The establishment of high-resolution age models for sedimentary successions is crucial for numerous research questions in the geosciences and related disciplines. Such models provide an absolute chronology that permits accurate dating of depositional episodes and related processes such as mountain uplift or climate change (see Gradstein 2012). Particularly in epicontinental settings, precise age estimates are often compromised by lateral and transverse changes in lithofacies and an absence of marine index fossils. The North Alpine Foreland Basin is a case in point. Here, the lack of continuous outcrops and the scarcity of volcanic ash or bentonites that provide radiometric ages render precise correlation of the sedimentary successions is crucial for numerous research questions in the geosciences and related disciplines. Such models provide an absolute chronology that permits accurate dating of depositional episodes and related processes such as mountain uplift or climate change (see Gradstein 2012). Particularly in epicontinental settings, precise age estimates are often compromised by lateral and transverse changes in lithofacies and an absence of marine index fossils. The North Alpine Foreland Basin is a case in point. Here, the lack of continuous outcrops and the scarcity of volcanic ash or bentonites that provide radiometric ages render precise correlation of the sediments with the Global Time Scale difficult (see Abdul Aziz et al. 2010; Grunert et al. 2013, 2015; Reichenbacher et al. 2013; Roetzel et al. 2014; Pippèr & Reichenbacher 2017; Sant et al. 2017).

The North Alpine Foreland Basin (NAFB) developed during the late Eocene and persisted as an important sedimentary basin of Central Europe until the late Miocene (e.g. Lemcke 1988). It extended from Lake Geneva through Southern Germany to Lower Austria, where it merges with the Carpathian Foredeep. The mainly siliciclastic sediments of the NAFB, usually referred to as ‘Molasse’, derive largely from the Alps. Other important sediment suppliers were the Franconian Platform, composed of Jurassic limestone, and the Bohemian Massif with its granitic rocks (Kuhlemann & Kempf 2002) (Fig. 1). The thickness of the sediments in the NAFB ranges from a few tens of metres in the north to 4000 m close to the Alps (Lemcke 1988).

Analysis of the Sr isotopic composition of fossil biogenic material is a well-established method for age determination. It is based on both the conservative behaviour of the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in the ocean and its long-term trend throughout the Phanerozoic (McArthur et al. 2012). Sr has a long ocean residence time on the order of several million years, which ensures its homogenous distribution in the oceans (Palmer & Edmond 1989). Over the course of the Phanerozoic, the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio in seawater changed as a consequence of fluctuations in weathering intensities resulting from orogenies, climate change (Qing et al. 1998) and increased hydrothermal input during phases of continental break-up (Palmer & Edmond 1989). In addition, variations in salinity levels – in marginal marine environments, for example – can result in local offsets in the $^{87}\text{Sr}/^{86}\text{Sr}$ signal (e.g. Ingram & Sloan 1992, Bryant et al. 1995, Reinhardt et al. 2003).
Age reconstructions based on Sr isotope ratios in the NAFB have relied mainly on fish teeth (Vennemann & Hegner 1998, Vennemann et al. 2001, Kocsis et al. 2009), although the technique has also been applied to ostracods (Janz & Vennemann 2005) and otoliths (Pipperr et al. 2007). The Sr isotope data obtained in these studies are not always easy to interpret because some reveal a significant offset with respect to the global seawater Sr evolution curve due to e.g. diagenetic overprints (Kocsis et al. 2009). In the present work, we asked whether Sr isotope analysis of well-preserved fossil fish otoliths from an epi- to mesopelagic environment in the NAFB could provide less ambiguous age estimates.

**Geological setting**

The NAFB is part of the Western and Central Paratethys domain. For the latter, regional chronostratigraphic stages have been introduced, because the presence of a largely endemic fauna and flora hinders accurate stratigraphic correlation with the Mediterranean area and the Global Time Scale (GTS) (e.g. Cicha et al. 1967, Papp et al. 1973, Steininger et al. 1976). The Burgdalian stage, to which this study refers, corresponds to the chronostratigraphic Central Paratethys stages of the Eggenburgian (except its lowermost part), Ottnangian and Karpatian (Piller et al. 2007).

The fish otoliths studied here were collected from a clay pit near the village of Mitterdorf, about 50 km northeast of Passau in Lower Bavaria, SE Germany (48° 29’ 56.23” N; 13° 16’ 59.99” E) (Fig. 1). The diggings there have exposed an approximately 10-m thick succession of the middle Burdigalian Upper Marine Molasse (Obere Meeresmolasse, OMM) and, more specifically, of the Neuhofen Beds (NH Beds). The NH Beds can be assigned to the lower Ottnangian based on specifically, of the Neuhofen Beds (NH Beds). The NH Beds can be assigned to the lower Ottnangian based on benthic foraminiferal stratigraphy (Wenger 1987, Pipperr 2011) and are up to 220 m thick (Doppler et al. 2005). The sample material originates from the second mining floor of the outcrop, approximately 9 m above its base. Samples were taken from homogenous greyish to greyish-blue marls of the NH Beds with a low sand content.

**Materials and methods**

*Material.* – Otoliths are aragonitic concretions located in the inner ear of teleost fish, where they serve as balance and hearing organs (Popper 1976, Popper et al. 2005). Previous work has revealed that the otoliths of marine fishes reflect the isotopic signal of the surrounding seawater (e.g. Kennedy et al. 2000, 2002; Walther & Thorrold 2006). Here we have used otoliths from the marine genera *Diaphus* (otolith lengths 1.5–2 mm) and *Coelorinchus* (otolith lengths 4–5 mm), which are known to thrive in epi- to mesopelagic environments. *Diaphus* is found at depths corresponding to those of continental shelves and slopes; it remains at 325–475 m during the day, and moves into shallower water (40–250 m) during the night (Hulley 1986). *Coelorinchus* is commonly found in about 200–500 m water depth (Cohen et al. 1990). We therefore assume that a clear open ocean Sr isotopic signal should be preserved in the otoliths of both *Diaphus* and *Coelorinchus*. Besides the otoliths we used bulk samples from the otolith-bearing sediment for Sr isotope analysis.

*Processing of samples.* – Nine well-preserved otoliths of both *Diaphus* and *Coelorinchus* were selected using the light orange colour and shiny gloss of the otoliths as indicators for unaltered material (see Pipperr et al. 2007). To check whether the Sr isotope signal is consistent within the otolith samples, both intact and fragmented otoliths were analysed (Table 1). Three of the otolith samples used (O1, O2, O3) were crushed between two glass slides prior to analysis, and fragments from both the core (O1, O2) and the rim (O3) were separated. Two other otolith samples consisted of complete and structurally intact otoliths (O4, O5). Each otolith sample was transferred to a 1.5-ml centrifuge tube, and samples O1–O4 were subjected to a leaching procedure designed to remove adventitiously associated, mobile Sr that might have overprinted the ambient seawater signal of the otoliths during diagenesis. The leaching procedure was carried out with 200-μl aliquots of 0.25 M acetic acid for a maximum of 20 minutes, replacing the supernatant every 2 minutes. After removal, each supernatant was transferred to a clean Teflon vial and dried on a hotplate with infrared light. The (residual) otolith material remaining after 20 minutes was dissolved in 6 M hydrochloric acid. A total of 20 subsamples were obtained from otolith samples O1–O4 after the individual leaching steps (see Table 1). In addition, the two bulk samples (S1, S2, each c. 200 mg) were leached for 5 minutes with 500 μl acetic acid (0.25 M). All samples were centrifuged, the supernatant was dried down and 50 μl of concentrated nitric acid was added. Then the sample was dried again, and another 50 μl of concentrated nitric acid was added. Sr was further purified on columns filled with 50 μl of Sr-Spec resin (mesh 50–100) following the method of Horwitz et al. (1992) and Bayon et al. (2002).
$^{86}\text{Sr}$ and $^{87}\text{Rb}$. The Sr isotope results were normalized to $^{87}\text{Sr}/^{86}\text{Sr} = 0.710248$ of the NIST SRM 987 standard (Jones et al. 1994), which was also used to derive the long-term reproducibility of the radiogenic Sr isotope measurements ($2\sigma = \pm 11$, $n = 15$) over 2 months.

**Results**

Both crushed and intact samples subjected to leaching yielded isotope ratios that declined from the starting values (up to $^{87}\text{Sr}/^{86}\text{Sr} = 0.70876$) measured in the first supernatant (Table 1). After a leaching time of 20 minutes or less, the residues of the leached otolith samples (O1–O4) showed a consistent $^{87}\text{Sr}/^{86}\text{Sr}$ ratio (0.708645 ± 15) (Fig. 2). The error values were the same for all samples, regardless of taxon (*Diaphus* or *Coelorinchus*) and whether the otoliths were fragmented or complete. Sample O5 (which was not leached) gives an $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.708711, indicating that it retains the mobile Sr phase that was removed during leaching of the other samples (Fig. 2). The leached fraction of the sediments, however, gave much lower radiogenic values ($^{87}\text{Sr}/^{86}\text{Sr} = 0.708612$ and 0.708552 respectively) than the leach fractions and residues of any of the otolith samples (Fig. 2).

**Interpretation of Sr isotopic data**

The efficacy of the leach procedure is revealed by the consistency between the Sr isotopic compositions of the residues of all leached samples (O1–O4) and is supported by the fact that the $^{87}\text{Sr}/^{86}\text{Sr}$ ratio is much more radiogenic in the unleached otolith sample relative to the leached
samples (Fig. 2). Moreover, the residues of all leached samples show Sr isotope signals that are statistically indistinguishable from those extracted from ostracods from the NH Beds at the Neuhofen locality itself (Janz & Vennemann 2005), which is not far from our study site (Fig. 1). This reinforces the reliability of our leaching procedure. Hence we assume that the $^{87}$Sr/$^{86}$Sr ratio of 0.708645 (average of the residues of O1–O4) reflects that of the ambient seawater at the time of deposition of the NH Bed at Mitterdorf. When compared with the recent global Sr seawater curve (LOWESS 5 Fit; McArthur et al. 2012), this Sr isotopic ratio indicates an age of 17.1 ± 0.3 Ma for the NH Beds (Fig. 3).

Several studies have been carried out with a view to optimizing the extraction of radiogenic isotopes (Nd, Sr) from various biogenic materials derived from the North Alpine Foreland Basin (Vennemann & Hegner 1998, Vennemann et al. 2001, Janz & Vennemann 2005, Pipperr et al. 2007, Kocsis et al. 2009) (see Figs 1, 3). Janz & Vennemann (2005) analysed the Sr isotopic composition of ostracods from two locations (Maierhof and Neuhofen) not far from Mitterdorf, the site studied here (see Fig. 1). The OMM deposits at Neuhofen belong to the NH Beds, but are slightly older than the NH Beds at Mitterdorf (Piller et al. 2007) (Fig. 3). The OMM deposits at Neuhofer belong to the NH Beds, but are slightly older than the NH Beds at Mitterdorf (Pipperr et al.

### Table 1. Sr isotopic composition of the leached otoliths from Mitterdorf.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Leach time (min)</th>
<th>$^{87}$Sr/$^{86}$Sr</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>O1 (Diaphus sp.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>2</td>
<td>0.708670 ± 16</td>
<td>Inner fragments of two crushed otoliths</td>
</tr>
<tr>
<td>Leachate</td>
<td>6</td>
<td>0.708641 ± 14</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>10</td>
<td>0.708642 ± 19</td>
<td>Sample was completely dissolved after 10 min</td>
</tr>
<tr>
<td>O2 (Coelorinchus sp.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>2</td>
<td>0.708745 ± 14</td>
<td>Inner fragments of one crushed otolith</td>
</tr>
<tr>
<td>Leachate</td>
<td>6</td>
<td>0.708708 ± 12</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>10</td>
<td>0.708677 ± 12</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>14</td>
<td>0.708678 ± 13</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td>0.708645 ± 12</td>
<td></td>
</tr>
<tr>
<td>O3 (Diaphus sp.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>4</td>
<td>0.708680 ± 17</td>
<td>Rim fragments of two crushed otoliths</td>
</tr>
<tr>
<td>Leachate</td>
<td>6</td>
<td>0.708663 ± 17</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>8</td>
<td>0.708659 ± 19</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>10</td>
<td>0.708653 ± 14</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>12</td>
<td>0.708646 ± 19</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td>0.708639 ± 16</td>
<td></td>
</tr>
<tr>
<td>O4 (Diaphus sp.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>2</td>
<td>0.708764 ± 17</td>
<td>Two uncrushed otoliths</td>
</tr>
<tr>
<td>Leachate</td>
<td>4</td>
<td>0.708748 ± 33</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>8</td>
<td>0.708670 ± 15</td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>12</td>
<td>0.708668 ± 17</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td>0.708648 ± 22</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td>0.708651 ± 10</td>
<td>duplicate</td>
</tr>
<tr>
<td>O5 (Diaphus sp.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td></td>
<td>0.708711 ± 16</td>
<td>Two uncrushed otoliths, not leached</td>
</tr>
<tr>
<td>S1 Sediment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leachate</td>
<td>5</td>
<td>0.708612 ± 13</td>
<td></td>
</tr>
<tr>
<td>S2 Sediment</td>
<td></td>
<td>0.708552 ± 13</td>
<td>10 m below S1, equal to O4</td>
</tr>
</tbody>
</table>

### Discussion

Previous work on $^{87}$Sr/$^{86}$Sr signals from the Upper Marine Molasse (OMM)

Several studies have been carried out with a view to optimizing the extraction of radiogenic isotopes (Nd, Sr) from various biogenic materials derived from the North Alpine Foreland Basin (Vennemann & Hegner 1998, Vennemann et al. 2001, Janz & Vennemann 2005, Pipperr et al. 2007, Kocsis et al. 2009) (see Figs 1, 3). Janz & Vennemann (2005) analysed the Sr isotopic composition of ostracods from two locations (Maierhof and Neuhofer) not far from Mitterdorf, the site studied here (see Fig. 1). The OMM succession exposed at Maierhof corresponds to the middle Eggenburgian ‘Ortenburger Sande’ (see Witt 1967, Hagn et al. 1981, Pipperr & Reichenbacher 2009). The ostracod Cytheridea eggenburgensis from Maierhof provided an $^{87}$Sr/$^{86}$Sr ratio of 0.708498 ± 9 (Janz & Vennemann 2005). This yields an estimated age of 19 Ma based on the most recent global Sr seawater curve (LOWESS 5 Fit) (McArthur et al. 2012), which is compatible with the assumed age of the middle Eggenburgian (Piller et al. 2007) (Fig. 3). The OMM deposits at Neuhofer belong to the NH Beds, but are slightly older than the NH Beds at Mitterdorf (Pipperr et al.
The ostracod *Cytheridea ottnangensis* from Neuhofern yielded an \(^{87}\text{Sr}/^{86}\text{Sr}\) value of 0.708624 ± 10 (Janz & Vennemann 2005), which is consistent with the values in the present work (O1–O4, 0.708645 ± 15). In light of previous biostratigraphic work, which dated the NH Beds to the lower Ottnangian (c. 18 Ma) (Witt 1967, Hagn et al. 1981, Wenger 1987, Pipperr 2011), the corresponding age of 17.1 ± 0.3 Ma indicated both by the results of our study and the aforementioned ostracod *C. ottnangensis*, appears to be at least 0.6 m.y. too young.

On the other hand, magnetostratigraphic evidence also suggests that previous biostratigraphic age estimates for the Ottnangian strata in the Molasse Basin of S Germany might be too high (Reichenbacher et al. 2013, Sant et al. 2017). According to these studies, the Kirchberg Formation, previously assumed to be upper Ottnangian in age and thus 17.2–17.4 Ma old, can now be correlated with the lower Karpatian, i.e. with the interval 16.7–17.2 Ma (Reichenbacher et al. 2013, Pipperr & Reichenbacher 2017, Sant et al. 2017 – age model 2) or the middle Karpatian, i.e. 16.4–16.5 Ma (Sant et al. 2017 – age model 1). This makes the allegedly ‘upper Ottnangian’ strata of the Kirchberg Fm 0.5 m.y. or even 0.8 m.y. younger than hitherto estimated. However, it is not yet clear whether the new age models affect previous age correlations for other Ottnangian strata. It has long been known that the middle and lower Ottnangian beds are separated by a hiatus from the younger strata, and this break in deposition may simply have lasted longer than has been suggested up to now (see Reichenbacher et al. 2013, Sant et al. 2017). As a result, one must also consider environmental factors that might possibly have biased the \(^{87}\text{Sr}/^{86}\text{Sr}\) signature obtained from the otolith samples studied here.

Deviation of the \(^{87}\text{Sr}/^{86}\text{Sr}\) signal owing to local inputs?

Several factors can alter the Sr isotopic composition of ambient seawater. Among the most prominent are strong terrestrial and/or riverine run-off, which might well have affected the study area in SE Germany or indeed the whole of the Paratethys (see also Vennemann & Hegner 1998, Kocsis et al. 2009). Thus, run-off and sediment input from the crystalline rocks of the Bohemian Massif or the Black Forest (see Pawellek et al. 2001) could have shifted the primary signal of Upper Marine Molasse seawater to more radiogenic values (Fig. 3). The opposite effect, i.e. a reduction in the magnitude of the ambient \(^{87}\text{Sr}/^{86}\text{Sr}\) ocean signal, could have occurred when drainage areas were

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**Figure 2.** Effect of leaching time on the \(^{87}\text{Sr}/^{86}\text{Sr}\) signal (light green shaded area) obtained from inner otolith fragments (yellow/orange diamonds), rim fragments of otoliths (lavender triangles) and the intact otolith sample (light blue circle). The dark blue circle illustrates the intact and untreated otolith sample O5. The hatched area marks the \(^{87}\text{Sr}/^{86}\text{Sr}\) isotopic composition of the ambient seawater extracted from the otoliths after completion of the 20-minute leaching procedure.
largely composed of limestones (such as the Mesozoic carbonates of the Alps or the Franconian Platform).

Mitterdorf is located very close to the coastal cliffs of the Bohemian Massif, which consist of Precambrian or Paleozoic granitic rocks with high $^{87}$Sr/$^{86}$Sr values (e.g. Liew & Hofmann 1988) (Fig. 1). Indeed, a direct influence of the Bohemian Massif has been documented for several localities close to Mitterdorf. Wenger (1987) showed that in Anderl, 8 km east of Mitterdorf, marine sands of the OMM are deposited directly on granites from the Bohemian Massif. He also described a granitic basement for the OMM at Oberschwäbenbach (5 km south of Mitterdorf) and Neustift (12 km northwest of Mitterdorf). Frieling et al. (2009) (Fig. 1). Today, 52% of the Naab’s catchment area consists of igneous rocks (Fichtelgebirge, Oberpfälzer Wald, i.e. Bohemian Massif), while 41% is made up of the carbonates of the Jurassic Franconian Platform, and its waters now have a $^{87}$Sr/$^{86}$Sr ratio of 0.7144 (Pawellek et al. 2001). The rivers Regen and Ilz drain an area whose sub-stratum is almost entirely igneous in character (94 and 98%, respectively), and is largely derived from the Bohemian Massif (Fig. 1). This results in a shift towards relatively high Sr isotopic ratios ($^{87}$Sr/$^{86}$Sr = 0.7147 and 0.7141, respectively according to Pawellek et al. 2001) in the river water.

Due to the very low Sr concentration in river water (0.5–0.65 μmol/L, see Pawellek et al. 2001) compared to open marine Sr concentrations, an immense volume of river water would have been necessary to alter the primary Sr isotope signature of the Palaeo-Naab (Lemcke 1985, Kuhlemann & Kempf 2002, Pippèr & Reichenbacher 2010) (Fig. 1). Today, 52% of the Naab’s catchment area consists of igneous rocks (Fichtelgebirge, Oberpfälzer Wald, i.e. Bohemian Massif), while 41% is made up of the carbonates of the Jurassic Franconian Platform, and its waters now have a $^{87}$Sr/$^{86}$Sr ratio of 0.7144 (Pawellek et al. 2001). The rivers Regen and Ilz drain an area whose sub-stratum is almost entirely igneous in character (94 and 98%, respectively), and is largely derived from the Bohemian Massif (Fig. 1). This results in a shift towards relatively high Sr isotopic ratios ($^{87}$Sr/$^{86}$Sr = 0.7147 and 0.7141, respectively according to Pawellek et al. 2001) in the river water.

Comparison with previous Sr isotope data for the North Alpine Foreland Basin (NAFB)

A single study has previously investigated Sr isotopes derived from the fossil otoliths of marine fishes from sediments in the NAFB (Pippèr et al. 2007). That otolith sample originated from the middle Ottnangian OMM of the Simsee area in the central Molasse Basin (Fig. 1). The mean $^{87}$Sr/$^{86}$Sr ratio obtained was 0.708606 ± 0.000018, which indicates an age of 17.8 ± 0.3 Ma based on the global Sr curve of Howarth & McArthur (2003) (see Pippèr et al. 2007) and on the latest version published by McArthur et al. (2012) (Fig. 3). Moreover, this age estimate also argues in favour of the assumption that the Sr isotope values in the present work are ‘too young’, because the Neuhofen Beds are lower Ottnangian and thus should be older than 17.8 ± 0.3 Ma. Consequently, one can conclude that, in principle, otoliths as well as ostracods provide reliable records of the Sr isotopic composition of the ambient seawater for age determination, provided that relevant aspects of the local and regional geological setting are taken into consideration.

Analyses of phosphatic fossils like shark teeth (Vennemann & Hegner 1998, Kocsis et al. 2009) have all yielded more radiogenic Sr ratios than expected for the corresponding ages when compared with the recent global Sr seawater curve (LOWESS 5 Fit) (McArthur et al. 2012) (Fig. 3). Kocsis et al. (2009) explained this offset, as discussed above, by invoking an erosional influence from crystalline rocks (e.g. Bohemian Massif or Black Forest), but in this context they also cite diagenetic overprinting and the poor preservation of the phosphatic material. Shark teeth from the OMM at Äpfingen (middle Ottnangian) produced Sr isotope ages of 16.8 ± 1 Ma on comparison with the Sr isotope evolution curve for the ocean after DePaolo (1986) (see Vennemann & Hegner 1998). However, when the Sr signature from Äpfingen is compared with the recent global Sr evolution seawater curve (LOWESS 5 Fit) of McArthur et al. (2012), the derived age is about 14 Ma (Fig. 3), which is much too young for the middle Ottnangian. Besides possible overprints due to diagenesis, multiple reworking of these phosphatic fossils could bias Sr age data from samples of shark teeth. Consequently, for the lower Miocene Upper Marine Molasse sediments in the S German Molasse Basin and Western and Central Paratethys, respectively, aragonitic or calcitic materials...
such as otoliths, ostracods or foraminifera (Pippér et al. 2007, Janz & Vennemann 2005) would seem to provide much more reliable Sr-based age estimates than phosphatic fossils (Vennemann & Hegner 1998, Kocsis et al. 2009). This assumption is additionally reinforced by a recent study on Sr isotopes from three fossil otoliths of middle Miocene age (Brzobohatý et al. 2016).

**Summary and conclusion**

We have analysed different fractions of otoliths from two fossil marine fish taxa (*Diaphus* and *Coelorinchus*) from the middle Burdigalian (lower Ottnangian) Neuhofen Beds at Mitterdorf. The study site is located in the SE German Molasse Basin, *i.e.* the westernmost Central Paratethys. For the first time, a leaching procedure was used to remove a mobile (non-primary) $^{87}$Sr/$^{86}$Sr phase from the samples prior to Sr isotope analysis and age interpretation. Comparison of the Sr isotopic signatures from leached and not-leached otoliths strongly indicates that the leaching procedure is essential for the extraction of a valid ambient $^{87}$Sr/$^{86}$Sr seawater signal from such fossils.

The otoliths from the Neuhofen Beds exhibited an $^{87}$Sr/$^{86}$Sr ratio which, according to the global Sr evolution seawater curve (LOWESS 5 Fit) of McArthur et al. (2012), indicates an age of 17.1 ± 0.3 Ma. However, this age is at least 0.6 Ma too young when compared to previous age estimates based on biostratigraphic data. A possible reason for this apparent discrepancy is strong riverine or terrestrial run-off from the granitic rocks of the Bohemian Massif during the relevant interval, as has been suggested in previous work based on foraminiferal palaeoecology. This strong freshwater inflow would have delivered material
from the granitic hinterland, thus shifting the Sr signature of the Molasse or Central Paratethys Sea towards more radiogenic (and thus ‘too young’) $^{87}\text{Sr}/^{86}\text{Sr}$ values.

Comparisons with previous studies of shark teeth, ostracods and otoliths from the S German Molasse Basin confirm that otoliths and ostracods constitute useful sources of Sr isotope data for age determination of marine successions, whereas shark teeth are less appropriate, possibly due to diagenetic overprint and multiple reworking. However, otoliths and ostracods used for age analysis must be carefully selected from marine settings without terrestrial or riverine influences.

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We thank Jürgen Pollerspöck (Stephansposching, Germany) for providing the studied otolith samples, Florian Weitzel (Munich) for his help in otolith selection, and Martina Pippér (LMU Munich) for fruitful discussions and valuable support concerning the biostratigraphy of the Mitterdorf site. We also acknowledge Ernst Hegner (LMU Munich) for providing the facilities for the Sr isotope analyses as well as Laszlo Kocsis (Universiti Brunei Darussalam) for constructive discussions.

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