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EDITORIAL

Advances in phytolith research in archaeology and paleoecology: developments and applications

Marta Dal Corso[1,2] · Ákos Pető[3] · Luc Vrydaghs[4] · Rosa Maria Albert[5,6] · Wiebke Kirleis[2] · Ana Polo-Diaz[7] · Welmoed A. Out[8]

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We are honoured to present this special issue in *Vegetation History and Archaeobotany* resulting from the 12th International Meeting for Phytolith Research (IMPR). The IMPR is the official conference of the International Phytolith Society (IPS, https://phytoliths.org/).

Phytoliths are microscopic bodies produced by living plants consisting of opal silica (for phytolith formation see discussion and references in Hodson et al. 2020). In the *longue durée*, they survive in multiple palaeoecological as well as archaeological archives (e.g. Strömberg et al. 2018; Cabanes 2020). Used alone or in combination with other proxies, they allow to address topical issues related to major socio-cultural, environmental and climatological developments in the past. Phytolith studies witnessed an increase in applications within the fields of archaeology, ecology and taxonomy, amongst others.

With the increase of phytolith-related studies, the demand for forums where phytolith researchers can share and exchange knowledge, manifested in the 1st IMPR held in Madrid in 1996. For a long period, the biannual meetings were organised by European research centres engaged in phytolith research: 1st IMPR Madrid 1996 (Pinilla et al. 1997); 2nd IMPR Aix-en-Provence 1998 (Meunier and Colin 2001); 3rd IMPR Brussels 2000; 4th IMPR Cambridge 2002 (Madella and Zurro 2007); 5th IMPR Moscow 2004; 6th IMPR Barcelona 2006 (Albert and Madella 2009). Looking back to the first meeting in Madrid, we can retrospectively state that the conference has established a highly diverse multi- and interdisciplinary platform for all those researchers, who were and still are engaged in the world of phytolith analysis, as reflected by the title of the Madrid proceedings: "*The state-of-the-art of phytoliths in soils and plants*" (Pinilla et al. 1997). The first non-European event within the line of IMPRs, the 7th IMPR, marks a historical meeting as it was held together with the 4th South American Meeting on Phytolith Research in 2008 at Mar del Plata, Argentina (Osterrieth 2008; Madella et al. 2013). The IMPR remained in the Americas for the following conference: the 8th IMPR was organised in Estes Park, Colorado, USA (2011), within the scenery setting of the Rocky Mountains. For the successive two events the IMPR returned to Europe: 9th IMPR Brussels 2014 (Neumann et al. 2017); 10th IMPR Aix-en-Provence 2016. During the 11th meeting, organised in Wuhan 2018, phytolith researchers came together for the first time in China and on the Asian continent. Subsequently, the 12th IMPR returned to Europe again. It took place in Germany and was part of the annual meeting of the European Association of Archaeologists (EAA), one of Europe's most popular archaeological meetings. By the time we prepared this special issue as outcome of the 12th IMPR, the 13th IMPR had taken place at the foot of Mt. Masada in

✉ Marta Dal Corso
marta.dalcorso@unipd.it

1 Department of Geosciences, University of Padua, Via Giovanni Gradenigo, 6, 35131 Padova, PD, Italy

2 Institute of Prehistoric and Protohistoric Archaeology, Kiel University, Johanna-Mestorf- Straße 2-6, 24118 Kiel, Germany

3 Department of Nature Conservation and Landscape Management, Hungarian University of Agriculture and Life Sciences, Villányi út 29-43, Budapest 1118, Hungary

4 Archaeology, Environmental Changes & Geo-Chemistry (AMGC) - VUB, Pleinlaan 2, Brussels 1050, Belgium

5 ICREA, Passeig Lluís Companys 23, Barcelona, Barcelona 08010, Spain

6 Department of Prehistory, Autonomous University of Barcelona (UAB), 08193 Cerdanyola del Vallès, Barcelona, Spain

7 Department of Archaeology, University of Sheffield, 40 Leavygreave Rd, Broomhall, Sheffield S3 7RD, UK

8 Department of Archaeological Science and Conservation, Moesgaard Museum, Moesgaard Allé 20, Højbjerg 8270, Denmark

2023, Dead Sea, Israel (Katz et al. in prep.), and the upcoming 14th IMPR will take place in Barcelona in 2025. An overview of the conferences and abstracts can be found at https://phytoliths.org/international-meetings-on-phytolith-research/. Aside from these worldwide conferences, and occasional sessions at other international conferences (e.g. Hart 2016), there are also more regionally and continentally oriented meetings, reoccurring taking place e.g. in Australia, South America, China and Europe, underlining the extent to which phytolith research is applied. For instance, the "South American Meeting on Phytolith Research", organised by the GSFACS (Grupo de Estudios Fitolíticos Aplicados del Cono Sur), took place several times in Argentina and the third "Latin American Workshop on Micropaleoethnobotany" will be held in 2025 in Estado do Paraná, Brazil.

Throughout the series of phytolith meetings, the scientific scope of these events broadened: besides botanical and pedological approaches, archaeology, environmental history/paleoecology as well as morphometric and taxonomic studies became more and more popular. The diversification of phytolith studies can also be measured in the establishment of various committees working under the auspices of the IPS (https://phytoliths.org/ips-standing-committees/). One main outcome has been the establishment of the International Code for Phytoliths Nomenclature by the ICPN working group (ICPN 1.0, Madella et al. 2005) later updated by the International Committee for Phytolith Taxonomy (ICPN 2.0, ICPT, Neumann et al. 2019). Another IPS committee is the International Committee for Phytolith Morphometrics (ICPM), which has published open source morphometric software and recommendations towards standardisation of phytolith morphometry (Ball et al. 2016), a review on morphometrics in archaeobotany (Portillo et al. 2020) and recently a study on inter- and intra-observer variation in phytolith morphometry to work towards improved standardisation, which also includes revised instructions for the open source software (Out et al. 2024a). Finally, the International Committee on Open Phytolith Science (ICOPS, https://open-phytoliths.netlify.app/) aims to increase the knowledge of and implementation of open science practices in phytolith research, whilst striving to make phytolith research more open, reproducible and FAIR (https://www.go-fair.org/fair-principles/). This committee has been organising training courses on GitHub, clinic sessions on open science, training workshops on open research, a project on increasing the FAIRness of phytolith data, and has provided guidelines on open publishing (Karoune 2022; Kerfant et al. 2023; Ruiz-Pérez et al. 2024).

One emerging key element of the IMPRs consists of workshops organised prior to or within the official meetings. These occasions serve as a venue for researchers to share and exchange experience at the microscope and beyond, but also form a significant part of the educational scene of the phytolith world, where knowledge is disseminated and exchanged by means of seminars, workshops and practicals in various fields of this interdisciplinary line of research.

The 12th IMPR was held in Kiel, Germany, in September 2021 and was hosted by the Environmental Archaeology group of the Institute of Prehistoric and Protohistoric Archaeology of Kiel University, with support from the Cluster of Excellence ROOTS "Social, Environmental, and Cultural Connectivity in Past Societies" and the Johanna-Mestorf Academy (Fig. 1a). To facilitate and expand interdisciplinary exchange and bring together people with different scientific backgrounds, the conference was organised within the framework of the 27th annual meeting of the EAA entitled "Widening horizons". While the meeting was originally planned to take place in 2020 independently and in person, due to the Covid19 pandemic it was delayed and then effectively held online. Although it was not possible to meet in person, positive outcomes of the online format were that a diverse group of scholars could participate, including people both from a wide range of scientific backgrounds and originating from different continents, including Americas, Africa, East Asia and Oceania, and that the environmental and financial impact of travelling were reduced. As a result, the meeting gathered an extremely international and interdisciplinary scientific community.

With the aim of improving our knowledge of the relationship between vegetation history and human history worldwide, and to gain a better understanding of plant-based economies in different archaeological contexts, the conference aimed to bring together scholars applying phytolith analysis in the fields of archaeology, archaeobotany, palaeoecology and geoarchaeology. The scientific committee of the meeting, coordinated by Marta Dal Corso and Welmoed A. Out, consisted of a team of international scientists and IPS members, who together led seven sessions, amongst them six with presentations and one online microscope session (see https://phytoliths.org/12th-international-meeting-for-phytolith-research/). The meeting started with a joint EAA, IPS and IMPR keynote lecture by Dolores Piperno from the National Museum of Natural History, Washington DC, and the Smithsonian Tropical Research Institute, Panama, titled "Phytolith analysis in neotropical palaeoecology".

The 12th IMPR sessions covered the following topics:

1. Phytoliths in integrated archaeobotanical and ethnoarchaeological studies; keynote speaker Emma Jenkins (Bournemouth University), chaired by Marta Dal Corso and Welmoed A. Out.
2. Phytoliths biogeochemistry – From phytoliths formation and role in modern plants to new proxies for archaeology and palaeoecology; keynote speakers Carla

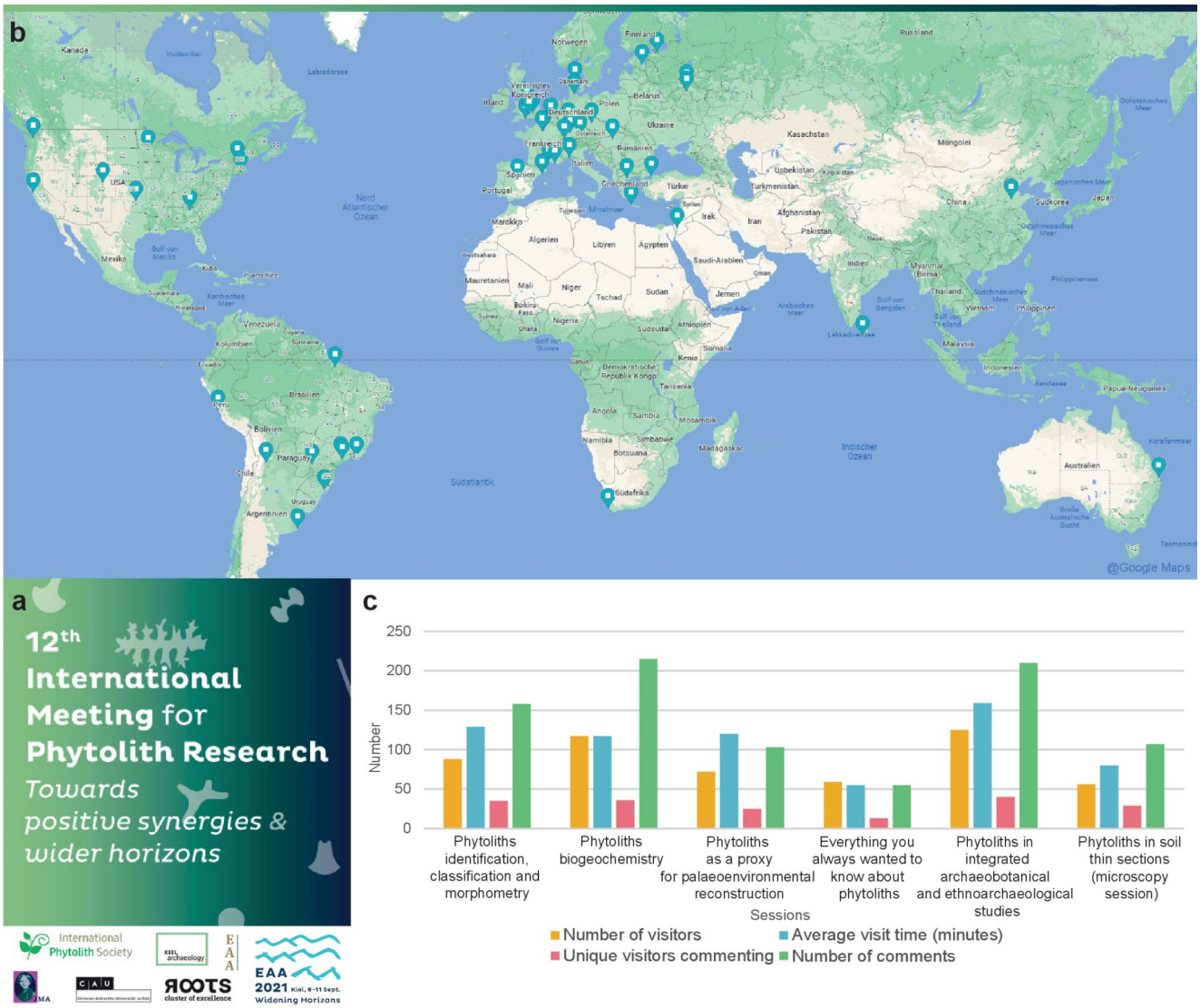

Fig. 1 **a** Logo of the conference designed by J. Cordts (Kiel University) and logos of hosting and supporting institutions; **b** countries of origin of the participants of the 12th IMPR; **c** statistics about the audience and participation in the online sessions

Lancelotti (ICREA, Universitat Pompeu Fabra) and Martin Hodson (Oxford Brookes University), chaired by Alexandre Chevalier, Marta Dal Corso and Stefan Dreibrodt.

3. Phytoliths as a proxy for palaeoenvironmental reconstruction; keynote speaker Doris Barboni (CNRS - CEREGE, Aix-Marseille University), chaired by Wiebke Kirleis and Ákos Pető.
4. Phytolith identification, classification and morphometry, chaired by Welmoed A. Out and Luc Vrydaghs.
5. Everything you always wanted to know about phytoliths (but were afraid to ask): Their contribution to the modelling of past human behaviour, chaired by Alexandre Chevalier and Rosa Maria Albert.
6. Phytoliths in geoarchaeology and micromorphology; keynote speaker Yannik Devos (Vrije Universiteit Brussel), chaired by Ana Polo-Diaz and Luc Vrydaghs.
7. Phytoliths in soil thin sections (microscopy session), chaired by Ana Polo-Diaz, Yannik Devos, and Svetlana Kamnueva-Wendt.

These sessions included 79 contributions, including 64 oral and 15 poster presentations, by participants originating from 24 countries worldwide (Fig. 1b). The posters, available online during the conference, were shortly presented orally. To support the visibility of women in research, financial support by the grant "*Frauen aufs Podium!*" of the Faculty of Arts and Humanities of Kiel University, arranged by Marta Dal Corso, covered the registration fees for 13 participants. According to EAA's statistics about attendance,

the conference audience of the 12th IMPR sessions included 517 participants (Fig. 1c). Since the IMPR is not only about science but equally about the people who make the community, we payed tribute to the memory of Barbara Eichhorn (1967–2020, Germany, see OR1 in Neumann et al. 2022) and her exceptional archaeobotanical work in Africa as researcher of the Goethe University, Frankfurt/Main. At the end of the conference, the IPS gave awards for best presentations to Kristýna Hošková (Hošková et al. 2022), Eduardo Trein Salgado (Salgado et al. 2021), and Francesca D'Agostini (see D'Agostini et al. 2024).

The present special issue contains papers from the first three sessions of the 12th IMPR as well as two other papers about comparable phytolith-based research. Papers that focus on the use of plants by past populations include four contributions, starting with the study of phytoliths from a Viking Age equestrian burial, which have been analysed both morphologically and morphometrically in the contribution by Out et al. (2022). Formalising identification criteria, this paper provides unique evidence of the use of oat as horse fodder in such a burial context, raising the hypothesis that many comparable, earlier excavated Viking-Age equestrian graves and ship burials also contained horse fodder as a grave good. In another study, Out et al. (2024b) for the first time present a study on plant economy combining macrobotanical studies with phytoliths and starch analysis of grinding stones from a northern European Funnel Beaker site. The analyses on the plant use and plant food preparation at this site, Frydenlund, show that although cereals were present, these were not ground, indicating that they most likely were prepared as gruel instead of bread. The study is complemented by a newly revised overview on the crop assemblage of Funnel Beaker sites in northern Europe, clarifying but also questioning the role of various wheat taxa, and showing the presence of both *Papaver somniferum* (opium poppy) and *Linum usitatissimum* (flax). In a subsequent paper by Ögüt and Karakaya (2024), phytolith analysis has been applied to investigate the Middle Bronze Age site of Zincirli Höyük in Anatolia where it contributes to the understanding of economic and architectural aspects in combination with other botanical and geoarchaeological proxies. The study focuses on food processing and storage installations, abandoned after conflagration and covered by debris of the fired structure. Phytolith assemblages from these installations suggest flour-based dough was prepared, whereas vessels were not used to store cereal grains. For mud brick production, cereal by-products were used as temper, and woody dicotyledonous taxa, reed and sedges provided material for the roof, as testified by the phytolith record. Hilbert et al. (2023) present a phytolith study from a pre-Columbian shell mound and an overlaying layer at the site of Tucumã on Marajó archipelago, Brazil, occupied from 4,425 to 4,245 to 1,693–1,523 cal BP. The adoption of certain subsistence strategies in reaction to environmental change is discussed. The outcomes shed light on the shell mound and post-shell mound inhabitants' diets, and indicate that maize and squash were introduced in the region earlier than expected. Ferreira Machado et al. (2022) use phytolith analysis to reconstruct environmental conditions at the archaeological site and discuss possible uses of plants. They focus on the case study of the shell mound Casa de Pedra in São Francisco do Sul, Santa Catarina, Brazil, which was occupied during the 6th and 5th millennium BP. In terms of methodological contributions, D'Agostini et al. (2024) present a detailed experimental study on the potential of phytolith analysis of the C_4-crops *Eleusine coracana* (finger millet), *Cenchrus americanus* (pearl millet) and *Sorghum bicolor* (sorghum) to reconstruct agricultural water management practices at archaeological sites in dryland regions. The outcomes show how phytolith composition in these different C_4-crops changes with water availability, supporting the potential of phytolith analysis to detect plant growing conditions, but also challenging the earlier model about fixed vs. sensitive phytoliths. Testé et al. (2024) explore auto-fluorescent phytoliths as indicators of fire in different modern and ancient subtropical and tropical contexts in Guatemala, Senegal and the Canary Islands. Elaborating on the recent discovery of phytoliths becoming fluorescent upon heating (Devos et al. 2021), they apply this method to detect fire in tropical and subtropical contexts to better understand human use of fire and landscape evolution.

The present special issue integrates papers on phytolith applications in archaeology and methodological advances in phytoliths research that reflect an active and critical research community, constantly reviewing both the determination criteria and the existing interpretation models in order to refine the information provided by phytolith analysis. By doing so the relevance of phytoliths for the reconstruction of past human-environment interaction is strengthened. Taken together, the seven papers represent an important update of the state of the art in the study of phytoliths, expanding and opening new avenues to improve our knowledge in the field from different perspectives.

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