselachians could have played an important role in the adaptation to brackish and freshwater realms.~~

The Kimmeridgian transgression (i.e. opening of new shallow-water niches) (**see Fig. 2**) and probably competing stress from quickly diversifying neoselachians could have played an important role in the adaptation to brackish and freshwater realms.

Figure change :



Page 21, figure 3

1) Referee Comment:  
... of Porrentury

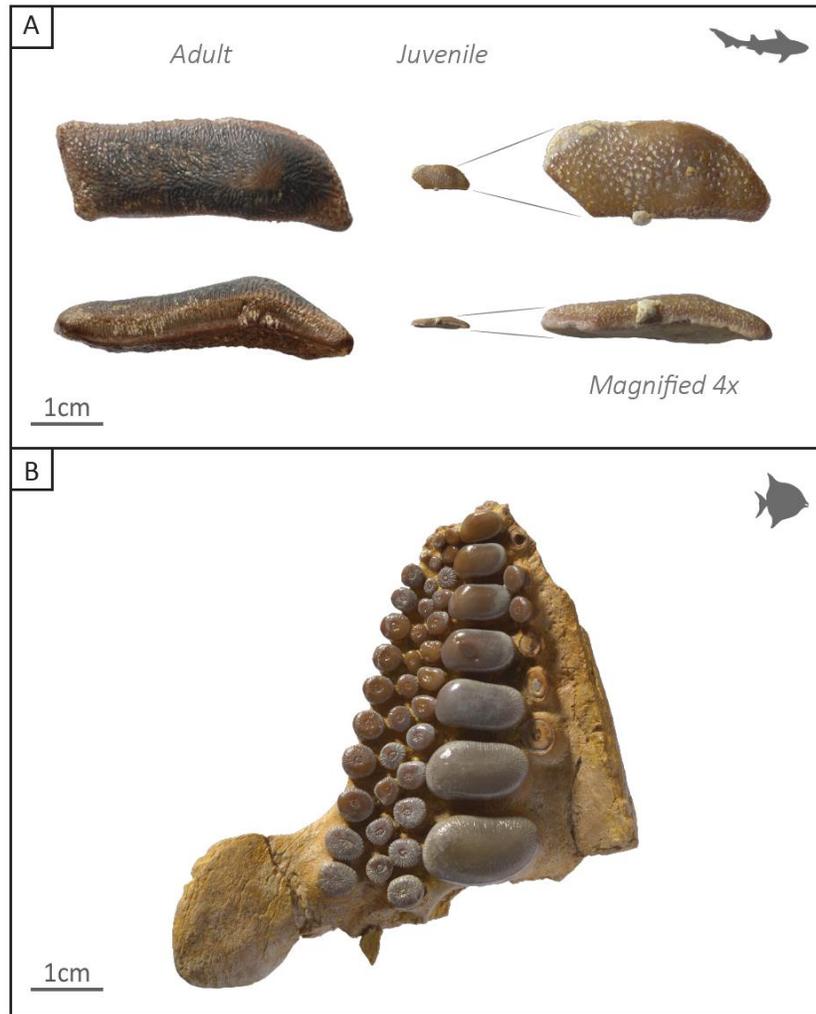
2) Author's response:  
Accepted.

3) Changes in the text:

**Figure 3.** Fossil material from the study site.

Figure 3. Fossil material from the study site of Porrentruy.

Figure change :



Page 22, figure 4

1) Referee Comment:

- The offset is based on what exactly? it appears arbitrary.
- Realistic based on what? Who decides what's realistic values? References or data? So, the offset appears to be arbitrarily

2) Author's response:

- This figure is a graphic representation of the Eq. 1. You are right, the offset is arbitrary, since no attempt is made of defining the water temperature. That's what we meant with "Arrows show **effect** of varying  $\delta^{18}\text{O}_w$ ". The water temperature resulting from Eq. 1 is only used to guide the interpretation, in our case to highlight the fact that the lowest *Asteracanthus* data points require lower  $\delta^{18}\text{O}_w$ , because of the very

high water temperatures they otherwise indicate. If we consider that *Asteracanthus* migrates from marine to less marine waters, all the intermediate are expected.

- We meant "realistic" referring to the maximum temperatures obtained for *Asteracanthus* if you keep the data points at the classical seawater value of -1 per mil. We discuss this point in the paragraph starting on line 5, page 9. Such high water temperatures would require a higher  $\delta^{18}\text{O}_w$  (because of higher evaporation rates) that would in turn rise even more the water temperature.

We agree the legend needs to be reformulated.

### 3) Changes in the text:

Figure 4.  $\delta^{18}\text{O}_p$  values of Porrentruy fish samples and related water temperature (T) resulting from Eq. (1). *Hybodus*, rays, *Ischyodus* as well as most *Asteracanthus* dentine samples are considered diagenetically altered. Arrows show effect of varying  $\delta^{18}\text{O}_w$  in Eq. (1) from classical seawater value (-1 ‰). Realistic and consistent temperatures for *Asteracanthus* and Pycnodontiformes imply the influence of respectively distinct paleoenvironments.

Figure 5. Comparison of  $\delta^{18}\text{O}_p$  values (average, standard deviation, end members) of Pycnodontiformes and *Asteracanthus* enameloid samples from Porrentruy, Solothurn and other European localities through time. The approximate geographical position of previously studied localities (Dromart et al., 2003, Lécuyer et al., 2003, Billon-Bruyat et al., 2005) is shown in Fig. 1. Detailed localities are available in the supplementary material.

Figure change :

