Rebuttal (responses in italics)

Reviewer R. Sparkes

Warden and colleagues have applied a modern, novel technique for analysing branched GDGTs to an existing sample set, the Tagus River, Spain, which had previously been analysed using a more simplistic GDGT protocol. The new isomer-sensitive approach has the potential to improve the use of brGDGTs as molecular biomarkers, and therefore it is a worthwhile endeavour to perform this sort of repeat analysis. The methods used are novel and appropriate, and their explanation in the text is excellent. The study is a useful addition to the emerging literature on isomerised brGDGTs and I think that it should be published following revisions.

We appreciate the positive assessment of the referee and thank him for the positive criticism of our manuscript. Below we explain how we will respond to these comments.

1) More information on the nature of the sediments used in this study would be useful. The conclusions reached are often dependent on the nature of the sedimentary material, yet there is little in the text or supplementary information to convey this information. I would suggest a supplementary table of sedimentary properties and/or a core description or core photograph and comments on the uniformity or bioturbation of the samples.

We see how this additional information on the nature of the sediments for the cores from this study could be helpful. In the supplemental of the revised manuscript we will include this additional information such as core photographs and core descriptions when possible and a reference to the core description in the case that it has already been previously published.

2) Line 573 talks about the correlation between BIT and ^{13}C, and claims a moderate negative correlation. I feel that this correlation may be overstated. While it would be expected that ^{13}C and BIT show similar trends, their relationship is not necessarily linear (see for example Sparkes et al., 2015, Biogeosciences). The offshore core samples all have very low BIT values, yet have outliers with very negative ^{13}C values. The terrestrial core and soil/sediment/SPM samples have significantly higher BIT values, but overlapping ^{13}C values. If the terrestrial samples are looked at on their own they have very poor/no correlation between the two measurements - within the terrestrial samples, $r^2 = 0.02$. Within the offshore samples (mudbelt + canyon head + canyon) $r^2 = 0.1$, and so what the graph is actually showing is that terrestrial and marine are different, but an r^2 value is not showing much about the nature of that difference. I do not feel that this correlation plot adds any value to the argument, and if it is included for reference/information then perhaps the authors should comment on why the two measurements, which should correlate quite well, are actually a poor match.

We agree with the reviewer that there is a poor correlation between the BIT index and the $\delta^{13}C$ values for the individual datasets. Therefore, in the revised manuscript we will remove that figure and the corresponding sentence description in the text since as the reviewer pointed out and we agree that it does not add much value to our arguments.

3) Line 586 assumes that soil-derived brGDGTs from across the catchment are delivered through the river to the marine sediments. This is quite an assumption, since there is the potential for both deposition and degradation in the river and coastal systems, even before the river was dammed in the 20th Century. There is also the question of connectivity between the river and canyon. River outflows contain freshwater, which is buoyant above salty seawater. Unless the sediment load in the river is particularly high, the sediment will disperse as a plume above the seawater rather than running down the canyon itself. Therefore the majority of the brGDGTs delivered from the river will be spread over the shelf rather than following the canyon down to 4000m. Do the authors know the phase/grainsize in which brGDGTs are travelling? Are they associated with larger grains, that would deposit quickly beside the river mouth, or fine grains that will disperse across the ocean? In the conclusion the authors state that most terrestrial material is not making it out the the ocean, and therefore palaeotemperature reconstructions will be difficult with datasets such as this one. I agree.

*The referee questions whether soil-derived brGDGTs from across the catchment are delivered through the river to the marine sediments and rightly so. However, we do not see the problem here because this was actually one of our main research questions that was tested in this study (see introduction). Previous studies that have been performed on this system have shown that little terrestrial material makes it down the canyon from the river (e.g. Jouanneau et al., 1998; de Stigter et al., 2011; Vis et al., in press) and most of the terrestrial material is being trapped inside the estuary even though the outflow from the Tagus River does form a plume that dominates the continental shelf (*Jouanneau et al., 1998). *Our results for the brGDGTs in Holocene sediments confirm this.*

For this study we did not look at grainsize of the particulate matter by which the brGDGTs are traveling from the continent to the open ocean. Although that would be an interesting topic of study, it is not one we pursued since as stated in the study, even if the terrestrial material were making it out to the canyon sediments, in-situ production in the river and marine systems is complicating the use of brGDGTs for MAT estimates in this region as is the fact that brGDGTs cannot be used for accurate MAT estimates even on the soils from the region. In marine sediments where brGDGTs would reflect the distribution of the soils in the watershed of the river the dependence of particle size on brGDGT distribution would certainly be an interesting line of research.

4) Line 517 concludes that in-situ production is a problem for all sample sets. This could have profound implications for all brGDGT based proxies. The authors should expand on this point.

We agree with the referee that this has profound implications for the brGDGT based proxies in this system as well as others where it has been shown that in-situ production is an issue. We believe, however, we have made this clear as we mention it several times throughout the manuscript;

Lines 556-561 However, even though the sum of the brGDGTs are lower in the marine sediment than in the Tagus River Floodplain sediments, the amount of brGDGTs in all four sediment cores are higher than in the Tagus soils (~6.8±6.5 μg gOC-1) indicating the origin of the brGDGTs in

the sediment cores are not all soil derived and pointing instead to riverine in-situ production as well as possibly in aquatic sediments (Fig.3b).

Lines 626-628 Additionally, we confirm the findings of Zell et al. (2014; 2015) that in-situ production of brGDGTs is occurring in the river and marine systems of the Tagus River basin and go on to show that there are indications that it occurred in the past as well.

Lines 650-653 Because of these unique features in this region, perhaps the development of a local calibration could assuage difficulties in using brGDGTs as a paleoclimate proxy for soils in the Tagus River basin. This would not, however, solve the issue of in-situ produced brGDGTs overwhelming the amount of soil derived brGDGTs in aquatic sediments.

Minor comments / typographical errors:

Line 232 – column
Line 288 – Section numbering error
Line 344 – Figure 4c should be 5c
Line 360 – BIT is given as 0.1 0.0. Would increasing the significant figures be helpful here?
Line 478 – Do the authors have p and n values for this correlation?
Not a p value but n value, it is for the entire data set so n=109.
Table 3 sample Lisbon Canyon Head 1cm has a ^{13}C value of 22.9, should be -22.9

We thank the reviewer for pointing these out and these minor things will all be fixed in the revised version.

Reviewer #2

A central goal of organic geochemistry is to utilize molecular-scale information to derive insight of major system properties. Such trace biomarkers have contributed improved knowledge on several aspects of past climate. The current ms explores how well different sets of branched GDGTs can inform on system variables such as MAT and pH in an Iberian land-ocean system. Using state-of-the-art analytical techniques and recent re-definitions of the proxies, they carefully assess and finds that the brGDGTs are not reliable in deriving e.g. past temperature records, at least not for this setting. However, the findings may have broader repercussions for this particular biomarker proxy. While this is an overall "negative" result, this is important for science, and for the credibility of organic geochemistry. The authors earn compliments for this effort. The paper is overall well structured and well written, yet I provide some suggestions below for their further consideration during revisions. My central recommendations are that the ms much more clearly articulate (i) the limitations of the brGDGT proxy for temperature (incl in title and abstract), and (ii) that the plethora of (abbreviated) biomarker indices are much better overviewed and explained (a Table would help). These changes would aid in making an ms like this one accessible and considered by geoscientists beyond biomarker experts.

We appreciate the encouraging response and positive assessment from the referee and thank the referee for the constructive criticism of our manuscript. Below we explain how we will respond to the comments and concerns brought up in the review.

1) **More clearly communicate the finding that brGDGTs are not reliable as a temp recorders in this and possibly other settings** The study does a heroic job in testing the proxy and assessing also why it may not work. They find that a combination of diverse terrestrial source systems, production along the transport route, dilution, as well possibly non-conservative transport of the brGDGTs fingerprint prevents application of these biomarkers for the originally intended application. This is an important finding and ought to be clear to any reader from the abstract and ideally also reflected in the title – this is the major contribution of the paper.

We thank the reviewer for the kind words and agree that these findings could be made clearer in the title and so we will change the title to "Examining the provenance of branched GDGTs in the Tagus River drainage basin and its outflow in the Atlantic Ocean over the Holocene to determine their usefulness for paleoclimate applications".

2) **Clarify the meaning of various org geochem tracers and terms** To leverage impact of studies like this one, it would help to keep a broader audience in mind and explain the different tracers in an accessible way. Terms like DC', IR, BIT; MBT, MBT', MBTx, CBT' etc is confusing to the vast majority of geoscientists, who then may stop reading/considering the study. Perhaps a table listing discussed biomarker proxies, possibly with columns/headings such as biomarker ratio, proxy for, end-member values, would help.

We agree with the reviewer that it would be useful to have a table to refer to the terminology specific to this field as well as helpful for readers from other fields to refer to and so in the revisited manuscript we will include a table with the terms, their abbreviation, and a brief description that can include end-member values.

3) **Title** Should reflect the testing/evaluation aspect of the study, and possibly that it is a "revisit" to brGDGTs in the Tagus system.

See our response to comment #1.

4) **Statistics** The standard approach, to calc mean and std dev may not always be the best to reflect properties such as distribution of concentrations of a population. It frequently results in a 1 s.d. nearly spanning into negative concentrations (and 2 sd stretching into such unphysical space). See e.g. p. 11. Consider instead to report conc distributions with IQR or 95% CI around the mean (or median).

We understand the point the reviewer is making about how the standard deviation is not always the best method for showing the distribution of concentrations and appreciate their suggestion for reporting IQR or CI instead. We do think, however, standard deviation is okay to report in this case and want to be consistent with how values were reported in many other studies of

GDGTs. In the future we might consider reporting IQR since, as the reviewer pointed out, in some situations it can be more appropriate than standard deviation.

5) **Section numbering** Need to be corrected. Both "Introduction" and "Study Area" is labelled "1". On page 11, Results start as "3" but then the first Results sub-header is 4.1….

We thank the reviewer for pointing this out; it will be fixed in the revised version.

6) **Removing carbonates for d13C-OC** Methods involving rinsing run the risk of losing some organic molecules that are solubilized in the acidic aquatic solution. Please provide test demonstrating minimal loss.

Although we agree with the reviewer that there is the risk of losing some of the organic molecules that are solubilized in the aquatic solution, this can only have a significant effect when the loss of organic matter during carbonate dissolution is large and they are isotopically distinct from the remaining organic matter. For Holocene marine sedimentary organic matter this is highly unlikely and in cases where similar measurements have been compared using both off-line and "in-cup" removal of carbonate differences in δ^{13}C-OC were minimal and will certainly not be larger than 0.2 permille. For our purposes (discrimination between marine and terrestrial OC) this is irrelevant. Therefore, we feel a test demonstrating minimal loss is not necessary.

7) **Resolution of reported data in Holocene cores** Lines 245-247 indicates that data was averaged for sediments covering 0-6kyr. It seems that a lot of temporal information is lost this way. Please provide at least in Supp Info and discuss.

We agree with the reviewer that by averaging the values over 6,000 years temporal information is lost, however, we believe this was the best way to compare the four records in this study. Furthermore, the temporal changes are relatively small. The individual values corresponding to the sediment depth and age can be found in Table 3.

8) **Values of proxies relative to end members** Line 293 states that "The BIT index is fairly high…". This is one example of where it would be really useful to readers to learn what the end-member values are to be able to make judgments and appreciate the biomarker results.

Please see our response to comment #2. Additionally, a sentence describing the end members and what the values mean will be included in the revised manuscript.

9) **Language** The paper is overall well written. Two aspects that can be improved throughout is (i) straight word order, and (ii) honing of topic sentence. Line 348 is a good example where improvements can be made.

We will carefully read over the manuscript again specifically concentrating on these two suggestions of improvement.

10) **Figure 1** The right hand legend is too small (even for figure placed in full page format). Furthermore, the meaning of the text at bottom right is not clear.

We thank the reviewer for pointing that out and in the revised manuscript the figure legend will be made bigger and the meaning of the text in the bottom right will be made clearer.

Changes made to Warden et al., 2016

1. In the supplemental of the revised manuscript sediment core descriptions were included.
2. In the revised manuscript figure 10 is removed and the corresponding sentence description in the text is removed as well.
3. Typo fixed in line 232
4. Section numbering error fixed in line 288
5. Figure 4c changed to 5c in line 544
6. Increased significant figures for reported BIT index in line 360.
7. In line 478 reported p and n values for the correlation.
8. In Table 3 sample Lisbon Canyon Head 1cm changed 13C value of 22.9 to -22.9.
9. Added a table into the supplementary, Table S1,that reports index abbreviations used in the text as well as a brief description, the definition of the index, end member values as well as what the values indicate, and references.
10. Changed the title to: *Examining the provenance of branched GDGTs in the Tagus River drainage basin and its outflow in the Atlantic Ocean over the Holocene to determine their usefulness for paleoclimate applications*
11. Section numbering errors were fixed.
12. Added a sentence describing the end members for the BIT index and what the values mean in the revised manuscript (lines 269-271).
13. In the revised manuscript the figure legend for Fig. 1 was made bigger and the meaning of the text in the bottom right was made clearer.
14. Added a table to the supplementary, S2, that reports the fractional abundance of the brGDGTs (%) for all samples used in this study.

~~P~~Examining the provenance of branched GDGTs in the Tagus River drainage basin and its outflow in the Atlantic Ocean over the Holocene to determine their usefulness for paleoclimate applications ~~rovenance of branched GDGTs in the Tagus River drainage basin and its outflow in the Atlantic Ocean over the Holocene~~

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Keywords: Tagus River basin, Holocene, temperature reconstructions, branched glycerol dialkyl glycerol tetraethers, paleoclimate

Abstract

The distributions of branched glycerol dialkyl glycerol tetraethers (brGDGTs), which are transported from the soils where they are predominantly produced to marine sediments via rivers, have been applied in reconstructing mean annual air temperatures (MAT) and pH of soils. However, paleoclimate reconstructions using sedimentary brGDGTs have proven difficult in arid regions including the Iberian Peninsula. Recently, six novel 6-methyl brGDGTs have been described using new analytical methods (in addition to the nine 5-methyl brGDGTs previously used for climate reconstructions), and so new pH and MAT calibrations have been developed that in a set of global soil samples were shown to improve the accuracy of reconstructions, especially in arid regions. Because of this we decided to apply the new method to separate the 5- and 6-methyl isomers along with the novel calibrations to a sample set that runs in a transect from source to sink along the Tagus River and out to the deep ocean off the Portuguese margin and spans the last 6,000 years in order to determine if it improves paleoclimate reconstructions in this area. We found that although pH reconstructions in the soils were improved using the new calibration, MAT reconstructions were not much better even with the separation of the 5- and 6-methyl brGDGTs. This confirmed the conclusion of previous studies that the amount of aquatically produced brGDGTs is overwhelming the soil derived ones in marine sediments and complicating MAT reconstructions in the region. Additionally, the new separation revealed a strong relationship between the new degree of cyclization (DC') of the brGDGTs and MAT not seen before that could be making temperature reconstructions in this and other arid regions difficult.

1. Introduction

Understanding past climate variability is important for predicting future climate change as well as how ecosystems, organisms and human society could be affected. The validation of climate proxies is imperative for the correct interpretation of climate archives and therefore also for the climate models building on these past climate data. Terrestrial environments play an important role in global climate, however, continental climate reconstructions are hindered by the lack of continental temperature proxies. In the future, changes in terrestrial climate are likely to have a large impact on human society just as they had in the past (e.g. Haug et al., 2003). Availability of trustworthy temperature data from the terrestrial environment will be essential for the development of reliable climate models.

The distribution of branched glycerol dialkyl glycerol tetraethers (brGDGTs, Fig. S1), a group of membrane-spanning lipids that occur in heterotrophic bacteria (Pancost and Sinninghe Damsté, 2003; Weijers et al., 2010) pervasive in peat (Weijers et al., 2006) and worldwide in soils has proven useful as a tool to obtain high resolution, continental temperature reconstructions (Weijers et al., 2007a; Schouten et al., 2008; Bendle et al., 2010). BrGDGTs are biosynthesized by bacteria (Sinninghe Damsté et al., 2011; 2014) living in soils and the distribution of brGDGTs in soils is affected by growth temperature and pH (Weijers et al., 2006). More specifically, the degree of methylation of the brGDGTs (expressed as methylation of branched tetraethers index, MBT; see Table S1 for a detailed explanation of all GDGT indices used in this study) relates to mean annual air temperature (MAT), and to a lesser extent soil pH, whereas the degree of cyclization (DC) of the brGDGTs (also expressed as the cyclization of branched tetraethers index, CBT) correlates solely with soil pH (Weijers et al., 2007a). MBT has recently been amended to become MBT' by eliminating the brGDGTs that rarely occur in soils (Peterse et al., 2012). These observations led to the development of a continental paleoclimate proxy based on the distribution of brGDGTs that

has been applied in paleosoils (Peterse et al., 2009; Weijers et al., 2007a; 2011). Branched GDGTs that are produced in soils are washed by runoff into streams and rivers where they are transported to and deposited in river sediment and in coastal marine sediment that are under the influence of major river systems. In this way, brGDGTs have been used as recorders of the continental paleoclimate (Weijers et al., 2007b; Bendle et al., 2010; Hren et al., 2010; Keating-Bitonti et al., 2011).

Complications using brGDGTs as a proxy for MAT have arisen in some settings. In marine sediments receiving a low input of soil organic matter (OM), it was found that the distribution of brGDGTs and the reconstructed temperatures were quite different from that observed in regional soils (Peterse et al., 2009). Peterse et al. (2012) found in arid regions temperature is no longer an important control on the distribution of brGDGTs and therefore MAT reconstructions in these areas should be interpreted with care. In the Iberian Peninsula, Menges et al. (~~2013~~2014) found that MBT' was not correlated to MAT but instead correlated with the aridity index (AI), a parameter for water availability in soils, and mean annual precipitation (MAP). In drainage basins with varying soil sources that had different MATs (i.e. mountainous vs. lowland), it was found that the provenance of the soil matter must be considered when interpreting MAT reconstructions (Bendle et al., 2010). In-situ production of brGDGTs can occur within the river systems (Yang et al., 2012; Zell et al., 2013, De Jonge et al., 2014b) and cause brGDGT distributions and MAT reconstructions that differ from those in the soils of the source area. These complications make it vital to investigate how varying environmental conditions, the transport of these terrestrially derived fossilized lipids, and in-situ production affect the implementation of brGDGTs for paleoclimate reconstructions.

Recently a set of six new brGDGT isomers that differ in the position of the methyl groups were identified and described (De Jonge et al., 2013). The relative abundance of these novel, 6-methyl brGDGTs are strongly dependent on pH and so by excluding them from the

MBT' index (newly defined as MBT'_{5ME}) the correlation with MAT is improved (De Jonge et al., 2014a). The CBT index was also redefined in this study, as CBT', to include all of the pH dependent 6-methyl brGDGTs and consequently yielded a higher correlation with soil pH as a result (De Jonge et al., 2014a). De Jonge et al. (2014a) also developed, based on a dataset of globally distributed soils, a new pH calibration taking into account the new CBT' as well as new MAT calibrations, defined as MAT_{mr} and MAT_{mrs}. In a global soil set they were shown to improve the accuracy of reconstructions, especially in arid regions. These indices and calibrations were applied in a coastal sediment core in the Northern Kara Sea off Siberia in a study emphasizing the importance of examining the provenance of brGDGTs when using these lipids for paleoclimate reconstructions (De Jonge et al., 2015).

A comprehensive study has been previously performed on the present day transport of brGDGTs in the Tagus River basin from source to sink (Zell et al., 2014). The results from this study demonstrated that the distribution of brGDGTs in the riverine suspended particulate matter (SPM) did not reflect that of the soils, implying that due to the aquatic production in river and marine environments the use of brGDGTs for paleoclimate reconstructions in the region would be complicated (Zell et al., 2014; 2015). Here we examine if the assessment of the provenance of brGDGTs in the Tagus River basin can be improved by the application of the analytical methods allowing the separation of the 5- and 6-methyl brGDGTs (De Jonge et al., 2013). In addition, we examine if the provenance of brGDGTs changed over the Holocene and if the distribution of brGDGTs in the past reflected continental sources and thus past temperature and pH of the soils in the drainage basin of the river. To this end we compare the down core brGDGT distributions in Holocene sediments retrieved from four locations along a transect in the Tagus River basin, which includes the river floodplain (Tagus River Floodplain core), the offshore mudbelt (Mudbelt core), and marine sediments from the canyons (Lisbon Canyon Head core and Lower-Sétubal canyon core) (Fig. 1), and compare them to brGDGT

distributions of soil and river SPM from the Tagus River watershed. This allows insight into the potential and limitations of using the novel MAT_{mrs}/CBT' proxies for climate reconstruction in this region and in river systems in general.

~~1.~~1.1 Study Area

The Tagus River drains the central part of the Spanish Plateau with an E-W orientation (Benito et al., 2003). The waters originate at an elevation of about 1600 m altitude in eastern Spain at the Iberian Range and the mouth of the river feeds into the Atlantic Ocean near Lisbon (Vis and Kasse, 2009). At 1,200 km long the Tagus River is the longest river of the Iberian Peninsula and it occupies 82×10^3 km^2 making it the third largest in catchment area (Benito et al., 2003). The Tagus Basin is surrounded by mountains on three sides with the Iberian Range to the east, the Central Range to the north, and the Toledo Mountains to the south. Present-day mean discharge at the Tagus River mouth is 400 m^3 s^{-1} (Vale and Catarino, 1996; Vaz et al., 2011) and the largest contribution of draining tributaries comes from the Central Range in the North (Benito et al., 2003). The Tagus River is characterized by extreme seasonal and annual variability, including periods of flooding with 30 times the mean discharge and an annual discharge cycle characterized by two peaks in the winter (December and then again February to March) and a discharge minimum in the summer (August) (Benito et al., 2003). Since the 1940s dams have been built along the expanse of the Tagus River for water supply, hydropower, and flood prevention (Dias et al., 2002), which have likely impacted the transport of brGDGTs in the Tagus River system since their construction.

Where the Tagus River debouches into the Atlantic Ocean, the narrow continental shelf and steep continental slope are deeply incised by the Lisbon-Setúbal canyon system. The head of the Lisbon branch of that canyon system is located 13 km offshore from the Tagus River mouth at 120 m water depth. From that point, the canyon descends over a length of 165 km

until it opens out onto the Tagus Abyssal Plain at 4860 m (Lastras et al., 2009). Even though the shelf is very narrow, sparse amounts of continental organic matter and clastic sediment reach the deep ocean in this region (Jouanneau et al., 1998; de Stigter et al., 2011; Vis et al., in press). This is because the Lisbon-Setúbal canyon is not a very dynamic system and has a weak down-canyon transport of sediments (Jouanneau et al., 1998; Jesus et al., 2010; de Stigter et al., 2011). A part of the continental shelf in this region is covered by mud deposits, which originate predominantly from the Tagus estuary (Jouanneau et al., 1998). According to this same study, the mouth of the much smaller Sado River is located further to the southeast and contributes only a relatively minor sediments volume to the shelf mud deposits.

Generally, the climate of the Tagus River Basin is characterized by seasonal variability and is considered continental Mediterranean (Le Pera and Arribas, 2004). Summers in the Tagus region are hot and dry and the winters are relatively mild and wet (Benito et al., 2003). During the summers, the climate regime in the Tagus Basin is controlled by the Azores high and in the winter by the westerlies (Benito et al., 2003). The MAT in the interior regions of the Tagus River basin varies from the highlands to the lowlands of the inner basin from 7.5 to 12.5°C, respectively and can increase up to 16°C along the Atlantic Coast (Le Pera and Arribas, 2004). The mean annual precipitation in the lowlands of the inner basin is mostly below 500 mm making it an arid region, however, some of the highest altitudes of the mountainous areas have a larger mean annual precipitation ranging from 750-1200 mm (Le Pera and Arribas, 2004).

The Iberian Peninsula is located between two major pressure systems, the Azores High and the Iceland Low, which make up the North Atlantic Oscillation (NAO). This climate phenomenon is caused by the varying pressure gradient in the North Atlantic and greatly influences climate conditions all over Europe (Hurrell, 1995; Hurrell and VanLoon, 1997). Because of the Iberian Peninsula's advantageous position for studying the shifting NAO, the

climate in this region has been intensively investigated (Zorita et al., 1992; Rodó et al., 1997; Trigo et al., 2004). Many of these studies are from an oceanic perspective, obtaining sea surface temperatures from marine sediments using the alkenone unsaturation indices (Abrantes et al., 2005, 2009; Rodrigues et al., 2009), coccolithophore assemblages (Cachao and Moita, 2000; Palumbo et al., 2013), and stable isotopic oxygen composition of foraminifera (Lebreiro et al., 2006 ; Bartels-Jónsdóttir et al., 2006; 2009). The terrestrial climate has been examined using continental paleoarchives such as speleothems (Munoz-Garcia et al., 2007; Martin-Chivelet et al., 2011; Stoll et al., 2013), tree rings (Andreu et al., 2007; Linan et al., 2012), and pollen (Huntley and Prentice, 1988; Lebreiro et al., 2006; Davis et al., 2003; Fletcher et al., 2007; Corella et al., 2013). The integrated continental and marine approach can give complimentary information to past climate in a region and by using the same proxy on the continent, in the ocean, and at the ocean-continent interface we would perhaps obtain a clearer picture of continental climate processes in an area rather than using separate studies or a multi-proxy approach.

~~2.~~2. Material and Methods

Sample collection. Soil samples, riverbank sediment samples, and river SPM from the Tagus River basin (Fig. 1b) were collected previously (Zell et al., 2014). These samples were complemented with four long sediment cores collected along a transect running from the Tagus River to the lower continental slope (Fig. 1). The Tagus River Floodplain core (0501.029) was collected in a low-energy backswamp of the present-day floodplain of the river at ~4 km west of the Tagus channel (Table 1). The sediment was collected using an Edelman hand auger for sediment above the groundwater table and a gauge for sediment below the groundwater table (Vis et al., 2008). The sediments were wrapped in the field for laboratory analyses. The other three cores were collected using a piston corer, during campaigns in May

2007 and March 2011 with RV *Pelagia* conducted by the NIOZ - Royal Netherlands Institute for Sea Research. The coring site for the Mudbelt core (64PE332-30-2) was to the west of the Tagus Estuary mouth, for the Lisbon Canyon Head core (64PE332-44-2) it was to the east of the Tagus Estuary mouth, and for the Lower Setúbal Canyon core (64PE269-39) it was on the crest of the northern levee of the lower Setúbal Canyon (Table 1). A detailed description of the cores used in this study is given in the Supplemental Information.

Age models. The accelerated mass spectrometry (AMS) ^{14}C measurements of the three marine sediment cores were carried out at the BETA analytic laboratory (USA) on benthic or planktonic forams, gastropods or shells fragments (Table 2). As for the Tagus River Floodplain core, the radiocarbon dating material was performed for a previous study and consisted of mostly terrestrial botanical macrofossils, but other bulk material was used as well (Vis et al., 2008). In order to establish consistent chronologies for the four sediment cores, all the AMS dates were calibrated into calendar ages using the CALIB 7.0, available at http://radiocarbon.pa.qub.ac.uk/calib (Stuiver et al., 1998). The calibration data and curve selection used for the three marine sediment cores was Marine13 and for the Tagus River Floodplain core IntCal13 was used (Reimer et al., 2013). All radiocarbon dates mentioned have age spans at the 2σ range and are expressed as calibrated ages (cal. BP) (Table 2, Fig. S2).

Bulk isotope data Prior to bulk carbon isotope analysis, sediment was decalcified using a 2 N HCL solution for approximately 18 h. The sediment was rinsed three times using double-distilled water and then freeze dried again. Total organic carbon (TOC) and $\delta^{13}C_{TOC}$ (Table 3) were measured in duplicate using the Flash 2000 series Organic Elemental Analyzer (Thermo

229 Scientific) equipped with a TCD detector. The $\delta^{13}C_{TOC}$ is expressed in relation to the Vienna
230 PeeDee Belemnite (VPDB) standard and the isotope analysis precision was 0.1‰.

231

232 **Lipid extraction and GDGT analysis.** Between 1-3 g of freeze dried sediment was extracted
233 using the Dionex^{TM} accelerated solvent extraction (ASE) with dilchloromethane
234 (DCM):methanol (9:1, v/v) as the solvent at a temperature of 100°C and a pressure of 1500
235 psi for 5 min with 60 % flush and purge 60 seconds. The extract was then collected and dried
236 using Caliper Turbovap®LV. Next, using DCM, the lipid extract was dried over a column of
237 anhydrous Na_2SO_4 and then blown down under a gentle stream of N_2. In order to quantify
238 GDGTs, 1 µg of an internal standard (C_{46} GDGT; Huguet et al., 2006) was added to the total
239 lipid extract before it was separated over a ~~e~~column of Al_2O_3 (activated for 2 h at 150°C) into
240 three fractions using hexane:DCM (9:1, v:v) for the apolar fraction, hexane:DCM (1:1, v:v)
241 for the ketone fraction and DCM:MeOH (1:1, v:v) for the polar fraction. The polar fraction,
242 which contained the GDGTs, was dried under a N_2 stream and then re-dissolved in
243 hexane:isopropoanol (99:1, v:v) at a concentration 10 mg ml^{-1}. Finally it was passed through a
244 0.45 µm PTFE filter and analysed with high performance liquid chromatography-atmospheric
245 pressure positive ion chemical ionization–mass spectrometry (HPLC-APCI-MS) with a
246 separation method that allows the separation of 5- and 6-methyl brGDGTs (Hopmans et al.,
247 2015). For the study of Zell et al., (2014) the samples were split into two different fractions
248 before the analysis, the intact polar lipid (IPL) fraction and core lipid (CL) fractions. For the
249 purposes of this study the IPL and CL fractions of the river SPM were analyzed separately on
250 the HPLC-APCI-MS for GDGTs (Hopmans et al., 2015) and then the amount of GDGTs
251 found in the CL and IPL fractions were combined. After analysis some of the GDGT based
252 indices were recalculated for the entire sample set.

Calculation of GDGT-based proxies. The Roman numerals refer to the GDGTs indicated in Fig. S1. The 5-methyl brGDGTs and 6-methyl brGDGTs are distinguished by an accent on the 6-methyl brGDGTs. The GDGT indicated by IV is crenarchaeol, the isoprenoid GDGT specific to Thaumarchaeota (Sinninghe Damsté et al., 2002).

The BIT index (Hopmans et al., 2003), which results in a value between 0 and 1 with those values closer to 0 designating a more marine signal and a value close to 1 indicating a more terrestrial signal, was calculated using the following formulae that specifically includes the novel 6-methyl brGDGTs according to De Jonge et al. (2015):

$$\text{BIT index} = (Ia+IIa+IIIa+IIa'+IIIa')/(Ia+IIa+IIIa+IIa'+IIIa'+IV) \quad (1)$$

The isomer ratio (IR) signifies the quantity of the penta- and hexamethylated 6-Me brGDGTs compared to the total brGDGTs and was calculated according to De Jonge et al., (2015):

$$IR=(IIa'+IIb'+IIc'+IIIa'+IIIb'+IIIc')/(IIa+IIb+IIc+IIIa+IIIb+IIIc+IIa'+IIb'+IIc'+IIIa'+IIIb'+IIIc') \quad (2)$$

The relative abundance of the penta- and hexamethylated 6-methyl brGDGTs are calculated according to (De Jonge et al., 2014b):

$$IR_{II} = IIa'/(IIa+IIa') \quad (3)$$

$$IR_{III} = IIIa'/(IIIa+IIIa') \quad (4)$$

The MBT'_{5Me} (which excludes the 6-methyl brGDGTs) was used to calculate MAT according to De Jonge et al., (2014a):

$$MBT'_{5Me} = (Ia+Ib+Ic)/(Ia+Ib+Ic+IIa+IIb+IIc+IIIa) \quad (5)$$

$$MAT = -8.57 + 31.45 * MBT'_{5Me} \quad (6)$$

The equation to determine DC (Sinninghe Damsté et al., 2009) was reformulated to specifically include the pentamethylated 6-methyl brGDGTs:

$$DC' = (Ib+IIb+IIb')/(Ia+Ib+IIa+IIb+IIa'+IIb') \quad (7)$$

To calculate pH and MAT the novel MAT_{mr} /CBT' calibration was used (De Jonge et al., 2014a):

$$CBT' = {}^{10}\log[(Ic+IIa'+IIb'+IIc'+IIIa'+IIIb'+IIIc')/(Ia+IIa+IIIa)] \quad (8)$$

$$pH = 7.15 + 1.59 * CBT' \quad (9)$$

$$MAT_{mr} = 7.17 + 17.1 * [Ia] + 25.9 * [Ib] + 34.4 * [Ic] - 28.6 * [IIa] \quad (10)$$

$$MAT_{mrs} = 5.58 + 17.91 * [Ia] - 18.77 * [IIa] \quad (11)$$

Statistical analysis. Using R software package for statistical analysis we ~~performed~~employed principal component analysis (PCA) based on the correlation matrix. ~~We performed the~~The PCA was performed on the fractional abundances of all 15 of the 5- and 6-methyl brGDGTs for the entire sample set along the transect from the land to the ocean.

~~3.~~3. Results

We report bulk and brGDGT data for four cores covering Holocene sedimentation in the Tagus River Basin and its outflow into the Atlantic. We compare these data with new results acquired through an improved LC method able to distinguish between the 5- and 6-methyl

294 brGDGTs (De Jonge et al., 2013) on the soils, riverbank sediments, and SPM samples
295 previously obtained by Zell et al., (2014).

296

297 **3.1 Bulk parameters of the sediments**

298 The age-depth models for the marine sediment cores (Fig. S2, Table 1) are based on
299 radiocarbon dating of picked foraminifera, gastropods, and shell fragments. The data show
300 that of the four sediment cores from the transect the Tagus River Floodplain sediments date to
301 6.7 cal. kyrs. BP, the Mudbelt sediments date to 5.8 cal. kyrs. BP, the Lisbon Canyon Head
302 sediments date to 8.7 cal. kyrs. BP, and the Lower Setúbal Canyon penetrated the oldest strata
303 (13.0 cal. kyrs. BP). Reported values for sediments from each location were averaged over the
304 interval 0-6.0 cal. kyrs. BP, so as to avoid a bias in the data since not all of the sediment cores
305 covered more than 6.0 kyrs.

306 The bulk carbon isotope data for the Tagus River SPM, riverbank sediments, and soils
307 has been previously discussed in Zell et al., (2014). The TOC values for the Tagus River
308 Floodplain sediments are relatively high and also highly variable with a range of 1.5-16 wt. %
309 and a mean of 6.5±4.3 wt. % (average ± standard deviation) and the mean $\delta^{13}C_{TOC}$ was -
310 27.0±1.0 ‰ (Fig. 2; Table 3). In the Mudbelt sediments the TOC is less variable than in the
311 Tagus River Floodplain sediments, ranging from 0.6-1.2 wt. % and with an average of
312 0.9±0.2 wt. % (Fig. 2; Table 3). The average $\delta^{13}C_{TOC}$ in the Mudbelt sediments, -24.3±0.2 ‰,
313 is higher than in the Tagus River Floodplain sediments. The average $\delta^{13}C_{TOC}$ of the Lisbon
314 Canyon Head sediments, -23.0±0.6 ‰, is higher than the Mudbelt sediments and the TOC
315 content is similar to that of the Mudbelt sediments, ranging from 0.25-1.5 wt. % with the
316 mean of 0.9±0.3 wt. % (Fig. 2; Table 3). The average $\delta^{13}C_{TOC}$ values in the Lower Setúbal
317 Canyon sediments (-23.4±1.5‰) are similar to those of the Lisbon Canyon Head sediments

with a TOC content ranging from 0.51-0.85 wt. % with a mean value of 0.65±0.14 wt. % (Fig. 2; Table 3).

3.2 Concentrations and distributions of GDGTs

Tagus Soils and Riverbank Sediments. The average concentration of crenarchaeol is higher in the riverbank sediments (~8.7±7.8 µg gOC^{-1}) than in the soils (~1.4±1.1 µg gOC^{-1}) (Fig. 3a-b; Table 3). The same trend is true for the brGDGTs with the average concentration being higher in the riverbank sediments (~33.9±24.5 µg gOC^{-1}) than the soils (~6.8±6.5 µg gOC^{-1}) (Fig. 3a-b; Table 3). The values of the BIT index were similar to those previously reported (Zell et al., 2014) for both the soils and riverbank sediments and ranged from 0.3 to 1.0 with an average of 0.7±0.2 (Fig. 3c; Table 3). The re-analysis of the brGDGTs in the soils reveals that the relative abundance of the novel 6-methyl brGDGTs is highly variable (ranging from 0.13-0.92) and can be quite high; the average values for the IR are 0.6±0.3 (Fig. 3e; Table 3). IR is even higher but less variable for the riverbank sediments with an average of 0.7±0.1 (Fig. 3e; Table 3). In general the penta- and hexamethylated brGDGTs show the same ratio of 5- and 6-methyl isomers (Fig. 4), however, in soils from an altitude of >350 m the 6-methyl brGDGTs are especially dominant (Fig. ~~S4~~S3). Values for the new MBT'_{5me} index, which excludes the 6-methyl brGDGTs (cf. De Jonge et al., 2014a), of the soils and riverbank sediments are quite similar with an average of 0.5±0.1 in both cases (Fig. 3f; Table 3). The DC' ratio deviates between the soils and the riverbank sediments (Fig. 3d; Table 3). The DC' for the soils is highly variable but on average low (0.2±0.1); for the riverbank sediments it is higher with an average of 0.4±0.1 (Fig. 3d; Table 3).~~-~~

Tagus River SPM. The SPM was obtained from the Tagus Estuary near the mouth of the Tagus River once a month over the course of a year (excluding the month of August).

342 Data from the Tagus River SPM showed that the summed brGDGT and crenarchaeol
343 concentrations in the river SPM varied throughout the year and were on average 45±23 µg
344 gOC^{-1}, and 9.8±6.8 µg OC^{-1}, (Figs. 3a-b; Table 3), respectively, resulting in only small
345 variations in the BIT index (i.e. 0.8±0.1; Fig. 3c; Table 3). The distribution of brGDGTs (Fig.
346 5c) was relatively constant throughout the year as is evident from the values for MBT'_{5me}
347 (0.5±0.0), DC' (0.3±0.0), and IR (0.6±0.0) for the river SPM (Figs. 3d-f; Table 3).

348 *Tagus River Floodplain sediments.* The average crenarchaeol concentration is fairly
349 low in the Tagus River Floodplain sediments, 2.8±1.7 µg gOC^{-1}, conversely, the average sum
350 of the brGDGTs in the sediments, 70±26 µg gOC^{-1}, is the largest out of the entire transect
351 (Figs. 3a-b; Table 3). The BIT index is fairly high and constant throughout the sediment core
352 with an average value of 0.9±0.0 (Fig. 3c; Table 3). The distribution of brGDGTs (Fig. 5d) is
353 somewhat similar to that of the riverine SPM (Fig. 54c) and shows no major changes over the
354 Holocene. The Tagus River Floodplain sediments has the lowest average values for MBT'_{5me},
355 0.4±0.1, and IR, 0.4±0.0, of all the sediment records in the transect (Figs. 3e-f). The mean
356 DC' throughout the sediments in this sample set is 0.4±0.1 (Fig. 3d; Table 3).

357 *Mudbelt sediments.* The average concentration of the brGDGTs in the mudbelt
358 sediments, 25±14 µg gOC^{-1}, is lower than in the Tagus River Floodplain sediments, however,
359 the concentration of crenarchaeol, 170±50 µg gOC^{-1}, is higher in the Mudbelt sediments
360 (Figs. 3a-b; Table 3). This results in a lower mean value of the BIT index (i.e. 0.09±0.03; Fig.
361 3c; Table 3). The brGDGT distribution is relatively constant over the Holocene and is fairly
362 similar to that of the Tagus River floodplain sediments with slightly higher fractional
363 abundances of Ia and IIIa' (cf. Figs. 5d-e; Table 3). The average value of the MBT'_{5me}
364 (0.5±0.0) is similar to the Tagus River SPM value (Fig. 3f). The average value of the DC' is
365 0.3±0.1 and the mean value of the IR is 0.5±0.0 (Figs. 3d-e; Table 3).

366 *Lisbon Canyon Head sediments.* The average sum of the brGDGTs, 31±9.3 µg g OC^{-1},
367 is about the same in the Lisbon Canyon Head sediments as in the Mudbelt sediments but the
368 amount of crenarchaeol, 390±130 µg gOC^{-1}, is larger in the Lisbon Canyon Head sediments
369 (Figs. 3a-b; Table 3). This results in lower BIT values (0.051±0.02) than in the Mudbelt
370 sediments (Fig. 3c; Table 3). The average brGDGT distribution (Fig. 5f) is fairly similar to
371 that of the Tagus Floodplain and Mudbelt sediments and is relatively constant over the
372 Holocene. The average of the MBT'_{5me} (0.5±0.0) is statistically identical to that in the
373 Mudbelt sediments (Fig. 3f; Table 3). However, the average IR, 0.6±0.0, and DC', 0.4±0.0,
374 are both a bit higher (Figs. 3d-e; Table 3).

375 *Lower Setúbal Canyon sediments.* The concentrations of the brGDGTs in these most
376 distal sediments are quite low, on average 16±5.5 µg OC^{-1} (Fig. 3a; Table 3), while the
377 amount of crenarchaeol in this sediment core is the highest out of the entire transect at
378 470±200 µg gOC^{-1} (Fig. 3b; Table 3). This results in a low average BIT index value of
379 0.02±0.01 (Fig. 3c; Table 3). The average distribution of brGDGTs in these sediments (Fig.
380 5g) is different from the marine sediments from the other two sites, with a higher fractional
381 abundance of IIIa'. However, another component with the same molecular ion eluted at
382 around the same time as IIIa' in the Lower Setúbal Canyon sediments (which we determined
383 was not the "mixed 5,6-dimethyl isomer"; cf. Weber et al., 2015), complicating integration
384 and quantification. This indicates that the brGDGT results from these sediments must be
385 interpreted with some caution. The average MBT'_{5me} (0.6±0.1) and DC' (0.4±0.1) are fairly
386 similar to the Lisbon Canyon Head sediments averages but the average IR (0.7±0.0) is the
387 highest of all sediments (Figs. 3d-f; Table 3).

388

389 **34.3 PCA**

In order to determine the variation in the distribution of brGDGTs, we performed principal component analysis (PCA) on the distributions of brGDGTs of all the samples examined. Most variation is explained by principal component 1 (PC1; 29.8 %) and is clearly related to the fractional abundance of the 5-methyl versus 6-methyl brGDGTs (Fig. 6a). With the exception of IIIc (which is typically a minor brGDGT with a fractional abundance of <1 %; Fig. 5), all of the 5-methyl brGDGTs score positively on PC1 and the 6-methyl brGDGTs score negatively. For the overall data set, PC1 is highly negatively correlated with the IR ratio (Fig. 7a, R^2=0.78). PC2 explains 25.6 % of the variance of the PCA. Branched GDGTs that score positively on PC2 are generally comprised of cyclized and more methylated brGDGTs (Fig. 6a). With the exception of IIIc (which is typically a minor brGDGT with a fractional abundance of <1 %; Fig. 4), all of the tetra- and penta-methylated brGDGTs containing no cyclopentane moiety (i.e. Ia, IIa, and IIa') score negatively on PC2. Consequently, PC2 is highly positively correlated with DC' for the whole data set (Fig. 7b, R^2=0.84).

4.4. Discussion

45.1 Environmental parameters affecting brGDGT distribution in Tagus soils

Evident from the earlier study by Zell et al. (2014) was that the distribution of the brGDGTs in Tagus soils varies widely. The primary environmental parameters influencing brGDGT distributions in soil (Weijers et al., 2006), i.e. MAT and pH, did differ substantially in the Tagus River basin. MAT varies from 10-17°C and pH from 5.5-8.6 (Zell et al., 2014) and both parameters show a distinct correlation with altitude (R^2=0.93 and 0.73, respectively). Applying the brGDGT global soil calibration of Peterse et al. (2012), Zell et al. (2014) arrived at unrealistically low (0-10°C) estimated MATs using the brGDGT distributions. This was attributed to the arid conditions in the region (MAP<800 mm yr^{-1}), which has in other studies,

including one that analyzed soils from the Iberian peninsula, been indicated as a likely cause for the discrepancy between actual and reconstructed MAT using brGDGT distributions (Peterse et al., 2012; Dirghangi et al., 2013; Menges et al., ~~2013~~2014). Our re-analysis of the soils taking into account the novel 6-methyl brGDGTs now provides the possibility to re-evaluate these data. It is clear that the fractional abundances of the novel 6-methyl brGDGTs vary to a large extent. The IR_{II} and IR_{III} vary from 0.1 to 0.9 (Fig. 4) and some of the soils score very negatively on PC1 (Fig. 6b), which is predominantly determined by the fractional abundance of the 6-methyl brGDGTs. From the global soil brGDGT dataset (De Jonge et al., 2014a) it was evident that the main factor influencing the fractional abundance of the 6-methyl brGDGTs is soil pH with an increased abundance in high pH soils. In the Tagus River basin soil pH indeed shows a large variation, i.e. from 5.5 to 8.6, and this likely explains the large variation in IR. When we calculate the pH from the brGDGT distribution using the new equation (9) of De Jonge et al. (2014a), which is based predominantly on the fractional abundances of 6-methyl brGDGTs, we find a highly significant correlation between measured and reconstructed pH (R^2=0.89) following the 1:1 line (Fig. 9a). Differences in soil pH also affect the degree of cyclization of brGDGTs (Weijers et al., 2007a; De Jonge et al., 2014b) and indeed we find a significant positive correlation between DC' and soil pH (R^2=0.74). The effect of MAT is not clearly revealed in the dataset. For the global soil brGDGT dataset a strong relationship exists between MAT and MBT'_{5Me} (De Jonge et al., 2014a). Although we observe substantial variation for MBT'_{5Me} in soils (i.e. 0.3-0.7; Fig. 3f) for this dataset, we do not observe a statistically significant relationship of MAT with MBT'_{5Me}. Also, reconstructed MATs are far too low, i.e. 0.5–13°C using equation (6) and 2.6–11°C using equation (10). Evidently, the "cold bias" of the brGDGT distributions in the soils of the Tagus river basin (Zell et al., 2014) is not solved when 5- and 6-methyl brGDGTs are individually quantified.

Previously it was postulated that in this region aquatic in-situ production and arid conditions are complicating the use of brGDGTs for climate reconstructions (Menges et al., ~~2013~~2014; Zell et al., 2014). Within the soil sample set a strong negative relationship exists between the DC' and the measured MAT in the Tagus basin (R^2=0.79), whereas the degree of cyclization up until this point has only been reported to be related to pH and not to MAT (Weijers et al., 2007a). Conversely, though, the MAT_{mrs} reconstructed values for the soils have a positive correlation with DC' (R^2=0.51) and it is lower than with the measured MAT. Although at this point we are unsure if this association occurs in other arid areas as well, we do believe this strong relationship between the DC' and the MAT could be affecting the applicability of brGDGTs for temperature reconstructions in this region.

~~4~~5.2 Provenance of brGDGTs in the Tagus River and its outflow

The application of brGDGTs in marine sediments influenced by river outflows for reconstruction of the continental paleoclimate (e.g. Weijers et al., 2006) rests on the premise that the distribution of the brGDGTs produced in the soils must be conserved throughout riverine transport to the sediments where they are archived. Therefore, we compare brGDGT distributions and concentrations from the rest of the sample set in the source-to-sink transect to determine if the soil signal is conserved during transport in the Tagus River basin. The PCA results (Fig. 6b) indicate that for the most part the distribution of brGDGTs from the river SPM and sediments along the transect is not similar to those from the soils or the Tagus Watershed. Sediments from three of the sample sets in the transect, the Tagus River Floodplain sediments, the Mudbelt sediments and the Lisbon Canyon Head sediments, all plot differently from the soils, and although the distributions of the Lower Setúbal Canyon sediments and the Tagus River SPM plot closer, there is still an offset from the soils. The

462 Tagus Riverbank sediments plot the most closely to that of the soils in the Tagus River basin,
463 however, again a slight offset still exists. So, even without considering the effects of
464 environmental parameters on brGDGT distributions, we can already conclude that the
465 brGDGTs in the sediments and river SPM only reflect the distribution of brGDGTs in the
466 Tagus soils by a minor extent and, thus, it is unlikely that Tagus soils are a major source for
467 brGDGTs in the marine sediments.

468 Using PCA (Fig. 6) we tried to determine what factors are causing the variation in the
469 distribution of brGDGTs in the Tagus River basin. PC1 is primarily related to the
470 predominance of 5-methyl versus 6-methyl brGDGTs (Fig. 6a) and thus pH (cf. De Jonge et
471 al., 2014a). This was confirmed for the soil data set where the calculated pH based on the
472 fractional abundance of predominantly 6-methyl brGDGTs shows a good correspondence
473 with measured pH (see Sect. 5.1). De Jonge et al. (2014b) showed that in the SPM of the
474 alkaline waters of the river Yenisei 6-methyl brGDGTs also predominate, indicating that pH
475 in all kinds of environmental settings determines the ratio between 5 and 6-methyl brGDGTs.
476 The Tagus riverbank sediments, river SPM and the Lower Setúbal Canyon sediments score
477 mostly negatively on PC1 as do soils from higher altitudes (>350 m) (Fig. 6b). The Mudbelt
478 sediments, Lisbon Canyon Head sediments, the Tagus River Floodplain sediments, and the
479 lower altitude soils (<350 m) have similar abundances of the 5- and 6-methyl brGDGTs or
480 higher abundances of the 5-methyl brGDGTs and plot mostly positively on PC1. Since the
481 Tagus River Floodplain sediments, the Mudbelt sediments, and the Lisbon Canyon Head
482 sediments do not have a predominance of 6-methyl brGDGTs, this indicates that either they
483 received an equal contribution of soil derived organic matter from the lower altitude soils in
484 the region (<350 m) as from the higher altitude region (>350m) or, more likely, that in-situ
485 production of brGDGTs is a large source of brGDGTs in these sample sets.

PC2 also explains a substantial part of the variance in the dataset (25.6 %, Fig. 6b) and is correlated with DC' (R^2=0.84, n=109, Fig. 7b). Since pH is also the main driver of DC' (Weijers et al., 2007a), it suggests that differences in pH are also responsible for the variance seen in PC2. The samples that standout are the sediments from the Lower Setúbal Canyon core, which are the most marine sediments in the sample set, and plot most positively, and the lowest altitude soils (28-344 m), which plot the most negatively. These latter soils are characterized by a low measured pH. The oldest (11.6-13.0 kys BP) sediments of the Lower Setúbal Canyon score most positively on PC2. A high degree of cyclization of brGDGTs has been observed previously in marine sediments from a Svalbard fjord and attributed to marine in-situ production in the alkaline pore waters of marine sediments (Peterse et al., 2009; Weijers et al, 2014). Re-analysis of the Svalbard sediments for brGDGTs actually showed that this cyclization affects the tetra- and pentamethylated brGDGTs to a much larger extent than that of the hexamethylated brGDGTs (Sinninghe Damsté ~~et al.~~, ~~unpublished results~~2016) and the same observation can be made for the sediments of the Lower Setúbal Canyon (Fig. 5g). Evidently, the high degree of cyclization of brGDGTs as a response to pH is not as clearly seen in the soils since the high altitude, high pH soils from the Tagus watershed (Fig. S3c) do not exhibit the pattern (i.e. fractional abundance of IIb' larger than that of IIa') observed in the Lower Setúbal Canyon sediments (Fig. 5g). This pattern is, to a lesser degree, also seen in the sediments of the Lisbon Canyon Head core (Fig. 5f). As mentioned earlier, the Lower Setúbal Canyon sediments also display a predominance of 6-methyl brGDGTs over the 5-methyl counterparts, especially with regards to the hexamethylated brGDGTs. In the Lower Setúbal Canyon sediments IIIa' is by far the most abundant brGDGT, consisting of 29 % of the entire brGDGT pool (Fig. 5g). This is comparable to Svalbard sediments (Sinninghe Damsté ~~et al.~~, ~~unpublished results~~2016) where IIIa' is also the most abundant brGDGT. Taken together this clearly indicates the influence of in-situ production in the Lower Setúbal Canyon

sediments. However, the degree of cyclization for Ia-c and IIa-c is not as high as observed for the Svalbard sediments, which still suggests some allochthonous input of brGDGTs even in these remote marine sediments.

Another way to determine if in-situ production is a factor affecting the brGDGT distribution in aquatic environments is by the calculation of reconstructed pH values. If in-situ production is heavily contributing to the brGDGT pool, then the reconstructed pH values should reflect that of the aquatic environment in which they were produced. The average reconstructed pH of the sample sets in the transect are relatively high with a clear trend to higher values with increasing distance from the river mouth (Fig. 8a), which would be in line with increased in situ production of brGDGTs in the alkaline pore waters of marine sediments. However, these values are still within the range of the measured (5.5-8.5) and reconstructed (Fig. 8a) pH of the soils and so this does not prove in-situ production as a major contributor of brGDGTs in these sample sets. Conversely, the newly calculated DC', also a reflection of pH, is quite variable throughout the sample sets in the transect except for in the river SPM where it is fairly constant (Fig. 3d; Table 3). Since the DC' is lowest in the soils (0.2±0.1) and then higher in the rest of the samples in the transect (0.3-0.4), this suggests in-situ production is an issue (cf. Zell et al., 2014) in all of the sample sets (Fig. 3d; Table 3).

45.3 brGDGTs as indicators of terrestrial OM transport by the Tagus River

Classically, the assessment of the contribution of terrestrial OM to marine sediments is performed by measuring $\delta^{13}C_{TOC}$ (Hedges and Oades, 1997 and references cited therein). In the earlier study of the Tagus River system, Zell et al. (2014) determined that the average $\delta^{13}C_{TOC}$ of the riverine SPM (~-29 ±0.8‰), like the Tagus soils, are consistent with a predominant C_3 higher plants origin (Fry and Sherr, 1984). Additionally, this study found the

535 $\delta^{13}C_{TOC}$ in marine surface sediments off the Portuguese coast in front of the Tagus River
536 increase with increasing distance offshore by an increased contribution of ^{13}C-enriched
537 marine OM. This trend is also evident for the Holocene sediments studied here. The most
538 terrestrial sediments of the transect, i.e. from the Tagus River Floodplain, also have a $\delta^{13}C_{TOC}$
539 value (~27±1.0 ‰; Fig. 2a; Table 3) consistent with a predominant C_{origin} of higher plants.
540 Moving offshore, the less negative $\delta^{13}C_{TOC}$ values of the Mudbelt sediments (-24±0.2 ‰), the
541 Lisbon Canyon Head sediments (-23±0.6 ‰) and the Lower Setúbal Canyon sediments (-
542 23±1.5 ‰) all indicate that the majority of the TOC off the Portuguese shelf is of marine
543 origin (Fig. 2a; Table 3). So, as Zell et al. (2014) found with marine surface sediments off the
544 Portuguese coast, the $\delta^{13}C_{TOC}$ (‰) averages from the sediments in our transect also increase
545 with increasing distance offshore, demonstrating that the present trend in the $\delta^{13}C_{TOC}$ signal
546 remained the same over the Holocene.

547 Zell et al. (2014) previously showed that in the present day Tagus River system the
548 amount of brGDGTs (µg gOC^{-1}) increases from the soils to the riverbank sediment to the river
549 SPM and explained this increase as proof of riverine in-situ production of brGDGTs.
550 Concentrations of summed brGDGTs in surface sediments in transects from the Portuguese
551 coast rapidly declined with increasing distance from the coast, suggesting that brGDGTs
552 could still be used as tracer for terrestrial organic matter (Zell et al., 2015). The trends
553 observed in these earlier studies are confirmed here for the Holocene. The Tagus River
554 Floodplain sediments have the highest concentration of brGDGTs (67±26 µg gOC^{-1}) in the
555 entire transect, much higher than in the soils (Fig. 3b; Table 3). However, the sediments in
556 this core are somewhat a-typical for the Tagus Floodplain as some layers consist of peat as a
557 result of the low-energy backswamp conditions in the vicinity, which could explain the
558 difference in brGDGT concentrations from the surrounding soils. This could also be due to
559 the addition of aquatically produced brGDGTs from the river during times of flooding

560 although it should be noted that the concentration of brGDGTs is even higher than in riverine
561 SPM (Fig. 3b). The summed brGDGT concentration decreases and is fairly similar among the
562 Mudbelt sediments (25±14 µg gOC^{-1}) and the Lisbon Canyon Head sediments (31±9.3 µg
563 gOC^{-1}), and then decreases further moving away from the coastline to the Lower Setúbal
564 Canyon sediments (16±5.5 µg gOC^{-1}) demonstrating the decrease in input of riverine
565 brGDGTs moving away from the shoreline (Fig. 3b). However, even though the sum of the
566 brGDGTs are lower in the marine sediment than in the Tagus River Floodplain sediments, the
567 amount of brGDGTs in all four sediment cores are higher than in the Tagus soils (~6.8±6.5 µg
568 gOC^{-1}) indicating the origin of the brGDGTs in the sediment cores are not all soil derived and
569 pointing instead to riverine in-situ production as well as possibly in aquatic sediments (Fig.
570 3b).

571 A previous study by Zell et al., (2015) determined that in the surface sediments off the
572 coast of Portugal the BIT index is influenced by both declining brGDGT concentrations and
573 increased crenarchaeol production with increasing distance from the coast. For the Holocene
574 sediments studied here, the average concentration of crenarchaeol in the Tagus River
575 Floodplain sediments is low (2.8±1.7 µg gOC^{-1}) and similar to that of the Tagus soils (1.4±1.1
576 µg gOC^{-1}; Fig. 3a; Table 3). The crenarchaeol concentration increases in the sediments with
577 increasing distance from the shoreline, signifying the increase in marine production with
578 water depth and distance from the coast (Fig. 3a). Consequently, the BIT index is the highest
579 in the Tagus River Floodplain sediments (0.94±0.03) out of the entire transect (Fig. 3c) and
580 then the BIT index decreases within the sediments along the transect with increasing distance
581 from the Portuguese coast potentially signifying a decrease in terrestrial input moving away
582 from the shoreline. ~~A moderate negative correlation exists between the BIT index and $\delta^{13}C_{TOC}$~~
583 ~~values for the entire sample set (R^2=0.55, Fig. 10), demonstrating that as $\delta^{13}C_{TOC}$ values~~
584 ~~become less terrestrial, the BIT index indicates less terrestrial input, so both parameters~~

~~corroborate a decrease in terrestrial influence with distance from the coast confirming the results from previous studies (Zell et al., 2014; 2015).~~

45.4 Factors affecting the application of brGDGTs for paleoclimate reconstructions off the Iberian Peninsula

Despite the caveats with respect to in-situ production of brGDGTs in aquatic environments as described in the previous section, we tested how the new soil calibration based on individually quantified 5-methyl and 6-methyl brGDGTs (De Jonge et al., 2014a) performed to reconstruct continental MAT in this region. For this comparison we will consider the present day MAT of the entire Tagus River basin, 14.6±2.2°C (Zell et al., 2014), assuming that soil derived brGDGTs from along the whole river basin are contributing to the marine sediments. The assumption that the brGDGTs from the entire Tagus River basin are being contributed to oceanic sediments is probably invalid for modern times as the construction of dams along the Tagus River, which began in the 1940s, most likely prevents part of the terrestrial material from upstream making it downstream and out off the coast of Portugal. However, since we are not looking at marine surface sediments in this study but instead sediments deposited during the Holocene, the placement of dams in the river should not affect our results except for with the riverine SPM. Despite the separation of the 5- and 6-methyl brGDGT isomers and the application of the new proxy, the reconstructed MATs using both riverine SPM and Holocene sediments is still substantially lower than 14.6°C (Figs. 8b and 8c), as noted for the soils (see Sect. 5.1). Using the MAT_{mr} calibration the Lisbon Canyon Head sediments the average temperature (12.4±0.5°C) comes closest to the modern day MAT in the region and using the MAT_{mrs} calibration the Lower Setúbal Canyon sediments (11.2±0.7°C) has the most similar average temperature (Figs. 8b and 8c).

Even though we used the new calibration to reconstruct MAT, it should be noted that the low BIT values (<0.15; Fig. 3c) of the Holocene sediments deposited at the three marine sites indicates that there were probably not enough soil-derived brGDGTs making it out to ocean and being deposited in the sediments over the Holocene for reliable climate reconstructions (cf. Weijers et al., 2014). By looking at the summed concentration of brGDGTs along the entire transect, it is apparent that since it is lowest in the soils that although the BIT index seems high enough for MAT reconstructions in the riverbank sediments and river SPM, the origin of the brGDGTs may not be solely soil derived and this could be complicating reconstructions throughout the transect as was discussed previously (see Sect. 5.2). This further supports earlier conclusions from preceding studies (Yang et al., 2012; Zell et al., 2013) stating that the amount and origin of brGDGTs in a system needs to be examined along with the BIT index when determining if brGDGTs can be applied for MAT reconstruction.

5~~6~~. Conclusions

We have established that the distribution of brGDGTs varies greatly within the Tagus River basin (Fig. 5) and although this may be partly explained by the varying contributions of higher altitude, which contain a greater proportion of 6-methyl isomers, versus lower altitude soils in the sample sets it is more likely due to the contribution of aquatically produced brGDGTs in some of the sample sets. In order to use sedimentary brGDGTs for paleoclimate reconstructions, the distribution of brGDGTs in the soils must be related to the MAT and conserved throughout riverine transport to the sediments where they are deposited, however, our results corroborate previous studies stating that most of the terrestrial matter is not making it out to the ocean and being deposited in sediments close to shore. The lack of soil derived

633 OM in offshore sediments along with the substantial input of aquatically produced brGDGTs
634 is complicating MAT reconstructions from sedimentary, marine brGDGTs in this region.

635 Additionally, we confirm the findings of Zell et al., (2014; 2015) that in-situ production
636 of brGDGTs is occurring in the river and marine systems of the Tagus River basin and go on
637 to show that there are indications that it occurred in the past as well. Although in-situ
638 production is complicating environmental reconstructions using marine sediments, another
639 issue is that accurate MAT reconstructions using brGDGTs cannot currently be performed on
640 the soils, even with the separation of the 6-methyl brGDGTs from the 5-methyl isomers using
641 the new method and calibrations. Previous studies have concluded that paleoclimate
642 reconstructions in arid regions using brGDGTs are complicated due to a breakdown in the
643 relationship with MBT' and MAT (Peterse et al., 2012; Menges et al., ~~2013~~2014). In this
644 study we confirm that there is not a strong relationship between the MBT'$_{5me}$ and measured
645 MAT in this arid region. However, we also do not observe the same relationship with MAP
646 and MBT'$_{5me}$ that has been previously reported between MAP and MBT' in arid regions and
647 has been implicated in making reconstructions difficult. Instead, we see a strong relationship
648 with the DC' and measured MAT in the area not observed before. We also see a
649 predominance of 6-methyl isomers, previously only reported in river SPM, in the Tagus soils
650 from greater than 350 m altitude. Although this might be a characteristic of arid soils and
651 related to MAP since it is below 550 mm yr^{-1} in most of the soil samples above 350 m, the
652 two highest elevation soil samples, which both have a MAP above 550 mm yr^{-1}, also
653 demonstrate this trend. Future studies need to be performed in arid environments to determine
654 if a strong relationship between MAT and DC' as well as a predominance of 6-methyl isomers
655 are characteristics of arid regions and contributing to the complications found using brGDGTs
656 for paleoclimate reconstructions. Also, higher elevation environments should be further

studied to determine if a predominance of 6-methyl brGDGTs is a feature of higher altitudes and complicating climate reconstructions.

Because of these unique features in this region, perhaps the development of a local calibration could assuage difficulties in using brGDGTs as a paleoclimate proxy for soils in the Tagus River basin. This would not, however, solve the issue of in-situ produced brGDGTs overwhelming the amount of soil derived brGDGTs in aquatic sediments. We did find that the new CBT' and pH calibration do an excellent job reconstructing pH in the soils of the Tagus basin and since pH is related to other environmental factors such as MAP this will be useful for paleoclimate reconstructions in terrestrial sites over the Iberian peninsula where in-situ production is not a complicating factor.

Author contribution

J.H. Kim and J.S.S. Damsté designed the study, which was carried out by L. Warden who completed bulk carbon isotope and brGDGT analysis on samples along with C. Zell. C. Zell, H. Stigter, G.J. Vis and J.H. Kim collected samples for this study. J. Bonnin picked forams for dating. L. Warden and J.S.S. Damsté prepared the manuscript with contributions from all co-authors.

Acknowledgements

The research leading to these results has received funding from the European Research Council under the European Union's Seventh Framework Programme (FP7/2007-2013) / ERC grant agreement n° [226600]. JSSD is supported by funding from the Netherlands Earth System Science Center (NESSC) though a gravitation grant from the Dutch ministry for Education, Culture and Science. We thank the captain and crew of the R/V Pelagia for their

support with sampling. We thank J. Ossebaar and E.C. Hopmans for their help with the HPLC-APCI-MS analysis, J. Ossebaar for his help with the element analyzer, and L.A.C. Rosales and A. Mets for help with sample preparation.

Data Availability

~~The All?~~The data presented in this paper can be found in Table 3 and S2.

Figure captions

Figure 1 The location of the study area on the Iberian Peninsula with the stations where the four sediment cores were sampled (indicated by black squares) along a transect from the Tagus River to off the Portuguese continental margin as well as the river SPM sampling site (indicated by a white diamond), riverbank sediment sampling sites (indicated by red circles), and soil sampling sites (indicated by black circles). The River SPM, riverbank sediments and soil samples were all collected for a previous study. Digital elevation data from Jarvis et al. (2006) and bathymetry from IOC-IHO-BODC (2003).

Figure 2 Boxplots of (a) $\delta^{13}C_{TOC}$ (‰) of the organic carbon and (b) TOC (wt. %) for each sample set along the Tagus River source to sink transect. The increasing $\delta^{13}C_{TOC}$ values in the sediment core locations with increasing distance from the coast indicates that more of the organic carbon in these sediments is marine derived.

Figure 3 Boxplots of (a) crenarchaeol concentrations (µg gOC^{-1}), (b) sum of brGDGTs (µg gOC^{-1}), (c) BIT index, (d) DC', (e) IR, (f) MBT'_{5me} for each sample set in the transect from the land to the ocean off the Portuguese coast.

Figure 4 Isomer ratio for the non-cyclized pentamethylated brGDGT (IR_{II}) plotted against that of the non-cyclized hexamethylated brGDGT (IR_{III}).

Figure 5 Average distribution of brGDGTs for each sample set along the transect of samples that runs from the land to the ocean off the coast of Lisbon. Evident from this figure is that the distribution of brGDGTs within this sample set varies greatly. Distributions of brGDGTs in marine sediments only reflects the distribution of the brGDGTs from the Tagus soils to a minor extent. The color of the bars reflects the brGDGT structure as labeled in the legend and the range indicated with the error bars equals 2xs the standard deviation.

Figure 6 Principal component analysis based on the fractional abundances of the 15 brGDGTs of samples in the transect that runs from inland to off the coast of Portugal plotting a) the scores of the brGDGT compounds on the first two principal components (PC) and b) the scores of the samples from each sample set used in this study.

Figure 7 Scatter plots of (a) PC1 against the IR (R^2=0.78) and (b) PC2 against DC' (R^2=0.84) for the entire set of samples used in this study.

Figure 8 Boxplots of all the sample sets within the transect from the land to the deep ocean off the Portuguese coast for (a) reconstructed pH, (b) MAT_{mrs} (°C) and (c) MAT_{mr} (°C). Red dotted line indicates estimated present day MAT for the Tagus River basin (14.6°C).

Figure 9 Panels a-c show scatterplots of the Tagus soil samples for a) reconstructed and measure pH (R^2=0.89), b) reconstructed MAT_{mr} (°C) and measured MAT (°C) (R^2=0.27), c) reconstructed MAT_{mrs} (°C) and measured MAT (°C) (R^2=0.38). For panels b-c the soil samples from an altitude greater than 350m are indicated in black and those from an altitude below 350m are indicated in green. Panels d-f show scatter plots of the Tagus riverbank sediments for d) reconstructed and measured pH (R^2=0.14), e) reconstructed MAT_{mr} (°C) and measured MAT (°C) (R^2=0.31), f) reconstructed MAT_{mrs} (°C) and measured MAT (°C) (R^2=0.23). Panel g is a scatter plot showing the reconstructed and measured pH for the Tagus River SPM samples (R^2=0.09).

~~**Figure 10** Scatterplot of the BIT index and $\delta^{13}C_{TOC}$ (‰ VPDB) for the entire Portuguese sample set (R^2=0.55). In general, higher BIT values correlate with more depleted $\delta^{13}C_{TOC}$ indicating a more terrestrial signal and lower BIT values correlate with less depleted $\delta^{13}C_{TOC}$ indicating a more marine signal.~~

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Table 1 ~~Pprovides the s~~Stations, sediment core names, locations of sampling and water depth for each sediment core used in this study.

Station	Core name	Latitude [N]	Longitude [W]	Water depth [m]
0501.029	Tagus River Floodplain	39° 23' 07.80"	08° 31' 55.56"	0
64PE332-30-2	Tagus Mudbelt	38° 39' 02.20"	09° 28' 07.68"	82
64PE332-44-2	Lisbon Canyon Head	38° 30' 20.19"	09° 15' 04.87"	259
64PE269-39-4	Lower Setúbal Canyon	38° 13' 12.00"	10° 10' 00.00"	4217

Table 2 Ssummarizesy of the data used to determine an age depth model for the sediment samples in this study. [a]Data is from Vis et al., (20082010).

Sediment core	Lab code	Depth in core [cm]	Mean depth in core [cm]	Uncorrected AMS^{14}C ages [yr BP]	Analytical error (±1σ) [yrs]	Ages (ΔR = 0 yr) (±2σ) [cal yr BP]	Ages [cal yr BP]	Analyzed material
0501.029[a]		0-2	1				0	
0501.029[a]		331-334	332.5	1136	38	964-1150	1057	Roots of fraction>125µm
0501.029[a]		331-334	332.5	1022	37	901-1001	951	Total organic fraction>125µm
0501.029[a]		604-607	605.5	3089	38	3209-3383	3296	Terrestrial botanical macrofossils
0501.029[a]		711-712	711.5	4129	42	4530-4821	4676	Terrestrial botanical macrofossils
0501.029[a]		1024-1029	1026.5	5790	40	6485-6676	6581	Terrestrial botanical macrofossils
0501.029[a]		1046-1050	1048	5900	45	6633-6805	6719	Terrestrial botanical macrofossils
64PE332-30-2		0-2	1				0	
64PE332-30-2	BETA 348791	20-22	21	500	30	40-236	138	Gastropod fragments
64PE332-30-2	BETA 348792	428-430	429	1730	30	1221-1349	1285	*Ammonia beccarii* (benthic forams)
64PE332-30-2	BETA 348793	678-680	679	2320	30	1848-2032	1940	Gastropod
64PE332-30-2	BETA 317911	976-978	977	5370	30	5643-5849	5746	Bivalve shell fragments
64PE332-44-2		0-2	1				0	
64PE332-44-2	BETA 317906	521-523	521.5	2330	30	1858-2044	1951	Mixed planktonic forams
64PE332-44-2	BETA 317907	770-772	771.5	5390	30	5664-5865	5765	Gastropod
64PE332-44-2	BETA 317908	924.5-926.5	925.5	8160	40	8515-8798	8657	Mixed planktonic forams
64PE269-39-4		0	0				0	
64PE269-39-4	BETA 330562	5	5	930	30	486-608	547	G. bulloides (planktonic forams)
64PE269-39-4	BETA 330563	100	100	4980	50	5205-5466	5336	G. bulloides (planktonic forams)
64PE269-39-4	BETA 330564	200	200	10190	40	11092-11271	11182	G. bulloides (planktonic forams)
64PE269-39-4	BETA 348794	280	280	11540	40	12865-13150	13008	G. bulloides (planktonic forams)

Table 3. Concentrations of GDGTs and brGDGT based indices for each sample set along the transect. ~~Values in red were previously published in Zell et al., (2014).~~

Sample name	Age (cal. kyrs. BP)	TOC[a] (wt. %)	$\delta^{13}C_{TOC}$ [a] (‰ VPDB)	~~Crenarchaeol (µg gOC^{-1})~~ ~~Sum brGDGTs~~ Concentration (µg gOC^{-1})		BIT index	MBT'$_{5me}$	DC'	IR	IR IIa	IR IIIa [JD1]
				Crenarchaeol	Sum brGDGTs						
Tagus soils											
TRS-8b	n/a	3.0	-27.8	2.2	19.2	0.88	0.51	0.13	0.39	0.36	0.43
TRS-7	n/a	5.0	-27.5	0.0	7.5	1.00	0.56	0.01	0.13	0.12	0.17
TRS-9	n/a	0.5	-27.2	0.1	7.8	0.99	0.68	0.01	0.14	0.14	0.15
TRS-3	n/a	0.7	-29.0	0.6	4.1	0.87	0.40	0.05	0.41	0.43	0.39
TRS-4	n/a	0.7	-28.7	1.2	5.3	0.81	0.42	0.04	0.39	0.41	0.30
TRS-5	n/a	2.2	-28.4	2.4	15.3	0.85	0.29	0.10	0.37	0.37	0.35
TRS-10	n/a	1.5	-28.5	1.4	1.6	0.49	0.60	0.19	0.84	0.88	0.83
TRS-12	n/a	0.2	-25.1	4.0	2.4	0.34	0.62	0.22	0.87	0.87	0.91
TRS-14b	n/a	0.8	-25.3	1.7	2.1	0.48	0.57	0.32	0.85	0.89	0.86
TRS-13	n/a	6.9	-27.0	0.9	1.2	0.54	0.33	0.13	0.74	0.80	0.71
TRS-15	n/a	0.9	-25.7	1.9	2.0	0.48	0.46	0.21	0.86	0.90	0.86
TRS-16	n/a	0.1	-24.8	1.6	3.0	0.62	0.56	0.19	0.92	0.93	0.93
TRS-20	n/a	0.1	-26.1	0.6	3.8	0.84	0.52	0.38	0.83	0.87	0.83
TRS-19	n/a	0.1	-25.7	0.7	19.7	0.95	0.56	0.44	0.84	0.85	0.89
Tagus Riverbank sediments											
TRS-6	n/a	1.7	-26.3	16.7	76.0	0.77	0.53	0.30	0.54	0.46	0.59
TRS-8a	n/a	0.2	-26.5	10.8	68.2	0.83	0.55	0.26	0.77	0.71	0.83
TRS 2a	n/a	3.3	-23.6	3.4	12.8	0.70	0.63	0.42	0.79	0.81	0.77
TRS 2b	n/a	0.5	-25.1	8.1	55.1	0.80	0.57	0.45	0.67	0.72	0.72
TRS 1a	n/a	0.9	-26.9	9.7	18.8	0.62	0.54	0.21	0.68	0.68	0.66
TRS1b	n/a	1.5	-27.6	26.1	19.7	0.28	0.64	0.53	0.72	0.82	0.80
TRS-11	n/a	1.3	-27.0	6.3	3.9	0.33	0.48	0.24	0.75	0.79	0.75
TRS-14a	n/a	3.0	-27.1	1.2	21.7	0.92	0.38	0.44	0.55	0.56	0.68
TRS-17	n/a	3.7	-29.6	1.6	37.8	0.93	0.41	0.51	0.70	0.65	0.66
TRS-22	n/a	0.6	-29.8	3.1	24.8	0.86	0.41	0.40	0.80	0.75	0.82
Tagus River SPM											
TR 2 Sup July	n/a	2.6	-29.2	6.2	33.1	0.80	0.51	0.28	0.60	0.53	0.64
TR 3#1 –Sup Sept.	n/a	1.8	-28.4	5.6	20.7	0.73	0.52	0.30	0.59	0.51	0.61
TR4 #1 Oct.	n/a	2.5	-30.9	8.6	38.1	0.77	0.52	0.30	0.61	0.54	0.62
TR5 #1 Sup Nov.	n/a	1.3	-28.9	5.8	54.8	0.85	0.49	0.25	0.62	0.55	0.68
TR 6 #1 Sup Dec.	n/a	2.4	-29.4	11.5	86.8	0.85	0.47	0.26	0.63	0.56	0.67
TR7 #1 Sup Jan.	n/a	2.4	-29.8	9.8	53.6	0.77	0.48	0.27	0.63	0.56	0.67
TR8 #1 Sup Feb.	n/a	1.0	-29.4	16.8	46.9	0.69	0.50	0.27	0.58	0.51	0.62
TR9 #1 Sup Mar.	n/a	2.2	-29.0	6.3	21.9	0.72	0.50	0.29	0.58	0.51	0.61
TR10 #1 Sup Apr.	n/a	1.9	-28.5	0.8	36.5	0.96	0.52	0.29	0.58	0.50	0.61
TR11 #1 Sup May	n/a	1.7	-28.5	26.3	80.8	0.69	0.52	0.29	0.56	0.48	0.59

TR12 #1 Sup June	n/a	1.3	-27.8	9.5	22.8	0.65	0.55	0.23	0.51	0.48	0.58
Tagus River Floodplain sediments (0501.029) depth (cm)											
10.0	0.0	1.7	-26.3	2.1	29.7	0.92	0.34	0.31	0.39	0.39	0.44
95.0	0.3	2.6	-26.5	6.4	66.8	0.89	0.36	0.24	0.43	0.43	0.45
195.0	0.6	1.5	-27.4	2.5	111.8	0.97	0.34	0.37	0.38	0.40	0.43
241.0	0.8	1.5	-26.0	5.2	62.0	0.90	0.40	0.24	0.35	0.36	0.38
341.5	1.0	11.2	-27.5	0.9	47.6	0.97	0.45	0.39	0.36	0.34	0.37
401.0	1.5	12.1	-27.7	1.2	90.6	0.98	0.38	0.38	0.40	0.36	0.46
453.0	2.0	8.0	-26.7	3.0	120.9	0.97	0.34	0.35	0.43	0.43	0.50
542.0	2.8	7.7	-27.3	3.2	91.9	0.95	0.37	0.39	0.40	0.41	0.42
577.0	3.1	4.6	-27.2	3.3	84.2	0.95	0.43	0.35	0.38	0.37	0.41
641.0	3.8	5.3	-28.1	1.0	59.6	0.97	0.52	0.39	0.34	0.35	0.39
681.0	4.3	6.6	-28.6	1.0	52.3	0.97	0.46	0.45	0.37	0.37	0.42
741.0	4.9	4.2	-24.4	4.2	74.3	0.92	0.43	0.45	0.38	0.38	0.36
862.0	5.6	16.2	-26.8	2.2	58.4	0.94	0.45	0.45	0.46	0.43	0.52
982.0	6.3	8.7	-27.7	1.5	46.5	0.95	0.46	0.49	0.37	0.36	0.37
1041.0	6.7	5.2	-27.2	4.4	48.2	0.87	0.48	0.45	0.40	0.39	0.41
Mudbelt sediments (64PE332-30-2) depth (cm)											
1.0	0.0	1.2	-23.7	200.9	28.5	0.09	0.58	0.35	0.51	0.45	0.54
25.0	0.2	1.0	-24.2	194.7	40.7	0.13	0.54	0.28	0.49	0.43	0.52
53.0	0.2	0.9	-24.5	189.3	36.4	0.13	0.52	0.26	0.47	0.44	0.50
75.0	0.3	1.0	-24.4	206.5	43.8	0.14	0.52	0.26	0.48	0.43	0.51
101.0	0.4	0.9	-24.3	228.9	44.4	0.13	0.53	0.27	0.48	0.43	0.51
151.0	0.5	0.9	-24.3	194.8	40.2	0.13	0.53	0.27	0.49	0.44	0.53
201.0	0.6	1.0	-24.5	187.9	31.9	0.11	0.51	0.27	0.47	0.43	0.50
248.0	0.8	0.6	-24.5	224.0	58.0	0.14	0.53	0.26	0.46	0.42	0.49
297.0	0.9	1.1	-24.5	168.3	30.6	0.12	0.50	0.26	0.47	0.42	0.51
347.0	1.1	1.0	-24.1	202.5	24.3	0.08	0.52	0.30	0.50	0.45	0.53
397.0	1.2	1.1	-24.1	180.4	27.3	0.10	0.49	0.30	0.48	0.43	0.52
429.0	1.3	1.2	-24.0	77.3	8.7	0.08	0.50	0.34	0.53	0.45	0.57
496.0	1.5	1.0	-24.3	143.8	15.1	0.07	0.52	0.32	0.53	0.46	0.57
546.0	1.6	0.9	-24.1	11.2	1.4	0.08	0.52	0.33	0.51	0.45	0.55
596.0	1.7	1.1	-27.3	141.3	14.8	0.07	0.51	0.34	0.52	0.45	0.56
645.0	1.9	1.1	-29.9	108.7	12.8	0.08	0.52	0.34	0.52	0.45	0.55
680.0	2.0	1.1	-27.4	142.1	17.4	0.08	0.54	0.31	0.50	0.44	0.54
741.0	2.7	0.8	-27.3	176.1	16.0	0.06	0.52	0.35	0.53	0.46	0.55
791.0	3.4	0.7	-24.5	240.8	19.8	0.05	0.50	0.37	0.55	0.48	0.58
840.0	4.0	0.9	-24.4	139.3	11.0	0.05	0.48	0.37	0.54	0.48	0.55
890.0	4.6	0.6	-24.6	180.2	14.2	0.05	0.48	0.39	0.55	0.47	0.57
977.0	5.7	0.7	-27.5	125.8	11.8	0.06	0.46	0.40	0.53	0.46	0.52
Lisbon Canyon Head sediments (64PE332-44-2) depth (cm)											
1.0	0.0	1.5	-22.9	420.5	27.1	0.04	0.60	0.41	0.55	0.48	0.56

45.0	0.2	1.2	-22.8	409.9	47.3	0.07	0.58	0.40	0.55	0.48	0.57
85.0	0.3	1.1	-23.4	440.4	48.1	0.07	0.54	0.36	0.53	0.46	0.55
130.5	0.5	1.2	-23.4	429.6	41.2	0.06	0.55	0.36	0.53	0.46	0.57
187.5	0.7	1.2	-23.7	308.4	27.6	0.06	0.56	0.36	0.53	0.45	0.56
221.5	0.8	1.1	-24.4	157.9	35.1	0.12	0.54	0.28	0.47	0.42	0.51
278.5	1.0	1.2	-23.2	283.6	22.7	0.05	0.54	0.36	0.51	0.45	0.54
326.5	1.2	1.0	-22.6	361.7	31.1	0.05	0.53	0.42	0.56	0.47	0.60
371.5	1.4	1.1	-22.6	374.1	26.5	0.05	0.53	0.41	0.55	0.47	0.58
429.0	1.6	1.0	-22.6	399.6	29.2	0.05	0.55	0.42	0.56	0.49	0.59
480.0	1.8	1.1	-23.4	242.3	18.0	0.05	0.54	0.41	0.55	0.48	0.57
502.0	1.9	1.1	-23.9	365.1	25.4	0.04	0.52	0.42	0.56	0.49	0.58
522.0	2.0	1.0	-23.4	376.8	30.9	0.05	0.55	0.39	0.55	0.48	0.57
550.0	2.4	1.0	-23.0	363.1	26.7	0.05	0.54	0.43	0.57	0.50	0.59
570.0	2.7	0.7	-22.6	493.6	34.3	0.04	0.53	0.43	0.57	0.50	0.59
630.0	3.6	0.7	-22.4	389.6	25.7	0.04	0.53	0.44	0.58	0.51	0.60
686.0	4.5	0.5	-22.4	640.2	40.7	0.04	0.54	0.45	0.59	0.51	0.60
728.0	5.1	0.5	-22.1	100.1	6.7	0.04	0.50	0.45	0.57	0.51	0.58
771.0	5.8	0.7	-23.3	620.7	37.3	0.04	0.53	0.44	0.58	0.50	0.59
805.0	6.4	0.3	-22.1	414.0	25.9	0.04	0.52	0.45	0.58	0.51	0.58
869.5	7.6	0.3	-22.3	538.9	35.7	0.04	0.54	0.41	0.57	0.50	0.56
925.5	8.7	0.3	-23.1	409.4	30.1	0.04	0.52	0.46	0.59	0.51	0.58
Lower Setúbal Canyon sediments (64PE269-39-4) depth (cm)											
1.0	0.0	0.8	-23.5	265.3	20.3	0.05	0.68	0.38	0.73	0.60	0.77
20.0	1.3	0.7	-22.3	506.5	15.6	0.02	0.60	0.39	0.77	0.60	0.80
40.0	2.3	0.6	-22.0	751.5	18.1	0.02	0.58	0.39	0.73	0.61	0.75
60.0	3.3	0.8	-22.2	540.7	16.2	0.02	0.56	0.46	0.75	0.61	0.74
80.0	4.3	0.8	-22.3	460.5	13.5	0.02	0.56	0.41	0.75	0.63	0.77
100.0	5.3	0.8	-22.8	204.7	7.3	0.03	0.57	0.37	0.74	0.66	0.75
120.0	6.5	0.7	-22.8	199.2	8.0	0.03	0.57	0.38	0.77	0.66	0.78
140.0	7.7	0.5	-26.1	433.3	13.6	0.02	0.51	0.41	0.73	0.67	0.74
160.0	8.8	0.5	-22.8	395.6	16.9	0.03	0.45	0.43	0.69	0.64	0.64
180.0	10.0	0.4	-24.9	709.2	25.6	0.02	0.48	0.43	0.69	0.58	0.65
200.0	11.2	0.5	-25.7	703.9	22.1	0.02	0.54	0.41	0.66	0.52	0.64
220.0	11.6	n/a	n/a	n/a	n/a	0.02	0.48	0.47	0.66	0.52	0.59
240.0	12.1	n/a	n/a	n/a	n/a	0.01	0.56	0.57	0.70	0.56	0.63
260.0	12.6	n/a	n/a	n/a	n/a	0.03	0.58	0.49	0.71	0.58	0.64
280.0	13.0	n/a	n/a	n/a	n/a	0.01	0.52	0.48	0.69	0.57	0.65

[a] Data for Tagus soils, riverbank sediments and SPM have previously been published by Zell et al. (2014).