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Interpretation of prehistoric reddish pit fillings on Easter Island: A micromorphological perspective

Interpretación de rellenos rojizos de fosas prehistóricas en la Isla de Pascua: una perspectiva micromorfológica
Interpretação de preenchimentos avermelhados de poços pré-históricos na Ilha de Páscoa: uma perspetiva micromorfológica

AUTHORS

Khamnueva S. [1,@]
skhamnueva@ecology.uni-kiel.de

Mieth A.[1]

Dreibrodt S.[1]

Out W. A.[2]

Madella M.[3]

Bork H-R.[1]

[@] Corresponding Author

[1] Institute for Ecosystem Research, Christian-Albrechts-University of Kiel. Olshausenstrasse 40. 24098 Kiel, Germany.

[2] Moesgaard Museum, Department of Archaeological Science and Conservation. Moesgaard Allé 20. 8270, Højbjerg, Denmark.

[3] Catalan Institution for Research and Advanced Studies (ICREA)/ University Pompeu Fabra. Department of Humanities, C/Trias Fargas, 25-27. 08005 Barcelona, Spain.

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ABSTRACT

In the context of geoarchaeological investigations on Easter Island several hundred human-made pits filled with reddish silty material were discovered in fluvial terraces of two valleys on the southern slope of Maunga Terevaka, the highest volcano of the island. Micromorphological analysis of one representative pit filling and comparison of its geochemical and physical properties with sediments in the surrounding terrace was performed in order to reconstruct the probable formation and use of the material in the pits. A hypothesis of pigment production by heating of minerogenic iron-rich substrate with grass fuel resulting in formation of hematite is suggested. It is assumed that the pits represented the places for production and storage of the pigments, which were used by Rapa Nui for cultural and ritual purposes. The ongoing interdisciplinary research will enhance the interpretation of the pits and their fillings and contribute to a better understanding of cultural development on Easter Island.

RESUMEN

En la Isla de Pascua, varios cientos de fosas artificiales rellenas de material limoso rojizo han sido descubiertas en las terrazas de dos valles de la ladera meridional de Maunga Terevaka, el volcán más alto de la isla. Se han efectuado análisis micromorfológicos del relleno de una de estas fosas, así como la comparación de sus propiedades geoquímicas y físicas con los sedimentos de la terraza en que se ubica, con el objetivo de reconstruir la formación y el uso del material de las fosas. Se sugiere la hipótesis de producción de pigmento mediante el calentamiento del sustrato (rico en hierro de origen mineral) con combustible herbáceo, dando como resultado la formación de hematita. Se asume que las fosas constituyen los lugares de producción y almacenamiento de los pigmentos, los cuales eran usados por los Rapanui para propósitos culturales y rituales. La investigación interdisciplinar en marcha mejorará la interpretación de estas fosas y de sus rellenos.

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RESUMO

No contexto de investigações geo-arqueológicas na Ilha de Páscoa, diversos poços de origem antrópica preenchidos com material limoso avermelhado foram descobertos em terraços fluviais de dois vales na base da vertente sul do Maunga Terevaka, o vulcão mais alto da ilha. Efetuaram-se análises micromorfólogicas do material de preenchimento de um poço representativo e compararam-se as suas propriedades geoquímicas e físicas com as dos sedimentos de um terraço próximo para reconstruir a provável formação e uso do material de preenchimento dos poços. Sugere-se a hipótese da produção de pigmentos através do aquecimento de sedimentos ricos em ferro usando combustível herbáceo e formando deste modo hematite Assume-se que os poços representavam lugares para produção e armazenamento de pigmentos, os quais foram usados pelos Rapa Nui em rituais e manifestações culturais. Esta investigação interdisciplinar irá contribuir para uma melhor interpretação e compreensão dos poços e dos materiais usados no seu preenchimento bem como do desenvolvimento cultural na Ilha de Páscoa.

KEY WORDS
Rapa Nui, pigment production, iron oxide, hematite, micromorphology.

PALABRAS CLAVE
Rapa Nui, producción de pigmento, óxidos de hierro, hematita, micromorfología.

PALAVRAS-CHAVE
Rapa Nui, produção de pigmentos, óxidos de ferro, hematite, micromorfologia.

1. Introduction

Landscape transformation on Easter Island (Polynesian: *Rapa Nui*) under human impact has been a topic for intensive discussions since the beginning of research activities on the island (Mann et al. 2008; Mieth and Bork 2010; Rull et al. 2010; Bahn and Flenley 2011; Rull 2016). Rapa Nui, located ca. 3,500 km west of the Chilean coast in the Pacific Ocean (27°9'S 109°26'W, **Figure 1**), is considered the most remote inhabited island on Earth. It remained uninhabited probably until around 700 or 800 AD, when the first Polynesian people arrived at this volcanic island. At this time it was covered with woodland, dominated by an endemic palm species beside other trees and shrubs (Orliac 2000; Mieth and Bork 2004; Delhon and Orliac 2010). Under this woodland Chromic Cambisols with thicknesses of 60-120 cm developed, while in the most eastern part of the island, on Poike peninsula, Ferralsols formed; later erosion transformed them mostly to Entisols (Mann et al. 2003; Louwagie et al. 2006; and investigations by the authors). Since the occupation of the island by Polynesians, the upper parts of the Chromic Cambisols have been widely transformed into Anthrosols by gardening practices, enforced by intensive organic mulching. The Polynesians practiced gardening first between palms in the woodlands and later, after extensive forest clearing which reached its peak between 1300 and 1500 AD, in the open land (Mieth and Bork 2018). Resulting soil erosion and loss of fertile Anthrosols dramatically deteriorated living conditions and cultural dynamics in some parts of the island (Mieth and Bork 2003, 2006, 2010, 2018). The decline of the woodland resources gave rise to the theory of collapse of the society and culture on Rapa Nui (Diamond 2005). However, latest findings disprove this popular theory and provide evidence for significant continuity and development of the Rapa Nui culture, e.g. monumental architecture and extensive stone mulching that required well-organized labour of a large population (Mulrooney 2013; Cauwe and De Dapper 2015; Mieth and Bork 2015; Stevenson et al. 2015).

The study presented here focuses on new findings from the island represented by more than 350 anthropogenic pits, with an average volume of 100 litres and filled with bright reddish silty material, that were discovered by the authors in March 2011. The pits were dug into

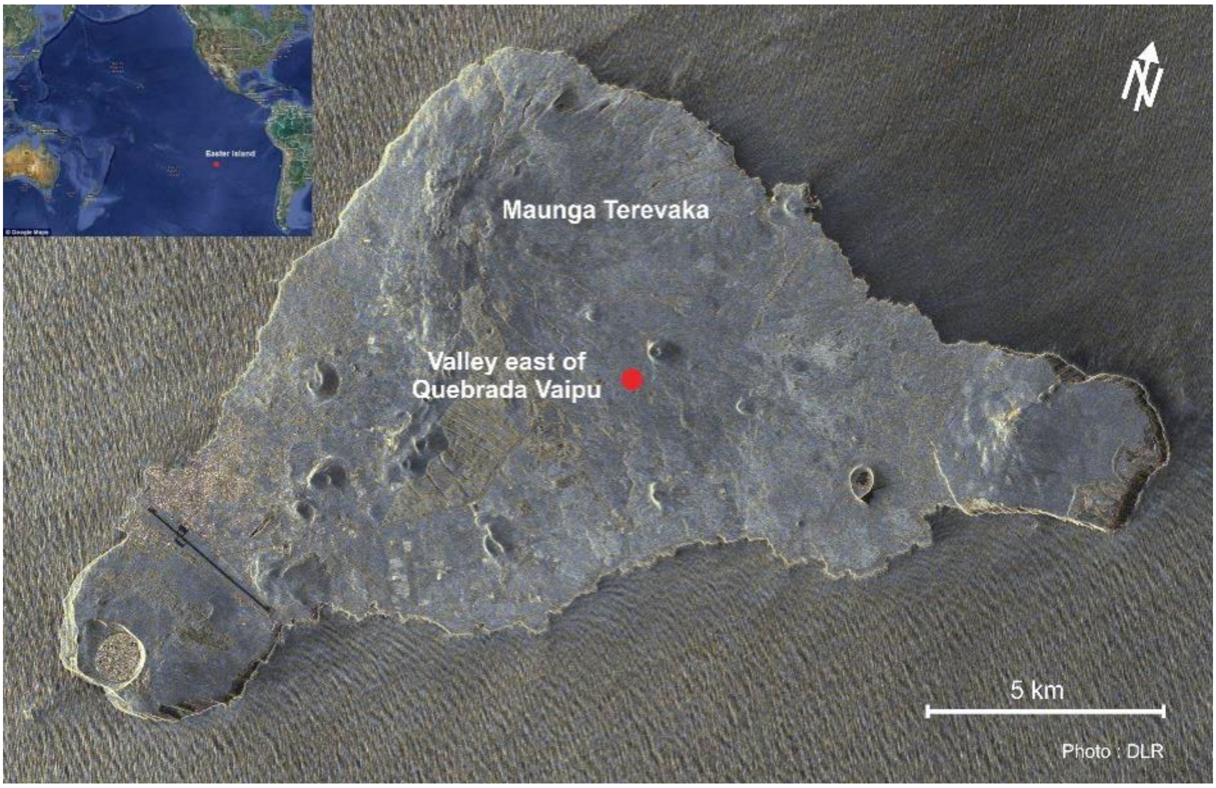

Figure 1. Radar image of Easter Island (produced by satellite TerraSar-X) with location of the study area (map in upper left corner: © Google Maps)

fluvial terraces along two valleys on the southern flank of Maunga Terevaka, which at 510 m a.s.l. is the highest volcano on the island. A fluvial terrace along a small tributary valley east of Quebrada Vaipu (**Figures 1 and 2**; "Quebrada" is the Spanish word for "gulch" or "valley") is particularly rich in such pits.

Two profiles (5 m and 11 m wide) were opened at the edge of the fluvial terrace along the tributary valley of Quebrada Vaipu for geoarchaeological investigation (**Figure 2**). One of the two profiles (profile 1) was investigated in this study in more detail with the aim to shed light on the genesis of the pit fillings and to contribute to the ongoing discussion of human-landscape interactions on Rapa Nui. In order to achieve this goal, geochemical and soil physical methods, as well as micromorphological analysis and analyses of phytoliths and diatoms were conducted for the fluvial sediments and one pit filling in profile 1.

2. Material and Methods

2.1. Geomorphologic setting of the investigation area

Numerous volcanic eruptions on Maunga Terevaka caused lava outflows and the deposition of many lava layers in the form of a large staircase. On the southern slope of Maunga Terevaka, water streams cut often deep ravines into the volcanic rocks (mostly unweathered olivine basalts) at the steps of the staircase. Below the steps, the streams cut 2 to 4 m deep and 10 to 20 m wide floodplains into the rocks. The floodplains are characterized by a low downstream gradient. A large part of the material that was eroded on slopes upstream and in the ravines, was deposited in the flat floodplain segments. Thus, in the longitudinal profile, streams consist of alternating segments of steep and deep ravines and flat and wide floodplains with terraces, covered with alluvial sediments. Due to the shape of the slopes –

convex lower slope segments are dominant – colluvial sediments were only deposited at small strips at the margins of the flood plains. Most material that was eroded on the slopes in the upper part of the catchments was transported into the valley and downstream at least to the nearest floodplain segment.

On top of the fluvial terrace along the tributary valley of Quebrada Vaipu, a gravel layer is exposed at the land surface. It consists of loose and rounded basalt gravel (5-15 cm in diameter), rounded by transport along the valley in a single, strong runoff event. The gravel is roughly layered parallel to the longitudinal profile of the valley. This sediment does not incline towards the neighbouring convex slopes. The hollows between the stones are not filled with fine sediment or other material. Thus, it could clearly be identified as a fluvial layer.

The base of the investigated flat floodplain segment of the tributary valley of Quebrada Vaipu is composed of an erosional surface in unweathered basalt. On this erosional base, coarse fluvial sediments and anthropogenic material were deposited. The bedding of all fluvial sediments is orientated roughly parallel to the longitudinal profile. Colluvial sediments are missing due to the shape of the slopes.

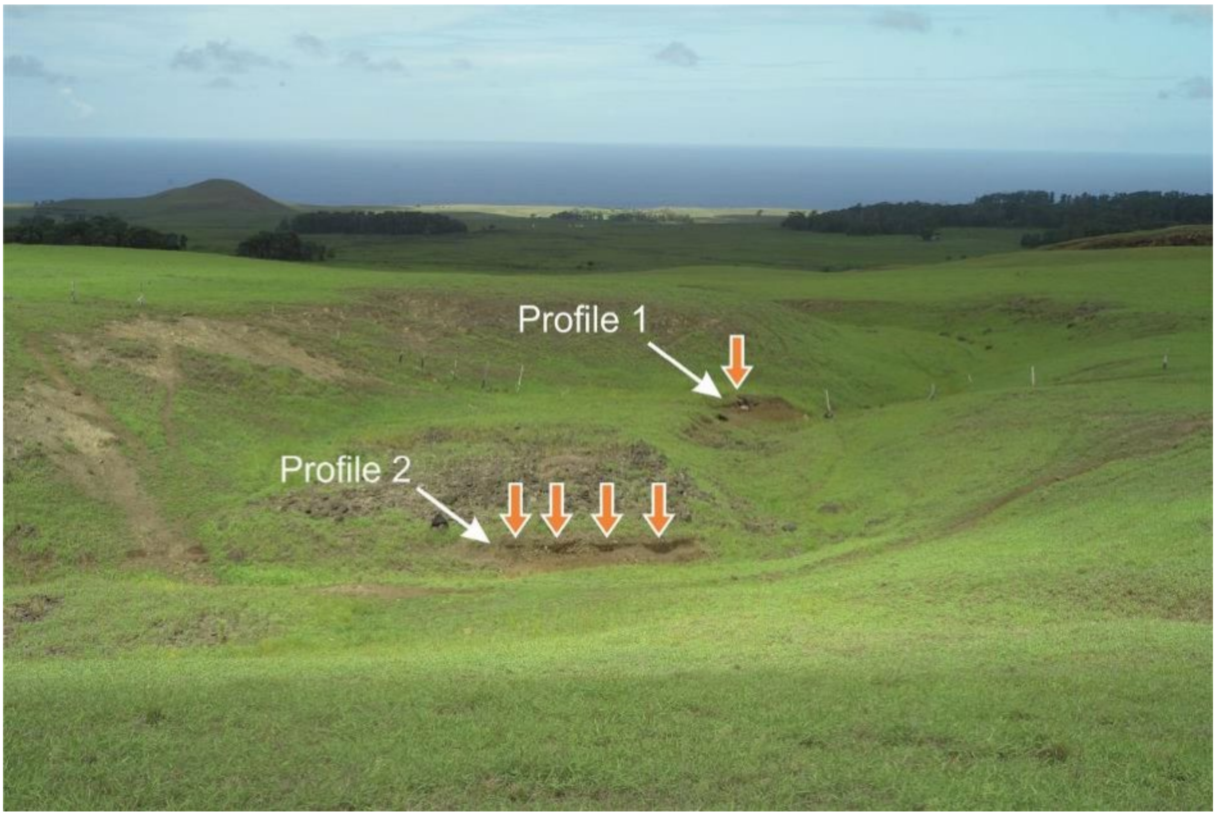

Figure 2. Tributary valley east of Quebrada Vaipu with two profiles in a fluvial terrace partly opened for investigation. Orange arrows mark locations of some of the pits.

2.2. Soil analysis

Soils and sediments were described in the field following FAO (2006) guidelines and documented by scaled drawings and photographs. ^{14}C dating was performed on charcoal fragments at Leibniz Laboratory for Radiometric Dating and Stable Isotope Research (KIA), University of Kiel, Germany, and at Beta Analytic Radiocarbon Dating Laboratory (Beta), Miami, USA. Bulk density was determined by a standard method with 100 cm^3 cylinders and by samples taken as cubes of 1 cm^3 volume from a short horizontal sediment core (**Figure 3**).

Measurement of total carbon content was performed by combustion at 1000 °C with subsequent chromatographic separation using Euro EA-CHNSO Element Analyser. Since the HCl test for presence of carbonates was negative for all samples, the measured values of total carbon were interpreted as total organic carbon (TOC) content. Grain size distribution was measured by laser diffraction method with Mastersizer 2000 particle size analyser. Grain size fractions correspond to the grain size limits used in the guidelines for soil description by FAO (2006): clay < 2 µm, silt 2-63 µm, fine sand 63-200 µm, medium sand 200-630 µm and coarse sand 630-2000 µm. Multi-element analysis was carried out by X-ray fluorescence using XL3t 900-series GOLDD+ instrument by Thermo Scientific Niton Analyzers. The obtained values were calibrated by means of regression models acquired by Dreibrodt et al. (2017). Ratio of silica to titanium is proportional to the biogenic silica content (Kylander et al. 2011; Liu et al. 2013) and was used as a proxy for the content of biogenic silica in the samples.

Magnetic susceptibility (MS) was measured at low (0.465 kHz) frequency using a Bartington Instruments MS2 meter. Calibration was performed using 1% Fe_3O_4 calibration sample. In a conjunction with the measurement of magnetic susceptibility, two heating experiments were performed to analyse the processes of ferromagnetic mineral transformations at different temperatures and under different conditions. In the first experiment, multi-heating process at temperatures 250 °C, 600 °C and 700 °C in a muffle furnace was performed with three replications following the experiment design of Jelenska et al. (2010). The samples were subsequently heated under oxidizing conditions. After each cycle of heating and cooling down to room temperature, magnetic susceptibility was measured. In the second experiment, potential magnetic susceptibility determined by a maximal conversion of ferrimagnetic minerals was assessed with three replications following the procedure of Clark (1996) and Crowther (2003). Household flour was added to the samples (5% of sample weight) to guarantee reducing conditions during the burning process and to minimize effects of differing organic matter contents. Afterwards the samples were heated at 650 °C for 1 hour in reducing conditions (with crucibles covered with a lid) and for 45 minutes in oxidising conditions (without the lid) in a muffle furnace. Magnetic susceptibility was measured after the samples cooled down to room temperature.

X-ray-diffractometry (XRD) was carried out to analyse the mineralogy using a Philips diffractometer PW1710 (Cu radiation, 40 kV, 25 mA). Conventional powder samples were measured on ground samples of the fine earth fraction < 2 mm (2Theta: 2 to 80°, step size: 0.02, time: 2 s).

For micromorphological analysis, an undisturbed oriented sample was collected from the pit filling. After air-drying, the block was impregnated in vacuum with a two-component epoxy resin Araldite 2020, cut, polished and mounted onto a glass slide (3.5 x 12 cm). The mounted slice was ground, polished to a thickness of 25 µm and covered with a coverslip. The analysis was performed using the terminology and guidelines of Stoops (2003) and Courty et al. (1989). Phytolith samples were processed following the procedure from Madella et al. (1998), which eliminates carbonates, organic matter and clays before mounting the final residue (Acid Insoluble Fraction) on microscopy slides with immersion oil. Phytoliths and diatoms were then observed under a light microscope at 630x magnification.

For a statistical comparison of the properties of the pit filling and the sediments, principal component analysis (PCA) based on a correlation matrix was applied using software PAST v. 3.15. The geochemical and physical properties determined were used as input variables.

3. Results

3.1. Stratigraphic context of the pits

In profile 1, which was excavated in one of the fluvial terraces of the tributary valley east of Quebrada Vaipu, a sequence of fluvial sediments with various archaeological structures embedded was found **(Figures 3 and 4).**

Figure 3. Central part of profile 1 with two generations of reddish pits in a terrace of the tributary valley of Quebrada Vaipu. The length of the folding rule in the photograph is 2 m.

An anthropogenic stone pavement underlain by a fluvial sediment is located at the base of the profile. The pavement is 5-10 cm thick and composed of stones with diameters of 5-30 cm (**Figure 4**). Within this pavement, a small pit of 35 cm in diameter filled with reddish silty material (pit 1) was discovered. Charcoal fragments found in the pit filling were dated to the period between ca. 1,210 and 1,390 cal AD (**Table 1**). The next overlying stratigraphic units include fluvial sediments of different ages (**Table 1**). Due to the layering of these sediments, their position in the floodplain and orientation of the bedding (parallel to the longitudinal profile, no inclination towards the neighbouring slopes), these sediments are definitely fluvial deposits. These fluvial sediments contain large stones deposited by humans. One major structure of stones and sediment (**Figures 3 and 4**) is interpreted in this study as an earth dam rich in stones. The dark brown sediment 4 covering pit 1 is represented by loamy material, while the brown to dark brown sediments 5 and 6 have a texture from sandy loam to silty clay loam. Charcoal fragments found in sediment 6 were dated to 1,310 – 1,420 cal AD (**Table 1**). Embedded in sediment 6, multiple pits filled with reddish material were found. The filling of the pit in the central part of the profile (pit 2) was dated to the period between 1420 and 1650 cal AD (**Table 1**). The pit 2 filling is covered with a very dark brown material, designated as pit cover, which also represents an anthropogenic deposit. Similar pit covers were found above other pits in the study area. The pit cover in the studied profile is buried under another fluvial sediment, which is exposed at the modern surface. Above this fluvial sediment, a gravel layer is present; however, loose stones, composing the gravel layer, slid down during the excavations and for this reason they are not visible in the profile photo and the scheme (behind pit 2 the gravel layer still exists). Under this gravel layer around the profile investigated more pits were identified. The filling of pit 2 showed macromorphological similarities to other pits and was characterized by excellent preservation conditions, thus it was the main object of this investigation, assumed to be representative for other such pits in the fluvial terrace.

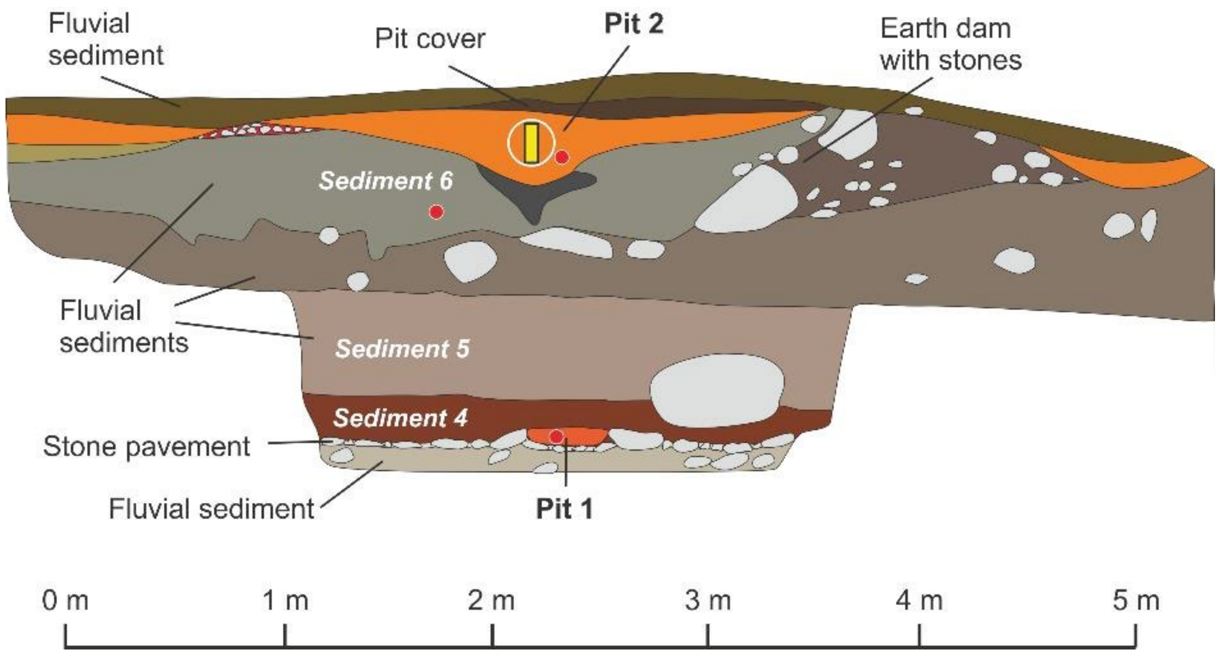

Figure 4. Scheme of the profile in a terrace of the tributary valley of Quebrada Vaipu (red dots: location of charcoal samples taken for dating, white circle – location of the sample for geochemical and physical analyses, yellow rectangle – location of the sample for micromorphological analysis).

Table 1. Radiocarbon data

Deposit	Lab number	Material dated	Radiocarbon age	Calibrated age (2σ range)
Filling of pit 2	KIA 49033	Charcoal	445 ± 30 BP	1419 – 1482 cal AD (95.4%)
	Beta 321021	Charcoal	320 ± 30 BP	1470 – 1650 cal AD (95.4%)
Sediment 6	KIA 48428	Charcoal	580 ± 20 BP	1306 – 1364 cal AD (63.7%) and 1385 – 1415 cal AD (31.7%)
Filling of pit 1	Beta 321020	Charcoal	710 ± 30 BP	1270 – 1310 cal AD and 1360 – 1390 cal AD (95.4%)
	KIA 48426	Charcoal	815 ± 25 BP	1211 – 1266 cal AD (95.4%)

3.2. Macromorphology of pit 2 filling

The reddish filling of pit 2 is finely layered, counting up to several hundred individual layers of < 1 to 10 mm in thickness. The majority of these layers is dominated by reddish silty material. These reddish layers are intermitted by mostly thin layers of light greyish-coloured material and by layers of dark brown material. An undisturbed horizontal core, 12 cm in diameter, was taken from the central part of pit 2 (**Figure 5**). Within this core, areas with domination of reddish, light greyish-coloured and dark brown material were distinguished and designated as core zones PF 1 – 7 (**Figure 5, Table 2**). In zones PF 1 and PF 7 dark reddish brown material is dominating. Zones PF 2, PF 3 and PF 4 contain bright reddish material abundantly intermitted by light greyish-coloured layers. The reddish material in these zones has under moist condition the same dark reddish brown colour as the reddish substrate in zones PF 1 and PF 7, but in a dry state (after drying at 40 °C for 72 hours) it shows a tendency towards lighter colour values (**Table 2**). In zone

PF 5 dark brown material predominates and zone PF 6 represents a transition area between the dark brown and reddish material. The core was used for further geochemical and soil physical analyses. From the centre of the core an oriented and undisturbed sample was taken for micromorphological analysis (**Figure 4**).

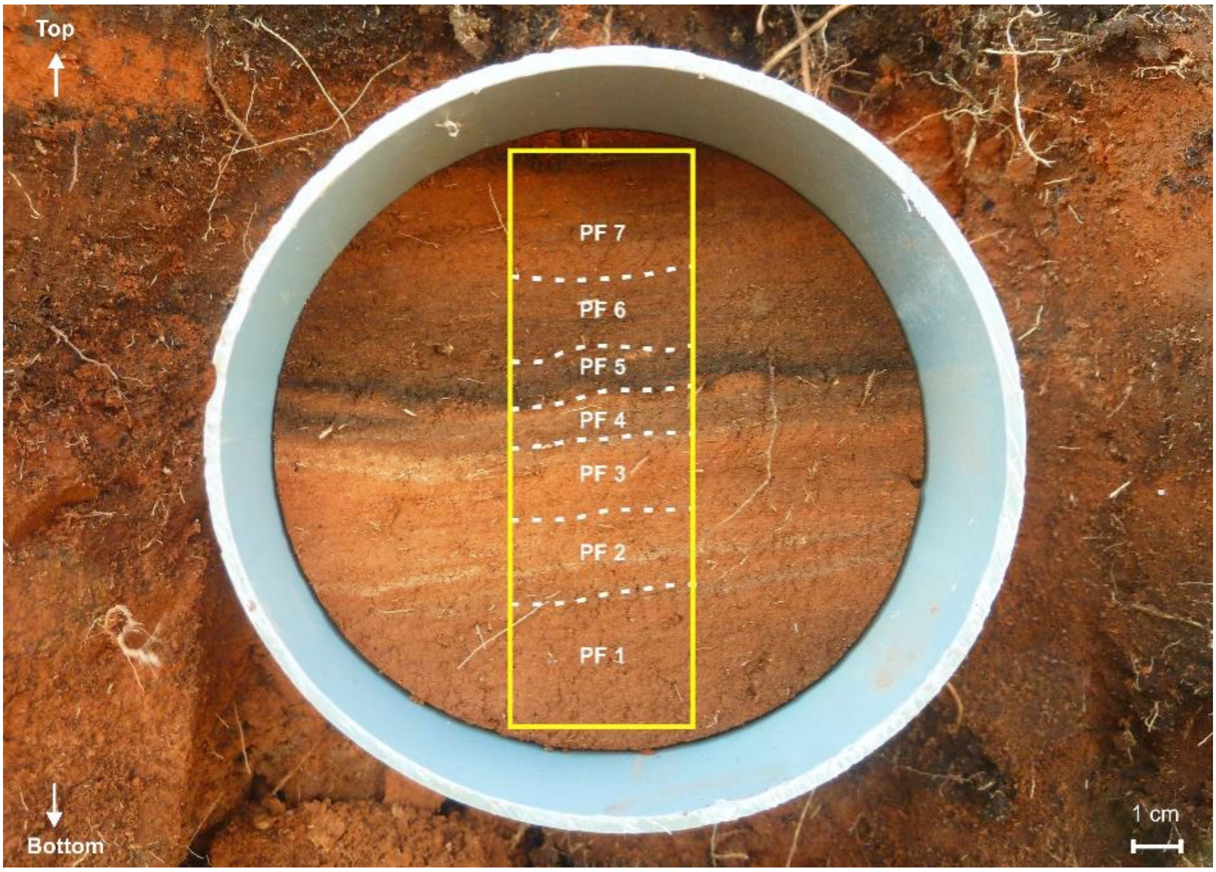

Figure 5. Differentiation of core zones PF 1 – PF 7 for geochemical and physical analyses and location of the sample for micromorphological analysis (yellow frame 3.5 x 12 cm).

3.3. Geochemical and physical properties of the sediments and pit 2 filling

Geochemical and physical properties were determined for the core zones PF 1 – PF 7 as well as for the fluvial sediments 4, 5, 6 and the pit cover from the same profile. The bulk density of the filling of pit 2 was measured in detail for each core zone. The bulk density is characterized by very low values between 0.3 and 0.5 g cm^{-3} (**Table 2**). A comparative investigation with the bulk density of 11 samples from six other pit fillings from the two profiles in Quebrada Vaipu showed a similar range with the lowest value of 0.5 g cm^{-3} and an average of 0.6 g cm^{-3}.

The pit filling is characterized by a relatively high content of total iron varying in a narrow range between 11.6% in zones PF 1 and PF 3 and 14.8% in PF 7. In the pit cover and underlying sediments, higher contents of iron were measured reaching the highest value of 20.5% in sediment 5. The content of total organic carbon (TOC) of the pit filling equals 2.4-3.6% in the reddish zones and in the zones with light greyish layers (zones PF 1 – 4, PF 7), while the dark brown layers have higher values reaching 9.5% in the dark zone PF 5. Pit cover and sediment 4 also have a high organic carbon content of 10.4% and 8.0% respectively, while sediments 5 and 6 have intermediate values (**Table 2**).

The pit filling is characterized by high values of Si/Ti ratio with a maximum of 19.6 in PF 4 zone and a minimum of 9.0 – 10.0 in the uppermost PF 6 and PF 7 zones. In contrast, the sediments and the pit cover were characterized by low Si/Ti values ranging from 1.8 to 4.4.

Silt is the dominant grain size component of the pit filling. Silt contents vary between 77.1 and 81.3% in PF 1 – 4 and PF 6 – 7 and somewhat lower (72.6 %) in zone PF 5, which has a higher sand content of 20%. The zones of the pit filling investigated were thus classified as silt and silt loam. The sediments underlying pit 2 are characterized by varying grain size distributions. Sediment 4 is a loam material with nearly equal amounts of silt and sand and 10% of clay. The overlying sediment 5 is dominated by silt with 58.5% and has a relatively high content of clay (29.1%). Sediment 6 is sandy loam with 66.8% of sand and 26.3% of silt. The grain size distribution of the pit cover is similar to sediment 4, it is also characterized by nearly equal amounts of silt and sand, but in contrast to sediment 4 it has a lower coarse sand content (**Table 2**).

Magnetic susceptibility (MS) was measured for five zones from the core of the pit filling and for the sediments 4, 5 and 6. The amount of the material available from PF zones 4 and 7 and from the pit cover was not sufficient for this analysis. The PF zones of the pit filling are characterized by high values of magnetic susceptibility between 201.1 and 268.8 10^{-6} m^3 kg^{-1}. Sediment 5 also has a high MS of 249.0 10^{-6} m^3 kg^{-1}, while in sediments 4 and 6 the MS values are considerably lower reaching only 148.9 10^{-6} m^3 kg^{-1} in sediment 4.

Table 2. Geochemical and physical properties of the pit filling and sediments in the profile (n.d.: not determined)

Unit	Colour dry	Colour moist	Bd g cm^{-3}	Fe %	TOC %	Si/Ti	MS 10^{-6} m^3 kg^{-1}	Clay %	Silt %	Fine sand %	Medium sand %	Coarse sand %
PF 7	5YR 4/4	5YR 3/4	0.3	14.8	3.6	10.0	n.d.	9.6	80.9	8.7	0.9	0.0
PF 6	5YR 4/3	5YR 3/4	0.3	13.2	6.9	9.0	201.1	6.6	77.1	10.9	3.9	1.6
PF 5	10YR 4/4	7.5YR 2.5/3	0.3	12.8	9.5	11.2	240.1	7.4	72.6	6.5	7.4	6.1
PF 4	7.5YR 6/4	5YR 3/4	n.d.	12.5	3.2	19.6	n.d.	6.5	78.6	7.9	2.8	4.2
PF 3	5YR 5/4	5YR 3/4	0.4	11.6	2.4	15.0	268.8	5.4	81.0	10.9	1.4	1.4
PF 2	5YR 4/4-4/6	5YR 3/4	0.5	13.8	3.3	14.8	239.9	4.9	81.1	11.7	1.5	0.7
PF 1	5YR 4/4-4/6	5YR 3/4	0.4	11.6	2.5	16.5	244.0	4.8	81.3	12.0	1.4	0.5
Pit cover	10YR 3/4	10YR 2/2	n.d.	16.4	10.4	4.3	n.d.	8.3	46.1	19.2	24.3	2.0
Sediment 6	10YR 4/3	10YR 3/3	n.d.	14.1	3.3	4.4	138.5	6.8	26.3	13.8	39.8	13.3
Sediment 5	10YR 4/3	10YR 3/3	n.d.	20.5	5.8	1.8	249.0	29.1	58.5	6.5	5.4	0.5
Sediment 4	7.5YR 3/4	7.5YR 3/3	n.d.	16.0	8.0	2.0	148.9	10.0	44.7	16.7	18.2	10.4

Two heating experiments were performed in order to trace the behaviour of magnetic susceptibility of pit 2 filling and sediments 4 and 5 under different burning conditions. As **Figure 6** shows, both sediments behave similarly in the multi-heating experiment, although the absolute MS values differ considerably. After heating at 250 °C, a slight increase of MS takes place in the sediments, while MS of the pit filling changes insignificantly. Dramatic changes occur during heating at 600 °C: MS of sediment 5 increases more than threefold and MS of sediment 4 increases more than twice in contrast to the MS of the pit 2 filling, which decreases by 21% of the value after 250 °C heating. At 700 °C, all materials behave in a similar way: MS strongly decreases.

The potential MS determined after heating to 650 °C in the maximal conversion experiment (**Figure 6**) is very high for the sediments (close to the MS values of strongest enhancement in the multi-heating process at 600 °C) indicating that they contain considerable amounts of minerals that can be converted to ferrimagnetic minerals maghemite/magnetite. On the contrary, the potential MS of the pit filling is relatively low, implying that the material contains only small amounts of iron-bearing minerals that are potentially convertible to ferrimagnetic minerals.

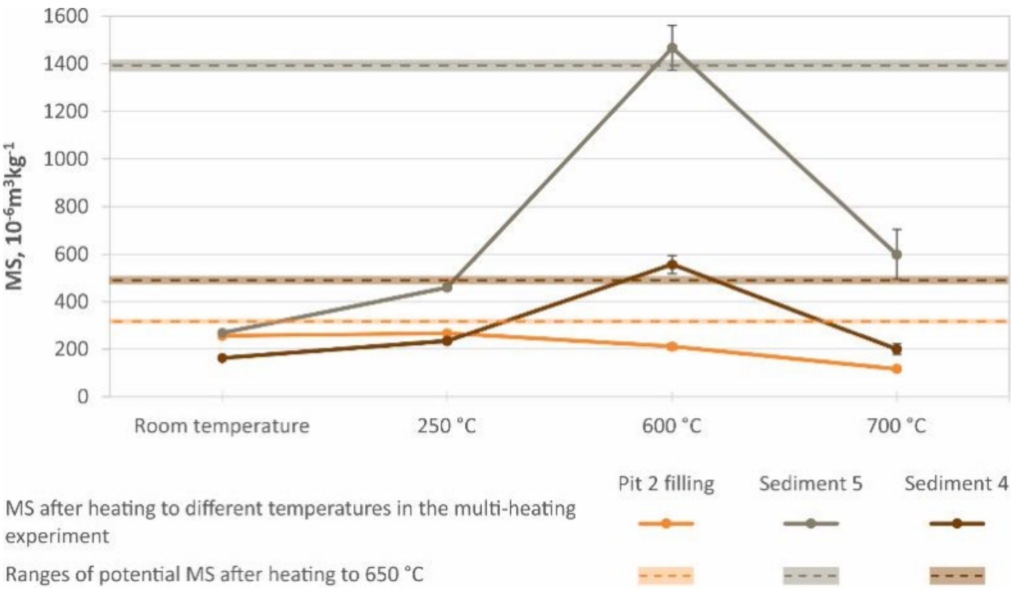

Figure 6. Changes of magnetic susceptibility in the multi-heating experiment (solid lines) and ranges of potential susceptibility reached in the maximum conversion experiment (dashed lines – mean values, transparent rectangles – ranges defined as mean ± standard deviation).

The XRD patterns of the three sediment layers indicate the presence of hematite and maghemite in varying amounts (**Figure 7**). This is clearly visible in the changing ratio of the peaks h100 and h75/m100. Sediment 4 contains more hematite compared to sediment 6 and especially to sediment 5. In sediment 5 small amounts of goethite are present and also the content of maghemite is higher in sediment 5 than in other sediment samples. Additionally, the aluminium oxides gibbsite and bayerite, as well as some quartz and anhydrite are present in the sediment layers. Sediment 6 contains rutile, additionally.

The mineral assemblages of the pit filling are harder to examine, since all samples of this material are characterized by a certain amount of amorphous material (biogenic silica) resulting in typical scattered inferences between ca. 17 and 27° 2Theta and an in general more diffuse pattern of peaks. Nonetheless, the presence of hematite and maghemite in the pit filling is clearly documented. The lower part of the pit fill contains more hematite compared to the upper ones.

3.4. Micromorphology of pit 2 filling

A thin section from the core of the central part of pit 2 filling was prepared containing the core zones PF 1 – 7 (**Figure 5**). Within the zones, alternating thin layers of reddish, light greyish-coloured and dark brown material can be well recognized in the thin section scan (**Figure 8a**). The thickness of the thin layers varies between ca. < 1 and 10 mm.

In transmitted and oblique incident light (**Figures 8a and 8e**) it can be seen that the reddish material is dominated by iron oxide. The microstructure of the reddish silty part of the pit filling is granular and in some places enaulic with non-interconnected vughs, vesicles and occasional burrowing structures and chambers (zones PF

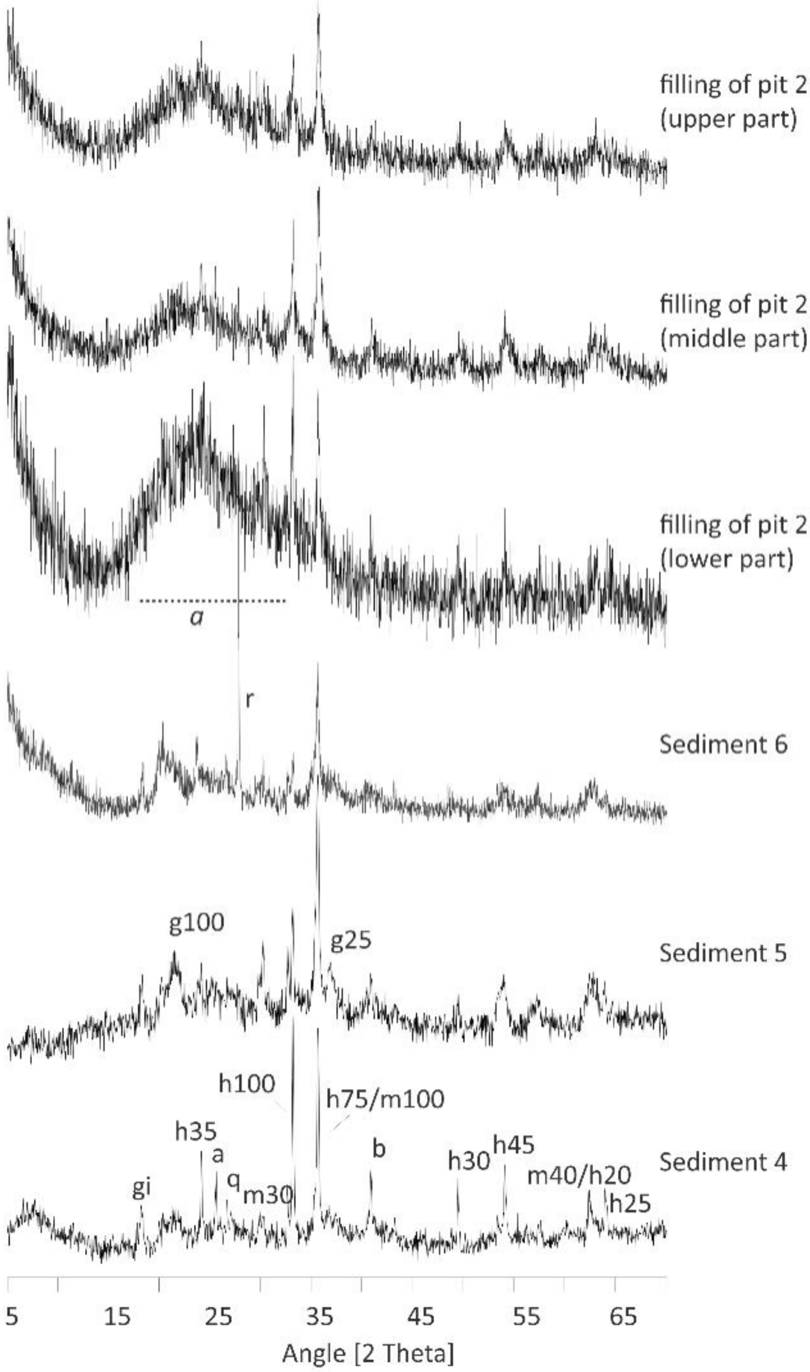

Figure 7. Representative XRD patterns of powder samples from three sediment layers from profile 1 and three parts (lower, middle and upper) of the pit 2 filling. Abbrevations: h – hematite, m – maghemite, g – goethite, gi – gibbsite, b – bayerite, a – anhydrite, q – quartz, r – rutile, a – amorphous material, opal (numbers give the relative intensity of peaks for selected minerals).

1, 2, 3, 7, **Figure 8b**). The c/f-related distribution is fine monic. Iron-rich material is represented by aggregates and granules of varying size (from 10 to 50 µm) of microcrystalline iron oxide compounds (**Figure 8c**). Within the reddish material in zones PF 2, 6, 7 interlayers with thicknesses of 10 – 20 µm representing slaking crusts were found. They are composed of the same but finer and more compacted material interrupted by bioturbation features (**Figure 8d**). Among pedofeatures, a few hypocoatings of iron-rich material along pores were identified. Small fragments of volcanic glass are distributed in the whole thin section.

Phytoliths are distributed in the whole matrix of core material, but form at least five distinct concentrated layers (1-3 mm thick) of horizontally oriented, partly articulated phytoliths (zones PF 2-4, **Figure 8g**). Ongoing analysis shows that the phytoliths in the filling of pit 2 are dominated by bilobates, notched bilobates and crosses, all representing grass short cells of the Panicoideae subfamily (C4 grasses); various types of elongated long cells, particularly psilate and twisted long cells, which can be assigned to grasses/sedges (Poaceae/Cyperaceae); few sedge cone phytoliths and few phytolith morphotypes typical of Dicotyledons. The grass and grass/sedge assemblage was dominated by disarticulated phytoliths (single cells) with some silica skeletons consisting of clusters of 2-6 cells, indicating good preservation and negligible pre-depositional transport. In the sediments outside the pit, globular echinate palm phytoliths (Arecaceae) predominate. In addition, diatoms are present in the light greyish-coloured phytolith-rich layers. A preliminary identification of diatom species points to the presence of species adapted to semi-terrestial/semi-aquatic conditions (e.g. *Pinnularia sp.*), which may occur in moist, air exposed environments (Guiry and Guiry 2017).

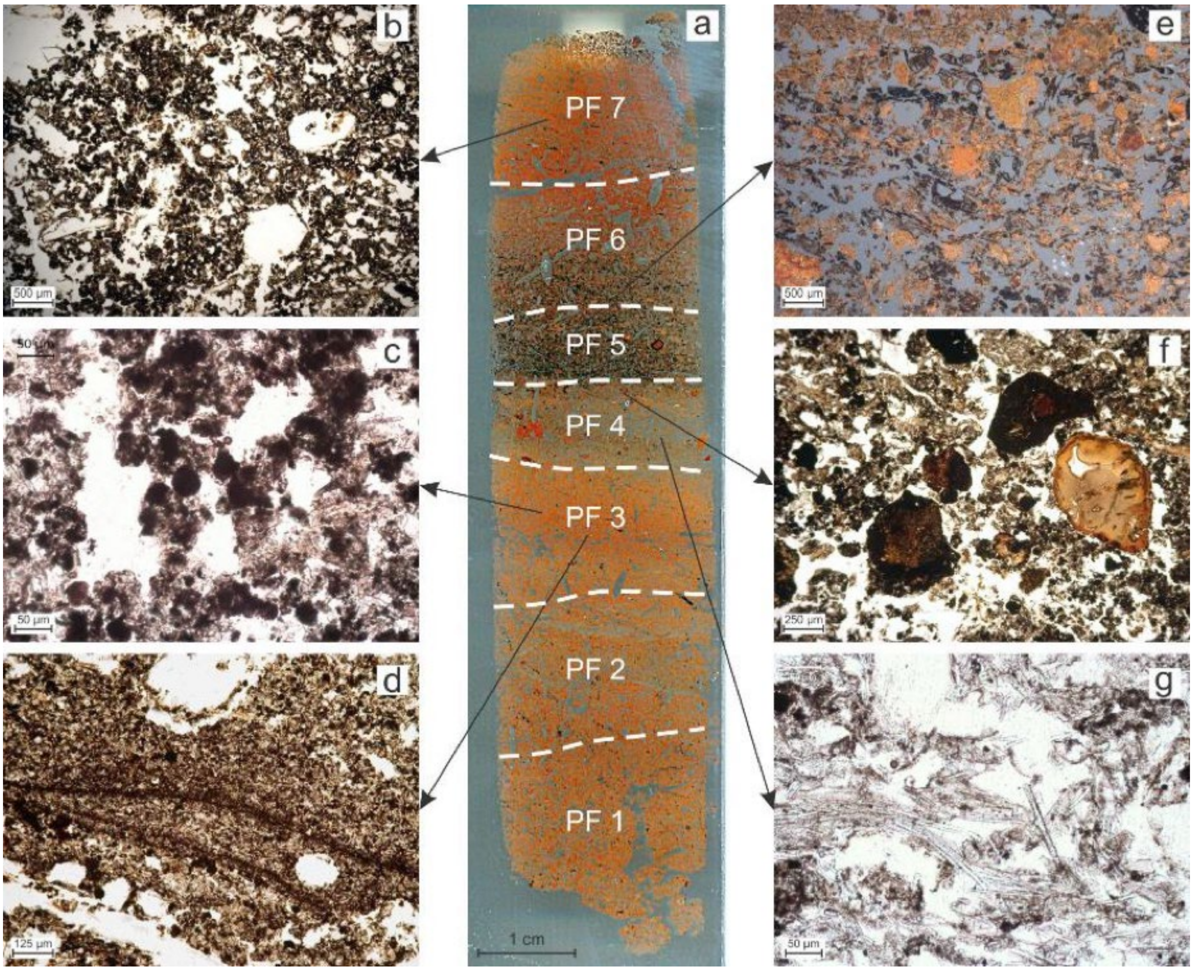

Figure 8. Scan of the thin section from the filling of pit 2 with microphotographs illustrating main micromorphological features; a: scan of the thin section from the pit 2 filling in incident light; b: microstructure of the reddish material with faunal passages, PPL; c: granules and aggregates of reddish material, PPL; d: slaking crusts represented by thin layers within the reddish material, PPL; e: microstructure of the dark brown layer enriched with charred plant remains, OIL; f: coarse volcanic rock fragments, PPL; g: phytolith-rich layer, PPL (PPL: plain polarized light, OIL: oblique incident light).

The dark brown zone PF 5 contains iron oxide granules and phytolith material, but it is distinguished in respect to other pit filling zones by a strong enrichment with charred plant remains (**Figure 8e**). The central part of the thin section, including the dark brown layer, contains some volcanic rock fragments of medium to coarse sand grain size and of rounded and subrounded shape (zones PF 4 and PF 5, **Figure 8f**), while the reddish and light greyish material in zones PF 1, 2, 3, 7 is nearly free of particles of coarse sand size. These relatively coarse grains, although concentrated in zones PF 4 and 5, are embedded in silty material (**Figure 8f**) and do not form any distinct sublayers.

4. Discussion

4.1. Comparison of the properties of pit 2 filling and sediments

The results of the analyses performed demonstrate significant differences in the geochemical and physical properties between the pit 2 filling and the underlying fluvial sediments and overlying pit cover (**Figure 9**). The pit filling material is well sorted and strongly dominated by the silt fraction with the exception of zones PF 4 and 5, which are characterized by higher contents of coarse sand. These two zones correspond to the areas of concentration of coarse volcanic rock fragments detected in the thin section. The pit cover and sediments 4 and 6 contain higher contents of sand fraction.

Although the pit filling exhibits a bright reddish colour in contrast to the mostly brownish sediments, its content of iron is lower than that of the sediments and the pit cover. The iron content of the sediments (14-21%) is in agreement with the results of element analysis of rocks and soils from the Rano Aroi watershed (which is part of the Maunga Terevaka) conducted by Margalef et al. (2014). Apparently, iron in the pit filling is mainly present as free iron forms occurring in crystalline iron oxides, as indicated by the reddish colours (Torrent et al. 1980), whereas the brownish colours of the sediments coupled with their higher amount of iron suggest a dominance of iron forms bound to organic or amorphous compounds. These findings agree with the results of XRD analysis that point to a larger amount of hematite and magnetite/maghemite in the pit filling compared to the sediments of the studied profile. The measured high values of magnetic susceptibility of the pit filling and the sediments lie in the range typical for soils and volcanic rocks on Easter Island (Fassbinder et al. 2007; Fassbinder and Bondar 2013).

The values of Si/Ti ratio suggest a significantly higher biogenic silica content in the pit filling (Kylander et al. 2011; Liu et al. 2013) than in the sediments, which according to micromorphological analysis is related to the large quantities of grass phytoliths and diatoms. Such phytolith-rich layers are typical of in situ decomposition of plant tissues at archaeological sites, such as mats/beddings (Miller and Sievers 2012) and animal dung layers (Albert et al. 2008) or in situ ashy layers from grasses used as fuel (Courty et al. 1989). The latter explanation, the in situ preservation of burned grass remains, is the most probable explanation of the phytolith-rich layers at the study site. Indeed, the phytolith data indicate the presence of C4 grass short cells and elongated long cells generally attesting to Monocotyledons, while Dicotyledons are very scarce. The idea that fire played a role in the formation of the pit filling is further supported by the presence of dark layers enriched with charred plant remains. As the woodland in this area had been cut before the period of pit formation, firewood could hardly have served as the main fuel source; hence, grasses must have represented the fuel material. The use of grass as fuel is consistent with anthracological work by Orliac and Orliac (1998) who described a significant change from wood- to grass-based fuel in fireplaces beginning in the period of extensive deforestation. And it is also consistent with palynogical records which proved the growing dominance of grassland during the major phase of deforestation from 1,350 AD onwards (Flenley and Butler 2018).

The layers surrounding the pits have a bulk density of approximately 1.3 to 1.6 g cm^{-3}. In contrast, the pit filling has a bulk density between 0.3 and 0.5 g cm^{-3}. These very low bulk density values of the pit filling are understandable also in the light of the results of the micromorphological analysis, which indicate high porosity of the material due to the granular microstructure and abundant features of post-depositional bioturbation.

The differences between the pit filling, pit cover and sediments are confirmed by principal component analysis (PCA) based on a correlation matrix (**Figure 10**). Geochemical and physical properties determined for pit 2 filling, sediments and pit cover in the profile investigated (**Table 2**) were used as input variables for PCA. Missing values of magnetic susceptibility for PF zones 4 and 7 and pit cover were replaced by mean values of the other PF zones and sediments respectively. Principal components 1 (PC 1) and 2 (PC 2) have eigenvalues above 1 and together

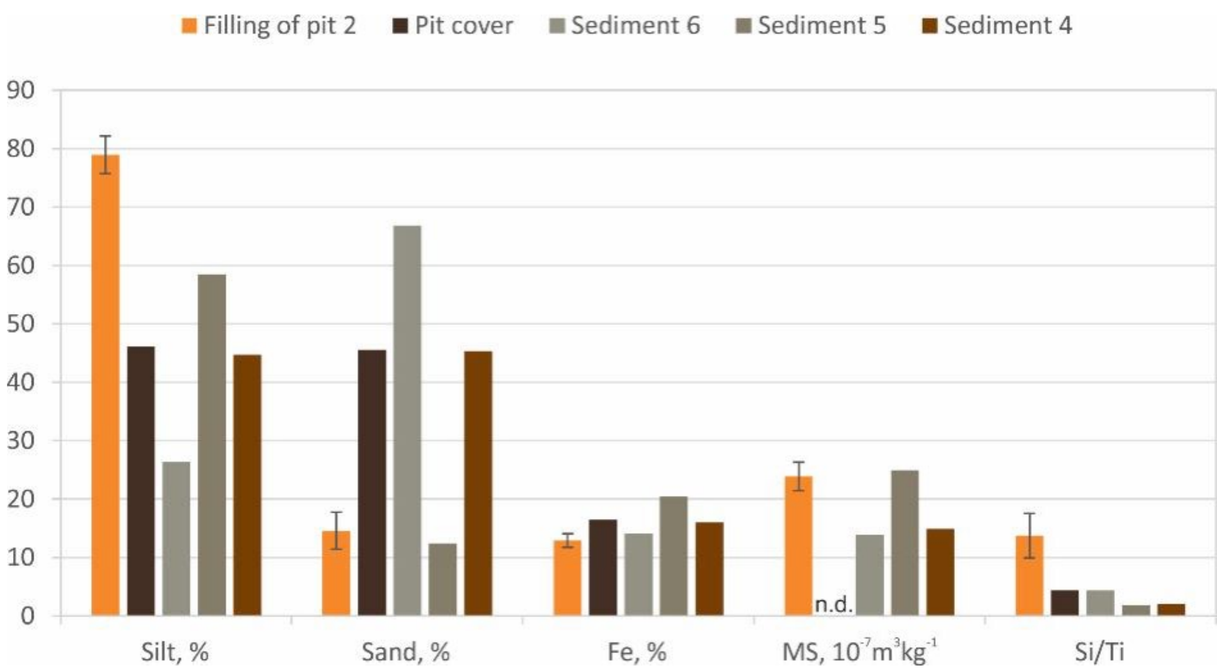

Figure 9. Comparison of properties of pit 2 filling (mean values and standard deviations) with the pit cover and fluvial sediments.

explain 85.9% of total variance. PC 1 (eigenvalue 4.4, 62.8% of variance) is characterized by relatively high positive loadings of MS (0.46), Si/Ti ratio (0.46) and silt content (0.42) and negative loadings of the contents of iron (-0.38), sand (-0.33) and organic matter (-0.28). Therefore, PC 1 is mostly responsible for distinguishing the pit filling from the sediments and the pit cover. PC 2 (eigenvalue 1.6, 23.1% of variance), being tied to iron content and grain size fractions – positively to clay and iron contents (0.62 and 0.45 respectively) and negatively to sand (-0.55), helps distinguishing materials of different texture and iron content mostly within the group of fluvial sediments.

PF zones of the pit filling form two groups associated with the positive values of the first principal component: zones PF 1 – 4 and zones PF 5 – 7 mainly due to the differences in organic matter content. The sediments and the pit cover tend to the negative values of PC 1 with higher contents of clay, sand, iron and organic matter. Here, the pit cover falls into the group of the sediments with strongest similarity to sediment 4. It has to be noted that the differentiation indicated by PCA cannot be directly interpreted as a genetic difference between the pit filling and the sediments, since the parameters responsible for these differences (e.g. biogenic silica, magnetic susceptibility and iron content) might partly represent secondary features formed or affected by human activity. However, the results of the mineral assemblage analysis and heating experiment rather point at a different origin of the pit filling and the sediments (see following sections).

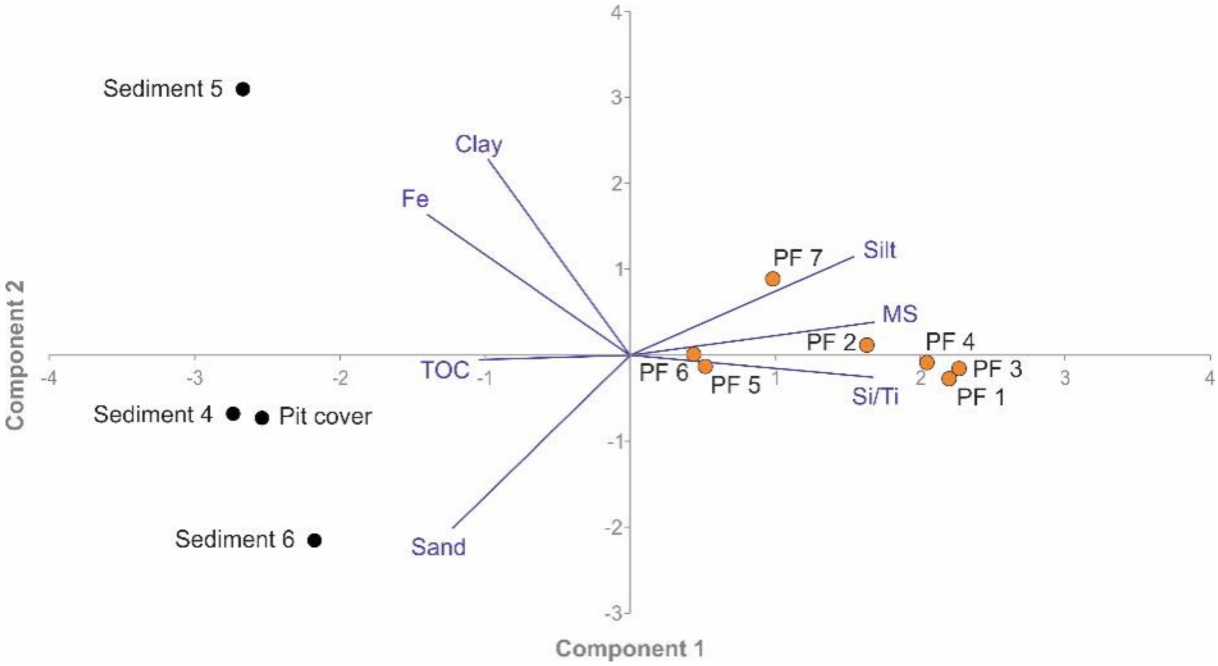

Figure 10. Results of principal component analysis: Projection of variables (TOC, MS, Si/Ti and contents of Fe, sand, silt and clay) and observations (PF zones of pit 2 filling – orange circles, fluvial sediments 4 – 6 and the pit cover – black circles) on the factor plane.

4.2. Genesis of the pits and interpretation of the pit filling

The spatial distribution, the shape and the filling of the pits with silty reddish material clearly indicate that they are not a result of natural processes: in total about 370 such pits are rather regularly distributed over the fluvial terrace which was proved by numerous plan profiles from the surface after clearing from the overlying gravel and uppermost fluvial layer. The gently U-shaped form of the pits seen in the vertical profiles differs significantly from typical irregular structures of potholes or other fluvial structures. Therefore, it is undoubted that these pits were formed by humans within the fluvial terrace. Based on radiocarbon ages of charcoal in the pit fillings and sediments in the investigated profile, at least two phases of pit formation are distinguished: one around 1,210 – 1,390 cal AD and the other around 1,420 – 1,650 cal AD. Both phases fall into the post-clearing period in the study area.

The filling of the pits is fine layered and loose. It consists of several crescent-shaped thin layers of charred plant material and of phytoliths, and of thick layers of silty reddish material. The layered material in the pits was not deposited by water, as the macro- and micro structures clearly indicate. No coarse material was deposited at the bottom of the pits as it would have been the case if fluvial processes were responsible for the deposition of the material. In the case of an infill by water the charred plant material would have settled on top of the other heavier material in the deepest part of the pit. The pit filling does not consist of volcanic ashes, only very few volcanic rock fragments were found in the filling. These rock fragments of medium to coarse sand size identified in the thin section, although being more abundant in some parts of the section, do not form any clear coarse sublayers and are embedded in the same silty matrix as in filling parts above and below. This also points at non-fluvial deposition of the filling material. The formation of thin layers composed of nearly pure phytolith material with horizontally oriented phytoliths, as it is the case in the pit filling, is difficult to explain by natural processes too. Reworking processes by running water at the land surface may concentrate materials with different bulk densities in different layers, but it would not result in phytoliths deposition with similarly oriented and articulated silica bodies (Madella and Lancelotti 2012). Thus, it can be concluded that the pit filling is an anthropogenic deposit.

The specific properties of the pit filling investigated, namely grain size distribution, colour, fine layering with bands of charred material, concentrated layers of phytoliths, low bulk density, lack of stones and obsidian flakes, differ from all other types of pit fillings which have been discovered on Easter Island before, e.g. planting pits (cf. Mieth et al. 2002; Stevenson et al. 2006; Wozniak and Stevenson 2008), storage pits (cf. Wozniak and Stevenson 2008), fire pits/hearths (cf. Stevenson et al. 2006) or cooking pits/umu (cf. Mieth and Bork 2003, 2004; Stevenson and Haoa Cardinali 2008a, 2008b). Based on grain size distribution and colour of pit 2 filling described in this paper (and also of the other pits in the area of investigation), a hypothesis can be proposed that the discovered pits represent sites for production and/or storage of pigments. The use of red and white pigments for ritual painting of human bodies, rock paintings, colouration of petroglyphs and rock sculptures, and for certain textiles has been common in the Rapanui culture: especially red colour was connected to sacredness and represented physical power, mana (spiritual power) and life (Lee 1992; Horley and Lee 2012). However, little reference in the literature has been given in regard to the spatial, geological or geochemical origin of red and white pigments on Rapa Nui. The Rapanui designation for red pigment is *kie'a*. While it becomes clear from the literature that it concerns pigment of geogenic origin, the precise description of the origin and local sources of *kie'a* is unclear. Sometimes it is described as “made from weathered tuff” (Horley and Lee 2012) by pulverization in stone mortars (Lee 1992) or just described as “red ochre” (Van Tilburg 2014). Orliac (2005) writes that the “red colour was obtained by crushing rocks rich in iron oxide”. These different references are not implicitly a contradiction. In fact, different local and geogenic sources of *kie'a* are plausible. The sourcing depended on taboos, exclusive rights of access for certain clans or persons, as well as secret and/or locally transmitted knowledge. Fischer (2005) describes red ochre as one of the “crucial resources” on the island, which were “highly localized” and “eminently tradable”. Previously, hypotheses of biogenic origin for the pigment in the same pits on Rapa Nui as investigated in present study were suggested (Mieth and Bork 2015). Due to the very low bulk density of the material, high content of iron and large amount of phytoliths in the pit fillings, it was suggested that rhizomes of the totora reed (*Schoenoplectus californicus ssp. tatora*, Cyperaeceae) were used to produce the pigments. However, the phytolith analysis of pit 2 filling is currently not able to confirm the presence of large quantities of sedge phytoliths, while also micromorphological, geochemical and physical properties of the filling that were determined in this research suggest an alternative way for pigment production in prehistoric Rapa Nui, at least for a part of the pigments used. It seems quite probable that humans used special iron-rich minerogenic materials from an unknown source to produce silty hematite-rich pigments.

The silty texture of pit 2 filling, which is very different from the sediments in the same profile, may be an indication of material properties at a source site, where raw material was taken. But it is also well known that raw materials used for pigment production, which may be represented by hard or soft ochre, were often crushed or ground in order to obtain a fine texture (Barnett et al. 2006; Wadley 2010; Meller et al. 2013). Grinding/crushing ochre to powder, on the one hand, makes pigment easier to apply on different surfaces; on the other hand, a brighter reddish colour is obtained by grinding/crushing, as hematite is known to acquire a brighter red colour with decreasing grain size (Cornell and Schwertmann 2003). Based on the data available, it cannot be excluded that the silty texture of the pit filling could be a result of the treatment of raw material. Since all coarser grains found in the thin section from the pit filling investigated were rounded and subrounded, at least crushing is less probable because it would produce rather sharp-edged grains. Any discussion of possible effects of a grinding action on the morphology of mineral grains would be a mere speculation as neither the material processed nor the tools utilized are known yet.

Presence of layers of charred material and phytolith layers, which were interpreted as grass ash layers, suggest that the material in the pits has been heated. Identification of combustion features based on (micro)morphological properties of materials only may be misleading and requires laboratory tests to firmly ascertain whether material has been subjected to heat in the past (Goldberg et al. 2017). The heating experiments coupled with MS measurements aimed to answer this question and provided strong arguments supporting the interpretation of material heating in the pits. Results of the multi-heating experiment are in agreement with XRD analysis: weak enhancement in the sediments after 250 °C heating can be explained by conversion of small amounts of goethite and traces of other iron-bearing minerals (ferrihydrite) to ferrimagnetic maghemite. In the pit filling, such minerals are absent, they may have been absent in the original material or they may have already been converted by heating before. The strongest magnetic enhancement in sediments at 600 °C is caused by a transformation of hematite to maghemite, which is known to occur at 500-600 °C in the presence of organic matter (Jelenska et al. 2010). In the pit filling such conversion does not occur; on the contrary, a decrease of MS is observed due to oxidation of maghemite to hematite due to the lower organic matter content. At 700 °C, iron-bearing minerals are oxidized in all samples to the final oxidation product hematite. Effects of organic matter content differences on the behaviour of MS in this experiment are possible, but in the maximal conversion experiment with reducing and oxidizing conditions, the differences are caused exclusively by the differences in the state of iron-bearing minerals due to the addition of organic material prior to the combustion. Thus, potential susceptibility measured in the maximal conversion experiment enabled further interpretation of the results. In contrast to the sediments, the maximum MS of the pit filling is slightly higher than its MS at room temperature and after 250 °C – meaning that there the maximum has nearly been already reached. This can be clearly attributed to previous heating of the material. Nevertheless, the observed small increase of the pit 2 filling material in magnetic susceptibility after heating to 650 °C under presence of organic matter indicates that small portions of iron-bearing compounds were not converted into a ferrimagnetic form. Thus, the temperatures of the fire in the pit were presumably below 650 °C. The observed large differences in absolute values of magnetic susceptibility point to the use of a material different from the local sediments for the pigment production.

In context of pigment production, the results presented above imply that even if the material at the source site did have a suitable silty texture, it apparently did not possess a sufficient content of hematite and hence not the necessary reddish colour. For this reason the raw material was heated in order to convert iron compounds to hematite. Reddish hematite-based pigments are known to have been used in many different regions of the Earth since the Palaeolithic (Hradil et al. 2003; Meller et al. 2013). The production of hematite by heating of iron-rich substrate (e.g. goethite) is known in historical context, but rarely described for prehistoric cultures (Pomíes et al. 1999). There have been studies that succeeded in distinguishing natural hematite from heated goethite (Brindley and Brown 1980; Pomíes et al. 1999). Goethite heated up to 250 -280 °C is known to transform into a disordered hematite that can be identified by XRD (Brindley and Brown 1980; Helwig 1997; Pomíes et al. 1999). Results obtained in this study indicate that the material in the pit might contain disordered hematite resulting from low-temperature heating of goethite, but the background noise and possible overlapping of the hematite peak with the 100% peak of magnetite/maghemite does not allow making a clear statement. The possibility of low-temperature fire to produce red pigment is supported by an experiment conducted by Wadley (2009). She showed that heating yellow ochre buried in sand under a fire at a temperature as low as 270 °C for 3 hours is sufficient for a successful goethite-hematite transformation (Wadley 2009).

There are also some indirect arguments supporting the hypothesis of low-temperature firing to produce pigment. Presence of dark layers enriched in charred organic remains points at an incomplete combustion of plant material and hence implies low temperature fires (below 300 °C) (Karkanas et al. 2007). This temperature range corresponds to temperatures typical of fires with grass fuel (Bailey and Anderson 1980; Aldeias 2017), which agrees with the presence of ash layers composed of grass-dominated phytoliths in the pit 2 filling. In addition, dark-coloured phytoliths were observed, possibly pointing to heating at high temperatures (Piperno 2006; Devos et al. 2013). Such a colour can, however, also be caused by processes other than burning. It is being explored whether further research (cf.

Elbaum et al. 2003) can give further information on whether the phytoliths were burned.

Evidence of material oxidation by firing delivers an argument against the use of the fluvial sediments from the nearest surrounding for pigment production. As it was shown by the high values of potential MS in the maximal conversion experiment, the fluvial sediments investigated still contain convertible minerals and that they have not been burnt before. However, if these sediments would have been burned to produce the pigment filling of the pit, the resulting material would have had a higher MS than the pit filling. It has to be pointed out that sediment 4 after heating at 250 °C does have a similar MS as the pit filling, hence one could suspect that sediment 4 could have been heated at low temperature to produce the pigment. But in this case, heating the pit filling at 650 °C in reducing conditions should have produced similarly high values of potential susceptibility as has sediment 4. Thus, additionally to the observed differences in sedimentological properties, based on their magnetic behaviour the sediments from the surroundings of the pit can be excluded as the origin of the pit filling.

Therefore, a hypothesis of the pigment production process on Rapa Nui can be suggested: iron-rich raw material was deposited in small portions in the pits and burned by firing with grass fuel to obtain reddish pigment. The processes of material deposition and firing in the pits must have taken place in cycles, which caused the alternation of reddish material with light greyish phytolith-rich layers. It has to be emphasized that formation of the layering due to sedimentation in standing or flowing water environment is improbable, as reddish silty material similar to the pit fillings is not present in the catchment of the valley and no sorting of the material based on grain size or bulk density, which would be typical for a fluvial deposit, could be identified in the sample. Slaking crusts that were identified during the micromorphological examination of the thin section from the pit filling imply post-depositional presence of small amounts of rain water (Valentin and Bresson 1992) in the pits with already existing fillings. A few slaking crusts present in the filling indicate that the pits filled with the pigment were exposed to rain for short periods of time in between the cycles of pigment production. The maximal duration of such periods would be several hours since in case of longer periods, aeolian deposition of silt would have taken place since this process is common on Rapa Nui, whenever soil material is exposed at the land surface and thus particularly in the post-clearing period (as observed by the authors during field work at the site).

In some pits of the two profiles investigated, features of multiple uses of the fillings were identified (**Figure 11a**). Clear traces of action of hands and fingers could be seen in vertical and horizontal sections of the pit fillings (**Figure 11b**). For storage of the pigments in the pits, anthropogenic pit covers were used most probably with the aim to protect the pigments in the pits from loss by water and wind erosion.

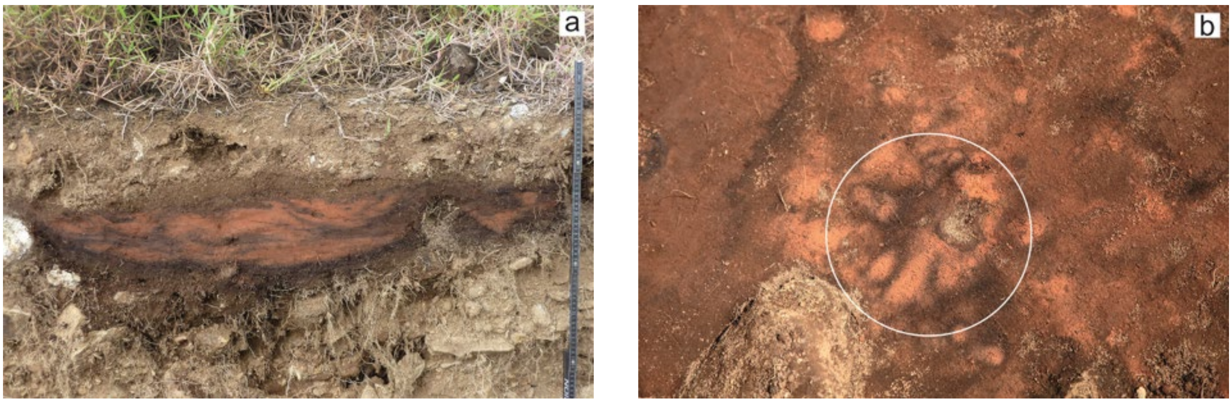

Figure 11. Features indicating multiple use of the pit filling; a: deformed layers in some pit fillings indicate removal / refilling of pigments in the utilisation phase; b: plan view of a pit filling with an imprint of fingers / hand (marked by the white circle).

The ongoing phytolith and diatom research may enable a more precise reconstruction of the plant source material used as fuel in the pits. An assumption can be made based on the preliminary results of diatom identification that indicated origin of the diatoms in a wet terrestrial or semiaquatic environment. Near the study site a few potholes are located in the valley bottom. The direct surrounding of these potholes is wet and contains abundant plant biomass. Thus, it can be proposed that plant biomass could have been taken from the potholes and their vicinity containing diatoms and used (after a drying process if necessary) as fuel for the pigment production, which resulted in the input of diatoms and phytoliths to the pit filling.

5. Conclusions

Prehistoric pits filled with fine-layered reddish material dated to the period around 1210-1650 cal AD were discovered on Easter Island. The filling of one representative pit was analysed geochemically and micromorphologically in order to reconstruct the formation of the reddish filling and its possible use by the inhabitants of the island. The properties of the pit filling show similarities in some aspects and differences in other aspects to the adjacent fluvial sediments. Analysis of the results suggests alteration of minerogenic iron-rich material to produce reddish pigments. Although the current research status does not enable to point out the exact source of material for pigment production at Rapa Nui, it can be excluded that fluvial sediments from the direct surroundings were used in this process. Based on an interdisciplinary investigation involving geochemical and physical analyses combined with micromorphological investigation, a hypothesis about the main stages of the production process is suggested. The main stages include cycles of material deposition and firing using predominantly Panicoid grasses as fuel. Pigment production by fire-supported oxidation of minerogenic material to produce hematite, and production and storage of such pigments in pits were so far unknown for Rapa Nui. Further research is being carried out in order to enhance the interpretation of the pits and their fillings, which will contribute to a better understanding of prehistoric pigment production on Rapa Nui and cultural development on the island in the post-clearing period.

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