Pharaonic Pyrolysis - Activity in the Libyan Desert - Interpretation of a Dyadic Ceramic

HANS-JOACHIM PACHUR[1]

ABSTRACT

In 1897, for the first time, the function of a dyadic predynastic ceramic was the focus of multiple considerations. The object of interest is a ceramic tube of conical shape, often bearing ownership marks, roughly 17 cm in height. A single perforated disc sealing the smaller tube-diameter and similarly marked as property is associated with to the object.

In 2011, Riemer (Cologne University) still wrote "Clayton rings and discs were used at El Karafish though we still have no clue to what purpose." (2011, p. 73), see also 2016.

Darnell (Yale University), in reference to his own publication, states: "The presence of these stands and discs" … "may at last shed some light on the mystery of the function of this curious combination that occurs only in desert environment." (written notice, 2016).

According to Pachur & Altmann (Freie Universität Berlin), a dyadic ceramic forms the reactor of a descending dry distillation apparatus that has been in use in the Eastern Sahara from approx. 5 *ka* BP, theoretically since ceramics were used. The argument is based on the in construction conformity with a traditional pyrolysis technique in the Tibesti and in Morocco. An experiment with tamarisk wood proves the suitability of the late-dynastic ceramic apparatus for the production of a pyrolysate. Only a reaction of the ceramic surfaces with graphite substances may create coloring effects. A ceramic surface appearing unblemished by the incineration of organic substances on the heated surface, thermal clearing, may therefore irritate the excavator.

The pyrolysis apparatuses as part of a survival technique in the "fully arid Western Desert of Egypt" at 5 *ka* BP cannot be verified.

The pharaonic pyrolysis technique offers the possibility to arrive at a pyrolysate by means of a brilliantly simple small-scale apparatus with human/veterinary medical as well as psychoactive potential. Funerary objects in the Nile Valley verify the value of the dyadic ceramic. The existence of a market for pyrolysis products in pharaonic society is discussed, based on hieroglyphs found at Awaynat mountain at the western boundary of the Libyan Desert.

The distribution of the pyrolysis apparatuses - a rough estimate suggests more than 1.000 cylinders - reveals a main focus in areas of higher net primary production of an Saharian Savanna such as the Libyan Desert Plateau and extramontaneous areas of the Libyan Desert.

Cattle pastoralism, hunting, grass gathering and transhumance - see circular camps - were strategies as peculiar to ethnic groups at the northern edge of today's Sahel.

KEYWORDS

A century-old discussion, pharaonic pyrolysis, thermal clearing, cedrium, lutum, manufactory production, cattle pastoralism, grass gathering ethnicity, wood oil

1 Freie Universität Berlin, Germany.
E-mail: pachurp@zedat.fu-berlin.de

URN: urn:nbn:de:bsz:16-propylaeumdok-33026
URL: http://archiv.ub.uni-heidelberg.de/propylaeumdok/volltexte/2017/3302
DOI: 10.11588/propylaeumdok.00003302

CONTENTS

1. A Century - Old Discussion
1.1 Conic Cylinder and Perforated Disc as Part of the Pyrolysis Apparatus
2. Simulation - Allothermal, Anaerobic Pyrolysis with a Pharaonic Model
3. The Potential of Pharaonic Pyrolysis
3.1 Overview on Pyrolysates of Wood and Herbacous Plants
4. Pyrolysis Tradition in the Sahara
5. Pyrolysis Equipment and Quasi-Manufactory Production in the Libyan Desert since 5 *ka* BP
5.1 Libyan Desert Plateau; Limestone Hamada with High NPP in the Grarets
5.1.1 A Ceramic Ensemble with a Special Function
5.2 Pyrolysis Apparatuses as Compartments of an Semi-Nomadic Used Grass Gathering Ecosystem at approx. 5 *ka* BP
5.3 The Libyan Desert as a Traversable Region for Cattle Pastoralists and Transhumance Using Sedentary Farmers
6. Market-Oriented Production
7. References
8. Acknowledgement

Pachur 2016

1. A CENTURY - OLD DISCUSSION

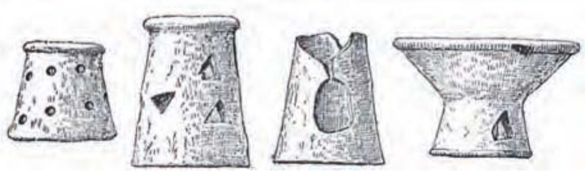
In the context of assessing the biological net primary production (NPP) of the Libyan Desert as a CO_2 basin around approx. 5 - 4 *ka* BP, it was necessary to adduce the strategies of use employed by the Neolithic ethnicity - possibly already serving as vassals and trading partners of pharaonic Egypt - as an indicator for the configuration of the natural environment apart from the currently known and familiar oases (Pachur & Altmann, 2014). A dyadic ceramic, often marked as property with specific ownership marks after firing and composed of a conic cylinder and a perforated disc sealing the smaller diameter, came into focus.

Its oldest reference dates to de Morgan (1897). Among the findings in the necropolis of Naqada at Abydos - "Le fin de l' Ancien empire" - four ceramic cylinders are listed (Fig. 1a). Image 382 à 386; p.123, is subtitled "Supports de vases en terre". This refers to containers similar to small amphorae with acute-angeled bottoms as found in the archaeological material. Four perforated discs, fig. 386 à 390, are interpreted as "Enfin les fusaïoles".

Among the objects one furthermore finds a bulbous ceramic flask, "période néolithique". A multi-perforated bottom functions as an outflow so that, for example, oil may flow with some delay or may be precisely controlled. An identically constructed flask, found within a distance of the ceramic perforated disc, cylinder and flint flakes, is known from El Karashif (Fig. 9).

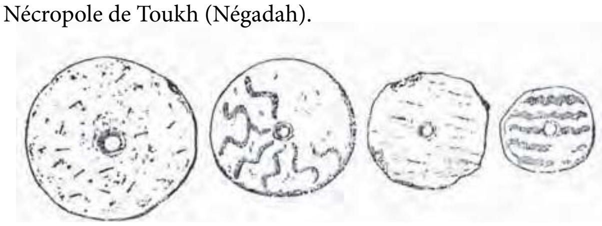
Fig. 1a First documentation of a dyadic ceramic, without knowledge of their function.

Necropolis Naqada at Abydos (Morgan de, 1897, p. 123).



382 383 384 385

Fig. 382 à 385. Supports de vases en terre.
Nécropole de Toukh (Négadah).



Enfin les fusaïoles.

Mac Iver & Macc (1902) report "four pots of pre-dynastic (really protodynastic date) with perforated circular lids, which bore pot-marks," found close to Al Amrah near Abydos. Interpretations of the pottery reach from the lining-up of gaming tokens to a "ring stand with appointed vase."

Thirty-four years later, from 1930 to 1931, during trigonometric recordings on the southern border of Egypt at 22°18'14"N; 27°14'30"E in the course of which he saved 37 refugees from Kufrah at Gabal El Uweinat, P. A. Clayton observed two cylinders forming a figure of eight, vertically protruding from the sand, evidently subject to corrosion. Below fig.14 it is noted: "The two potteries rings and discs". The marks on the latter are visible. Furthermore it states: "I have no clue as to their purpose." (Clayton, 1937, p. 255).

Fig. 1b Deflated reactor and perforated disc. Location of finding: Selima Sandsheet, discovered by P. A. Clayton at 1930/31 (1937).

The cylinders, often inserted vertically into the substrate, most commonly sand, are reduced in height due to effective sand abrasion close to the surface.

The term "ring" accordingly describes a geomorphologically conditioned exceptional case; the more general case applies to the following example: later in 1938, G. W. Murray finds a perforated ceramic disc east of the Nile "just North of Aswan" which was "tightly jammed inside a hollow tube of earthen wear about 20 cm long", (Fig. 1c).

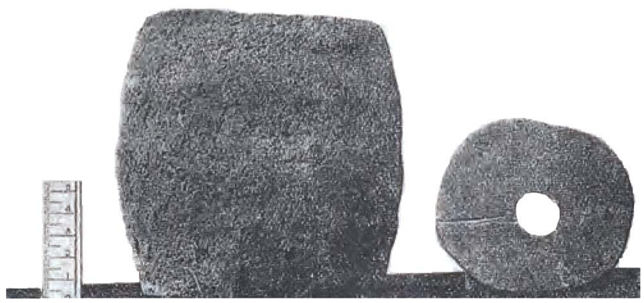


Fig. 1c Eartherware tube and perforated disk from near Aswan, Pitt Rivers Museum, Oxford.

In 1938, Ms. Murray (Murray, 1951, p. 155, fig. 2) makes a find close to the Porphyry-quarry of the pharaonic empires at Djebl Dukhan (Fig. 8) in the Eastern Desert in proximity to a scattering of stone artifacts that included two "lamp-shades", a pot of about the same size, and three perforated discs of the"first or second dynasty", ~2920-2649 BC.

Fig. 1d Excavation by Ms. Murray, 1938.

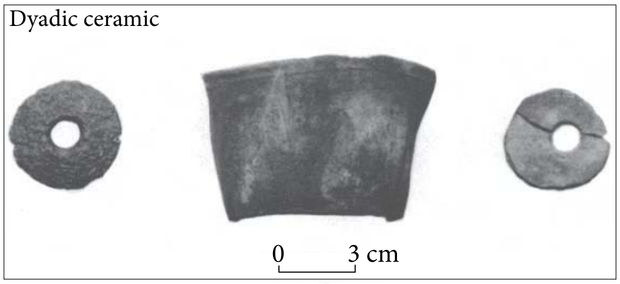


Fig. 1e Disc and piece "lampshades" from Tanida, Dakhla Oasis. Murray, 1951

Approximately contemporary - 3124 ± 152 *cal. a* BC - potteries were utilized in the Libyan Desert south of Regenfeld (Fig. 8; II); their distance measures 1.000 km.

Tentative dating between 3.0 - 2.7 *ka* BC exists from the Libyan Desert Plateau (Fig. 9), roughly at the midway point (Darius & Nussbaum, 2011).

In Nubia, at the mouth of the Wadi Melik and the late middle Holocene Wadi Howar flowing into the Nile, with a riparian ecosystem of high NPP whose worthiness of protection is underlined by a powerful fortification at Gala Abu Amed (Pachur & Altmann, 2006, p. 242), lies an outpost of Old Dongolas. Penn (1931, fig. 10) recovered at least six ceramic cylinders of exceptional size in the dilapidated buildings constructed of burned bricks. It unresolved whether they were used for ore smelting.

In assessing the situation in the Libyan Desert Darnel writes: "Caton - Thompson 1952, p. 43, compiled a list of occurrences but offered no suggestion as to their function, which remains unknown." Riemer and Kuper's (2000) comprehensive study is a substantial contribution toward understanding these objects, yet, as they point out, no conclusive evidences of how they were used has been forthcoming." Their utilization is then discussed with regard to bird traps. In summing up, he formulates: "The presence of these" … "may at last shed some light on the mystery of the function of this curios combination that occurs only in desert environment." (Darnel, ibid., p. 160).

In the Yale research project "Desert Road Survey", conducted between the Nile and the oases of the Libyan Desert, Darnell (2002, p. 159-160) mentions the "lamp shade", following Murray's nomenclature, inside (!) as well as in the surrounding of the "Cave of the Wooden Pegs/Rayayna Desert," "present in abundance" beneath a layer of ash, alongside botanic and faunal evidence and predynastic ceramics of the Tasian culture (approx. 4.5 *ka* BC); these are the oldest apparatuses thus far.

After an intensive research phase and an increased amount of findings, Marchand (2003) states: "Les Clayton rings son des objets inigmatiques pour leurs function et unique dans leurs forme."

Hartung & Hartung (2005) also describe dyadic ceramics near Naqada. They are assumed to have originated in the Western Desert; whether they were indeed used on-site remains unclear. Classification in the context of the Naqada-II culture (3.5 - 3.2 *ka* BC) is considered.

Kuper (2006; Abb. 92) states: "Rätselhafte konische Keramik-Ringe ohne Boden, meist vergesellschaftet mit einer durchlochten Tonscheibe, wurden an zahlreichen Stellen zwischen Nil-Tal und libyscher Grenze gefunden. Bisher fehlt jeglicher Hinweis auf die Verwendung dieser sogenannten ‚Clayton Ringe.' "

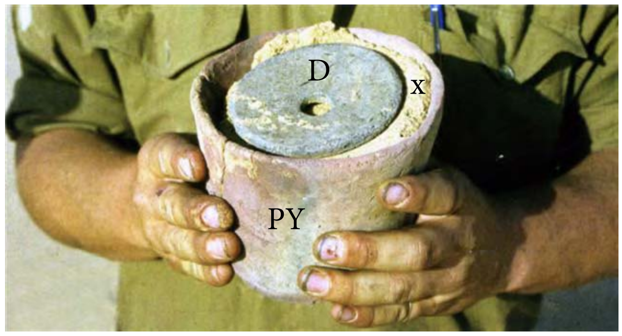


Fig. 2 Pyrolysis reactor (PY) and perforated disc (D) according to Pachur/Altmann, 2014. Mineral soil (x) in which the ceramic was embedded. Photo Kuper (2006).

Finally, more than 100 years later, Riemer (2011, p. 73) summarizes the level of knowledge after his treatment of ceramic finds, ranging in age from 2.8 *ka cal.* BC to 3.0 *ka cal.* BC (five data sets), from the Libyan Desert Plateau, El Karashif. Quoting verbatim a part of the Clayton citation, Riemer remarks: "Clayton rings and discs were used at El Karashif though we still have no clue to what purpose." See further equipment of desert travellers.

1.1 CONICAL CYLINDER AND PERFORATED DISC AS PART OF THE PYROLYSIS APPARATUS

In our opinion the dyadic ceramic - Fig. 2; S 2 -1; S 3-2 - functions as the centerpiece of a pyrolysis apparatus (PY) which has been in use after approx. 5 *ka* BP - theoretically since pottery was first in use at 10.250 - 8.750 *cal. a* BP (Pachur & Altmann, 2006, p. 339) - in the Eastern Sahara and which is, in principle, still in use today (Pachur & Altmann, 2014). The argument is based on:

- the congruence in construction with an allothermal anaerobic two pot-pyrolysis-technique as employed in the Tibesti Mountains and the Moroccan mountain region as well as the pyrolysis tradition in the entire Sahara;
- the pharmaceutic-chemical potential of small-scale, dry distillation;
- a pyrolysis experiment with pharaonic ceramic models, comp. chapter 2;
- the frequency of distillation as an investment suitable for daily use in the Libyan Desert characterized by shrubland with locally high biological net primary production (NPP) (Fig. 9).

In Central Europe, downward dry distillation is described by Pliny the Elder (approx. 25-79 AD). Adhesive techniques, particularly the mounting of tools, among other means by using birch tar, are known from Campitello, 200 *ka* ; at Inden/Altdorf an open cast mining in the Rhineland 120 *ka (*Eemian interglacial); Königsaue, 43.8 *ka* (bitumen pieces); Umm el Tiel in Syria, 40 *ka* ; Les Vachons, 30 *ka* and, finally, from tools of the Similaun "glacier mummy", 3.3 *ka* BC (Grünberg, 1999; Ambrose, 2010; and others).

Pharaonic Ceramic Pairs in the Levant

It is contested whether the evidence of two complete pyrolysis apparatuses, in a crono - cultural context dated "somewhat earlier than c. 3.50 - 3.15 *cal* BC", from an excavation horizon at Afrida in the Ashqelon region, can indeed be traced back to an exchange with pharaonic Egypt - thus also potentially documenting their meaning and importance (Braun und van den Brink, 2008); see however the pyrolysis "cleaning" effect of the ceramic, chapter 2, Fig. 10-2. Utilization of the pharmaceutical-chemical method in the southern Levant was based on the use of species-rich and still dense primary vegetation. As a "living" paradigm, the juniper-rich regions of Morocco and the extraction of wood oil by means of small scale apparatuses need to be adduced.

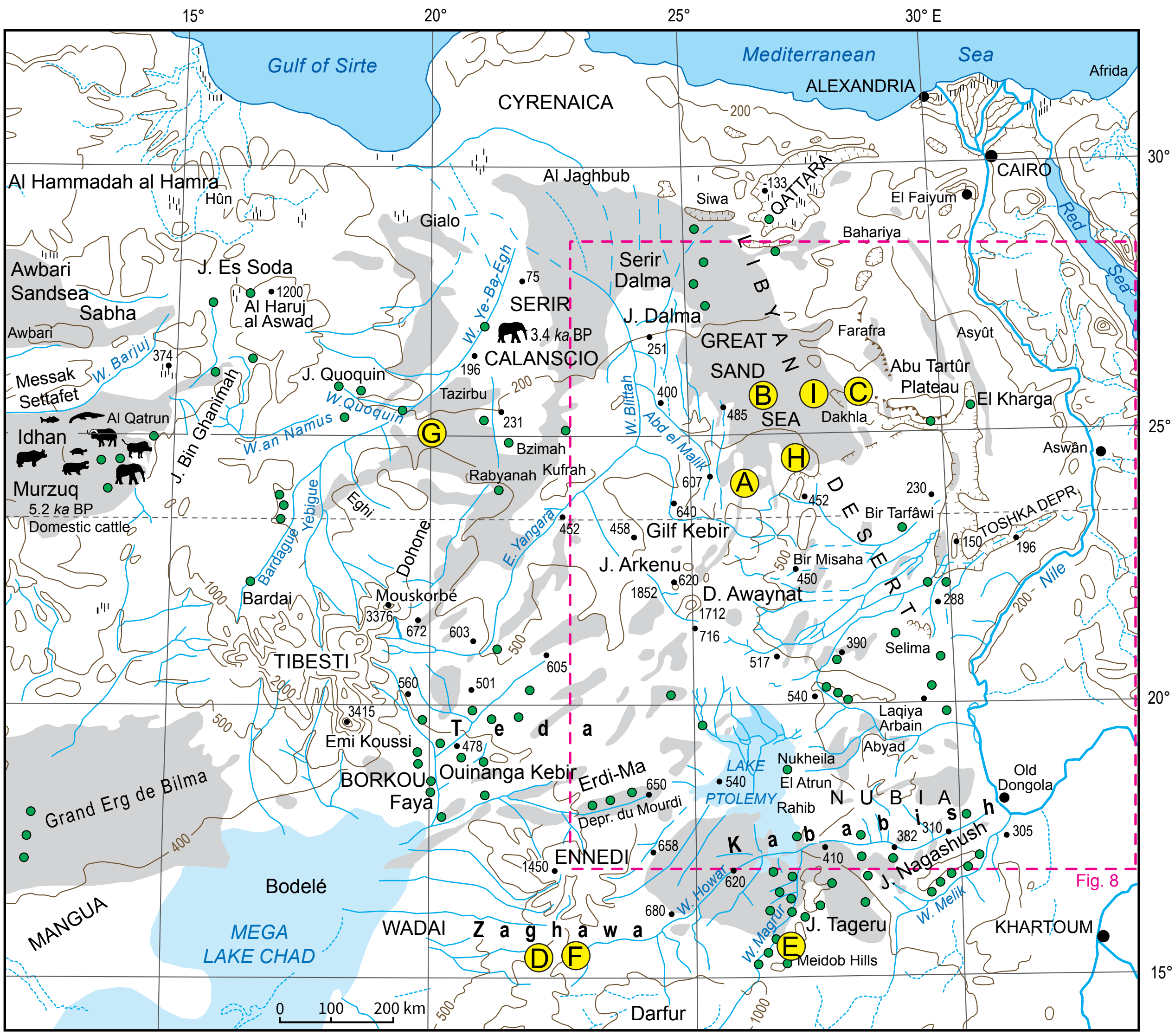


Fig. 3 East saharian palaeodrainage systems, seasonal partially water bearing at 5 *ka* BP. Max. extension of lakes early Holocene. Selected osteologic holocene remains, late Holocene.

Dunes, sand covered areas late Holocene rainfall dependent grass cover, qoz. Gizu by dew.

Hypothetical drainage systems

Early to mid-Holocene Carbonatic-aragonitic-limnic deposits, diatomite; contains fish bones, freshwater molluscs and ostracodes; some deposits lead salt minerals.

Ⓐ Comp. Fig. 20

2. SIMULATION - ALLOTHERMAL, ANAEROBIC PYROLYSIS WITH A PHARAONIC MODEL

The reconstruction of tar-oil production with a pharaonic apparatus is illustrated in the following paragraphs. The experiment was conducted on the grounds of the open-air museum Düppel/Berlin. The procedure was able to refer to the experiences of Ing. D. Todtenhaupt and staff in the pyrolysis of pine- and birchwood by means of the double-pot method, including the mixture of lutum (comp. references).

The main feature of the pyrolysis method is the lack of chemical artifacts on the surface of the most intensively used pottery pieces: the inner walls of the cylinder and the perforated disc. It is likely that the explanation for the one-hundred year-old confusion regarding the function of the widespread ceramic apparatuses lies here. This is aptly outlined by Prof. J. C. Darnell (Yale University) in an epistolary communication in 2016: "A number were found in a cave at Rayayna, in which considerable food preparation occurred. Also the sherds were buried in ash layers, they did not reveal any evidence for have been placed directly in or above an open source of flame."

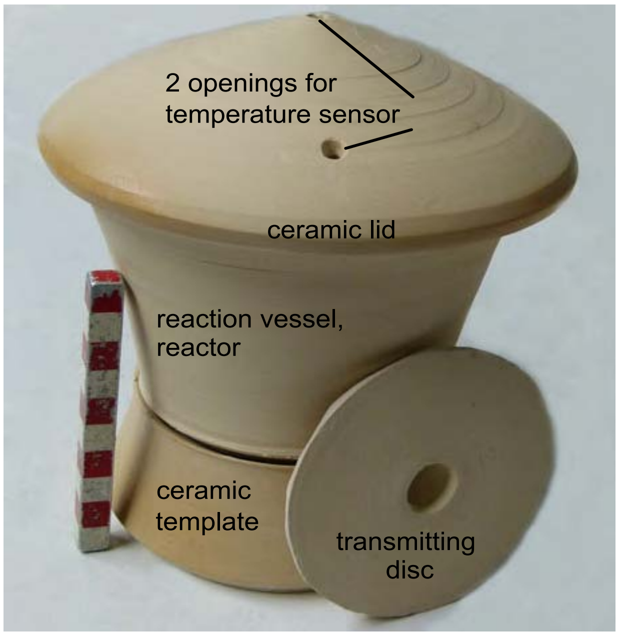
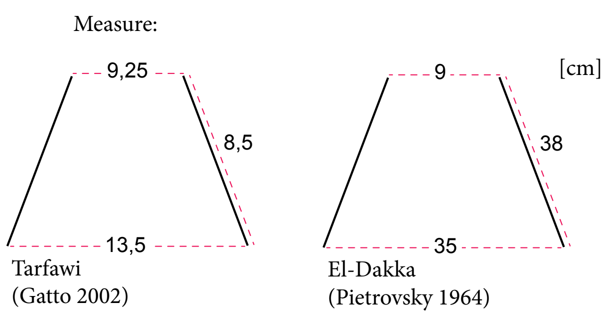


Fig. S 1 - 1
Pyrolysis apparatus by average size of conic ceramic cylinder (support de vases, lamp-shades, Clayton rings) and perforated discs with a centric hole (enfin le fusaïoles, perforated circular lids, Clayton discs) in the Libyan Desert, necropoles of the Nile Valley, and the Eastern-Arabian Desert. The ceramic lid was not documented. Instead, herbal material mechanically supporting the lutum was used to close the cylinder hermetically airtight.

Fig. S 1 - 2
Model for frequently measured sizes of ceramics.

Fig. S 1 - 3
Owner shipmarks (wasms) on pharaonic ceramics with firing stains. Libyan Desert Plateau. Repository: C. Bergmann, Photo: Pachur.



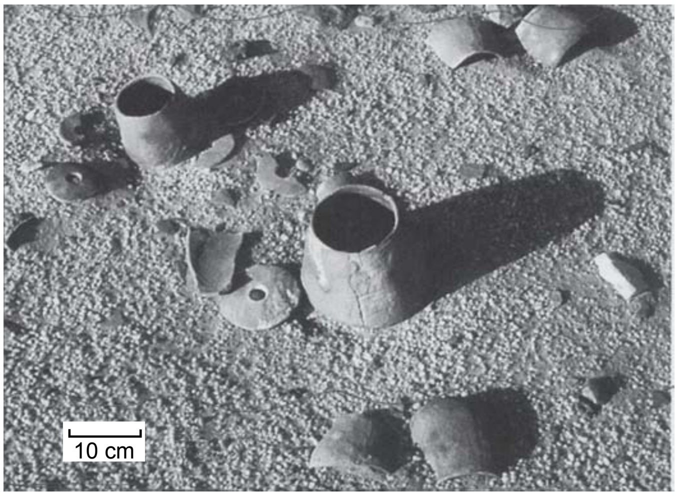


Fig. S 2 - 1
Analogon to pharaonic ceramic. Intact conic cylinders, perforated discs and sherds. Arrangement by tourists. Libyan Desert, location: "Mery-Outlayer". Photo: Riemer 2011 (fig. 205).

Fig. S 2 - 2
Cylinder and perforated disc. Coarse fabric utility ceramic, fire stains. Cleaned in the charcoal fire. Repository: C. Bergmann, Photo: Pachur.

Fig. S 3-1
Conicle ceramic cylinder, fed by wood of *Tamarix spec.*.
The cylinder at the base is closed by the perforated disc.

Fig. S 3-2
Concentration of "Clayton ring" during excavation at the Great Sand Sea (Riemer & Kupper, 2000, fig. H). Lutum residue visible?

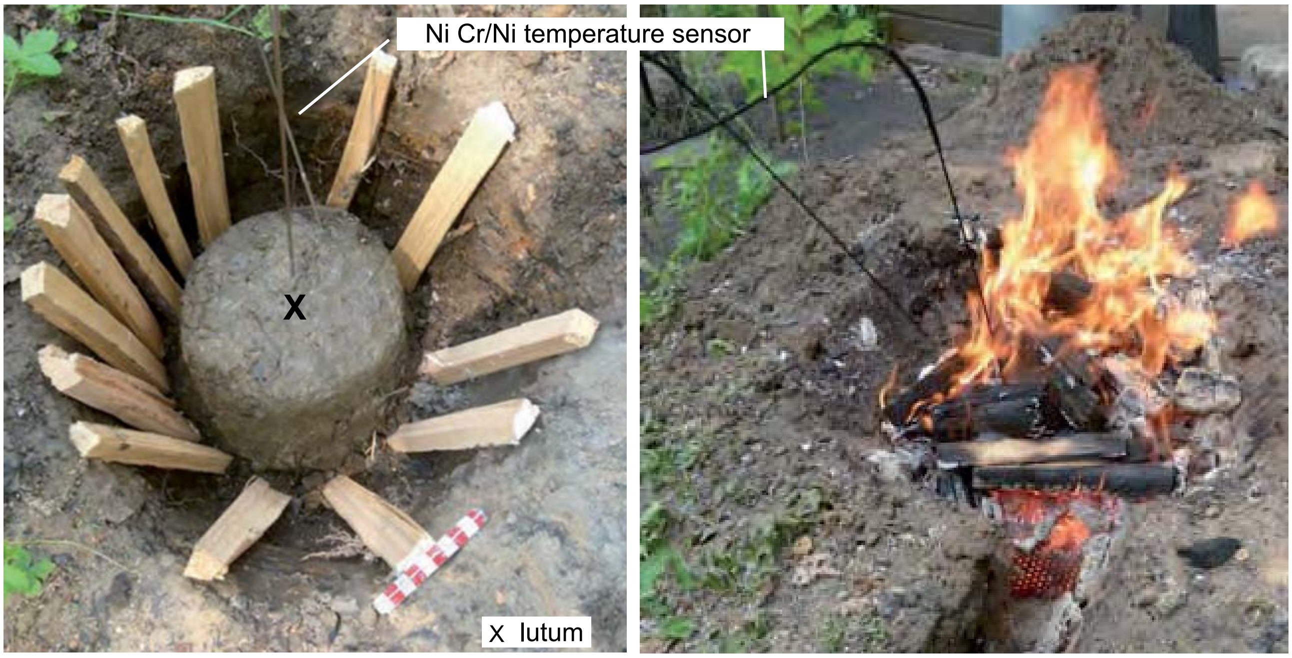


Fig. S 4
Coating the entire apparatus with clay and tempered with sand and organic material, the lutum.
The dry wood fire with low temperatures is meant to repair cracks before the apparatus is completely buried by charcoal and wood.

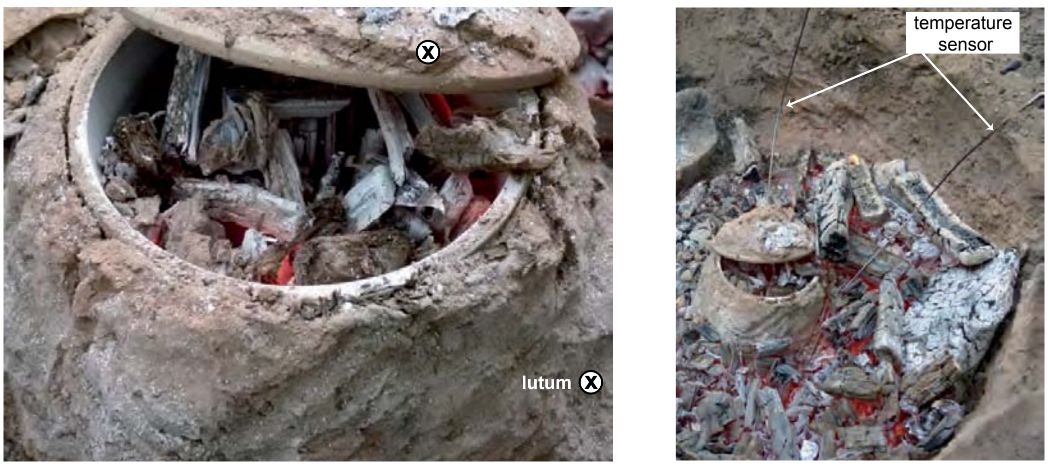


Fig. S 5
Exposing the apparatus to 660 °C. Opening of the reaction vessel. No adherences on upper left wall. Wood is converted to charcoal, glowing red. The surface of the charcoal formed a catalyst for numerous chemical reactions. Lutum configured “clay artifacts” which would be accumulated in the firing pit. The weight of tamarix wood taken 392 gram, the weight of charcoal 99 gram.

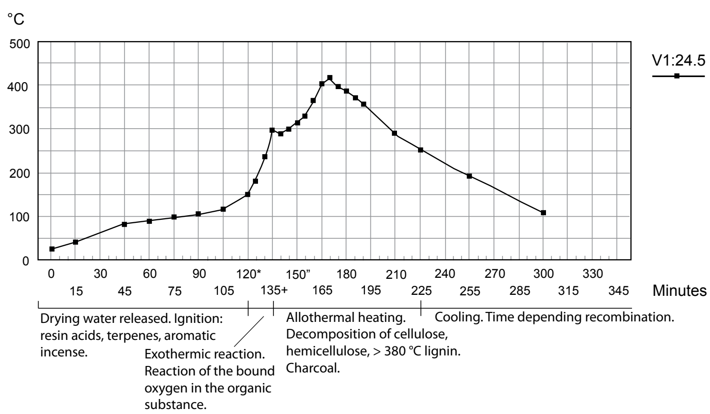
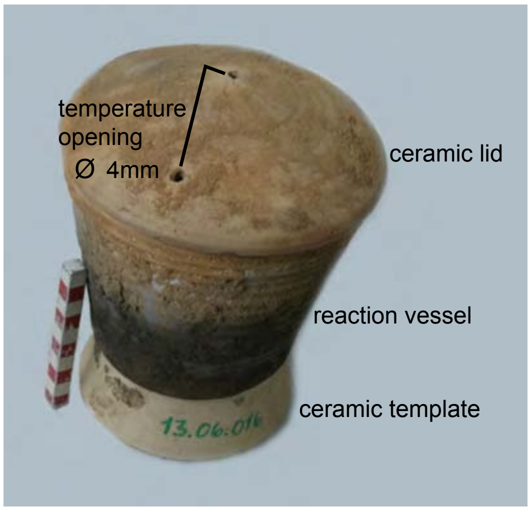


Fig. S 6
Temperature during allothermal anaerobic thermolysis of resin-rich spruce wood. Open wood fire. Reactor with an anaerobic sheating, comp. Fig. S-4. Temperature sensor suspended in the reactor, field trial . Todtenhaupt (2016).



A: Reactor after deposited in a charcoal-fire by max. 722 °C.

Fig. S 7
Pyrolysis apparatus to remove the lutum. Loose relicts of the lutum adhere to the outside wall of the reaction vessel. It can be cleaned mechanically or by contact with a charcoal fire, comp. Fig. S 2-2, S 8 and S 11. The structure of the clay mineral changes when water is eliminated from the kaolinite at 500 °C; montmorillonite, illite at ~ 600 °C, and muscovite, mica and chlorid between 600-900 °C. Goethite, limonite is dehydrated at 350 °C and oxidized to a ferric oxide. Limestone is decomposed at 800 °C, the maximum primitive firing temperature of pyrolysis. Plaster ($CaS0_4 \cdot 2H_20$) transforms anhydrite into a powder.

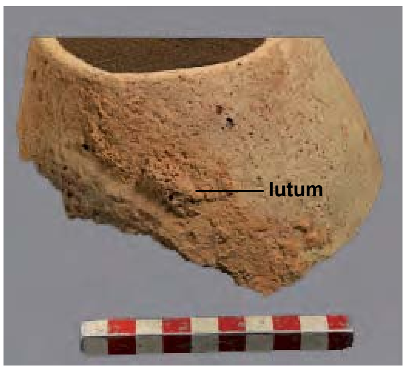


Fig. S 8
Due to uncommon high process temperature relicts of the sintered quartz grains. Photo: Pachur. Object was discovered near Farafra by C. Bergmann (2006).

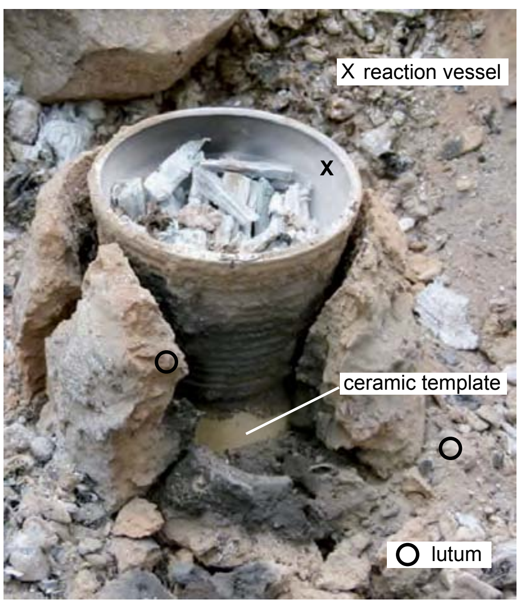


Fig. S 9
Opening of the reactor. The wood converted to charcoal while reducing volume. The inner wall is free from adhesives. Color variations occur only locally by reaction of graphite substances with the ceramic surface. Ceramic template is less effected by heating.

Fig. S 10 - 1
Internal view of the reactor after removing the charcoal. The inner wall is clean of adhesives. Discoloration in violet / black metallic - atomic layer with interference effect - is caused by reaction of the ceramic surface with graphite substances. Some mg of loose ashes. Black graining on the plate is caused by breaking of the lid covered by sand so as to slowly cool down over night, a practice in accordance with the technology employed by the Tubu in the Tibesti mountains.

Fig. S 10 - 2
Inner part of the reactor after the aerobic action of temperature of 700 °C, thermal clearing.

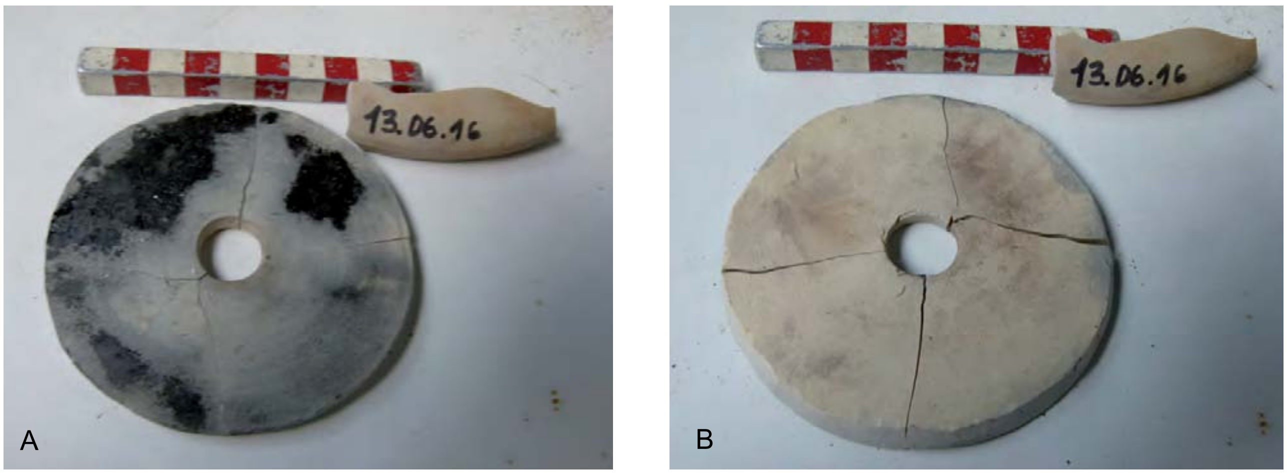
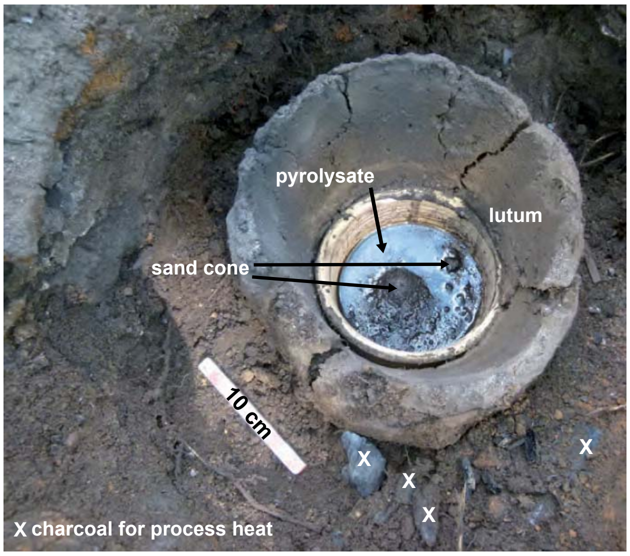


Fig. S 10 - 3
Perforated disc (transmitting disc) after pyrolysis process at maximum temperature of 630 °C.
A: Disc from the reactor side
B: Bottom of A

Fig. S 11
Analogon. Internal view of a pyrolysis cylinder with graphite reactive pattern. Photo: Pachur. Complex of fragments near Farafra by C. Bergmann (2006).



Substance group analyzed of Tamarix wood

Nonaromatic Compounds
Acetic acid; Propionic acid; Pentanoic acid; Butanoic acid, 3-methyl-; 2-Butenoic acid, (E)-; Oxalic acid, allyldecylester; Methanol
Nonaromatic Ketones: Acetol; Hexandion, 2,5-; Butanone, 1-hydroxy-2- (Acetoin); Propanone, acetyloxy-2-; Cyclopenten-1-one, 2-; methyl-2-; Cyclopenten-1-one, 3-methyl-2-; Cyclopenten-3-one, 2-hydroxy-1-methyl-1-; 2-Butanone, 3,3-dimethyl-< (Pinakolon); 2-Butanone, 1-(acetyloxy)-; 2-Butanone; 2(5H)-Furanone, 5-methyl-; 1,3-Cyclopentanedione, 2,4-dimethyl-

Heterocyclic Compounds
Furanone, 2(5H)-; Furaldehyde 2-, 5-methyl-2-; Ethanone, 1-(2-furanyl)-; Furan-2-one, 3-methyl-, (5H)-; y-Butyrolactone, (Γ-Butyrolactone)
Pyrans: Maltol

Carbohydrates
Levoglucosan; Levoglucosenone; Anhydrosugar unknown; Dianhydro-D-Glucitol

Aromatic Compounds
Cresol, p-; m-; Phenol, 3-ethyl-; Phenol; Guaiacol 3-methyl-; 4-methyl; Guaiacol 4-ethyl; Guaiacol; Isovanillin; Acetoguajacone; Guaiacyl acetone; Syringol; Syringol, 4-methyl; Syringol 4-ethyl; Acetosyringone; Syringol acetone; Syringaldehyde

Other Organic Compounds
Acetic acid, 2-hydroxy-, methyl ester; Pyridine, 3-methoxy-; Acetamide; Pyridinol, 3-(NISTMQ94); Four PAH; Tetradecane

Fig. S 12
Pyrolysate in the ceramic template. Reflection of the sky blue on the slightly viscose emulsion with an oily film by propionic acid and black suspended flakes. Odour strictly aromatical. Centric cone and black spots consist of sand due to cracking at the apparatus lids after overnight cooling. Gas chromatographic report analysis of qualitative substances by M. Windt, c/o Johann Heinrich von Thünen Institut (vTJ), Hamburg.

The simulation proves the suitability for use of the dyadic pharaonic pottery for the production of a pyrolysate, a pyroligneous acid usable as an aromatic and preservative. It was completely surrounded by a hermetic layer of tempered clay (lutum). To avoid the formation of cracks, the thus surrounded apparatus is initially exposed to a wood fire before a three-hour heating of up to a maximum of 600 °C occurs under full covering with charcoal and wood. After adding a layer of sand, cooling is initiated over the night hours.

It can be demonstrated that the inner surfaces of the ceramic, including the perforated disc, emerge from the process without adhesives of organic substances. Merely the reaction of the ceramic surfaces with graphite substances results in atomically thin layers that only account for few cm^2 whose metallic gloss and color can be traced back to interference effects.

The pyrolysate is located only inside the template. It presents, depending on the choice of temperature and time period of heating, as an oily liquid or adhesive, tar-like mixture of various chemical compounds.

The pyrolysis reaction material, tamarisk wood, converts to wood charcoal while reducing in weight and volume. Minerals in the lutum can develop a close compound with the outer walls of the reaction vessels by means of the burning process. The rule, however, is an outer surface of the reactor that is free from any adhesives.

The lutum remains as a porous - due to incineration of the organic temper, for example animal dung - burned artifact in the firing pit.

Process heat is created by wood, charcoal, dung and so forth, the ashes and charcoal particles of which stay behind at the production site in form of reactives with the ground, such as burned clay, fritted iron humates, seldom sintered quartz etc. .

3. THE POTENTIAL OF PHARAONIC PYROLYSIS

In *Naturalis historia*, first volume 16, p. 45, Pliny the Elder (23-79 AD) in an impressive manner describes the production of a pyrolysate: "In Europe liquid bitumen is boiled from the 'torch tree' " - Pinus nigra according to the Meyer K. - Lexikon, 1888 - "and serves the purpose of waterproof coating for vehicles as well as multiple other uses. The wood of this tree is cut into pieces and 'baked' in ovens heated from all around the outside. The first output flows out like water in a runnel, is called cedrium in Syria and of such effect that corpses embalmed with it in Egypt do not rot." The next fraction of slightly higher viscosity consists of pyrolysis oil and, finally, tar. If the anaerobic state of the apparatus is discontinued, soot may develop.

Pyrolysis - pyro = fire, lysis = unbinding - is a thermochemical decomposition of organic compounds in the absence of atmospheric oxygen at > 600 °C with specified residence times. According to Masuko (1990), the one - to eleven - hour pyrolysis time correlates with the length of side chains of phenolics.

The heating, which reaches temperatures of 500 °C in the case of wood, occurs within roughly 40 minutes so that charcoal is still able to form. This is in contrast to coke, which is produced within seconds in modern flash-heating procedures.

Goal and main product of pyrolysis conducted with small-scale apparatuses is cedrium - a dark brown, watery to low viscous liquid. The oily surface arises from short-chain carboxylic acids such as piperic acid. Its smell is strongly aromatic. The pyrolysis oil contains low-molecular fragments and recombinations of cellulose, hemicellulose (polybioses), lignin, tannin and secretions (oleoresines); Fig. 5 includes some components.

Essential substance groups - comp. Fig. S 12 - are carboxylic acids, ester, alcohols, furans, aldehydes, ketones, phenol derivatives, terpenoids (α-pinene; limonene), aliphatic aromatic compounds, PAHs (i. a. resin), sugar and syringol. Phenols, among which one finds guaiacol - see aromas of roasted insects also produced in the gut of desert locusts (e.g. Chistocera gregaria) - are described as particularly efficient embalming components of bones in pharaonic Egypt (Kaup et al., 2003). Pyrolysis oils contain less PAHs than fumed smoke. They need to be classified, however, as mutagenic (Blin & Gerard, 2006).

C-C and C-H-bonds remain largely intact. This ensures that the pyrolysis oil can sustain combustion processes. The oil may have been utilized olfactorily; see, for example, incense burners in necropolises and with habitats of A-group pottery - 3.8 to 3.1 *ka* BC - (Gatto, 2006), temple ceremony of the 19th dynasty (Fig. 4) and various facilities in the Meriotic temple "Holy Marriage" of Musawwarat Sufra (Eigner, 2002).

Fig. 4 Funeral ceremony preceded by a priest burning incense (Strouhal, 1992, p 2624). 19th Dynastie, 1307-1196.

Pyrolysis oil is not a thermodynamic system of equilibrium. During storage time, in absence of aldehydes and phenols and under dehydration processes, a tarry, water-insoluble and viscid mixture results: pyrolisis lignin (likely first discovered by Piskiorz et al. (1988 and Scholze & Meier (2001)). Organic acids form ester and water and phenolic units condense under methylene bridging (Hanser, 2002).

In contrast to fossil oil, pyrolysis oil may exhibit a high amount of water present at a generally low pH-value. This originates in the moisture of the substrate - 26.6 % H_2O in beechwood - and the chemical reaction on the catalyzing surfaces of charcoal, see also traces of heavy metals.

3.1 OVERVIEW ON PYROLYSATES OF WOOD AND HERBACEOUS PLANTS

Starting with the substrate of wood, cum grano salis, and a brilliantly simple pottery apparatus, handlers of pharaonic tar-smoulder ovens exploited, theoretically ever since pottery had been developed, a still undocumented number of substances and their action spectrum in the Eastern Sahara; a terrain characterized by shrubland and local dense grass savanna. Variation was multiplied by the plant species selected. This was likely in line with the surviving practices of modern day inhabitants of the Sahara. In Morocco, wood mixtures of different juniper species as well as of cedar (*Cedurs atlantica*), sandarac (*Tetraclinis articulata*) and acacia (*Acacia gummifera*) are deliberately used for the production of medical wood oil.

Wood forms a polymer of the components cellulose (cellobiose), hemicellulose (polyose), which links cellulose strands with lignin by means of hydrogen and ether-bridges, as well as secretions. The proportion of cellulose accounts for 43-46 % of the total amount of wood; this refers to β-1.4 d-glucose units (Fig. 5).

The gaseous phase (Fig. 5), with a share of 15-20 % of the pyrolysate, starts with a higher viscosity of resins below 150 °C and the release of wood moisture. Within the range of 150-170 °C, initial isomerization reactions occur; chemical dehydration begins. In-between the cellulose strands, H_2O is enclosed in hydrogen bonds with low activation energy so that aqueous vapor is particularly included in the pyrolysis gas within the range of 100 °C. Process water results from roughly this cellulose equation $3\ (C_6H_{10}O_5)$ Cellulose —> $8\ H_2O + C_6H_8O + CO + CH_4 + 7C$. In the temperature range of 150-190 °C, activation energy of 183 kJ / mol is required for bonds at the oxygen atom present in the cyclic compound of the glucose molecules (Fig. 5). Therefore, saccharides (d - glucose) develop most frequently. Since the proportion of O_2 to biomass accounts for 44 % in beechwood, for example, oxidative reactions may take place.

Hemicellulose, polyoses (mass fraction of 27-37 % of the total amount of wood), particularly harden via H-bonds and cellulose strands in hardwood. They are primarily made up of pentoses, which additionally supply aromatic substances, and heterocyclic aldehyde, which is pre-existent in the cellobiose units, and are subject to dissimilation under 200 - 260 °C.

Cracking of cellulose at 300 - 400 °C decomposes intra-molecular, glycosidic bonds. Under processes of dehydration - pyrolysis oil contains up to 27 % H_20 - levoglucosan forms (comp. Fig. 5). Release of CO leads, via propanal, butanoic acid whose ester is used for boilies as well as for aromatic substances (pineapple), propionic acid (E 280) supplies preservatives, odorous substances and medication used to cure chronic inflammations. In Egypt, its role as an anti-demonic, soul-cleansing substance is essential.

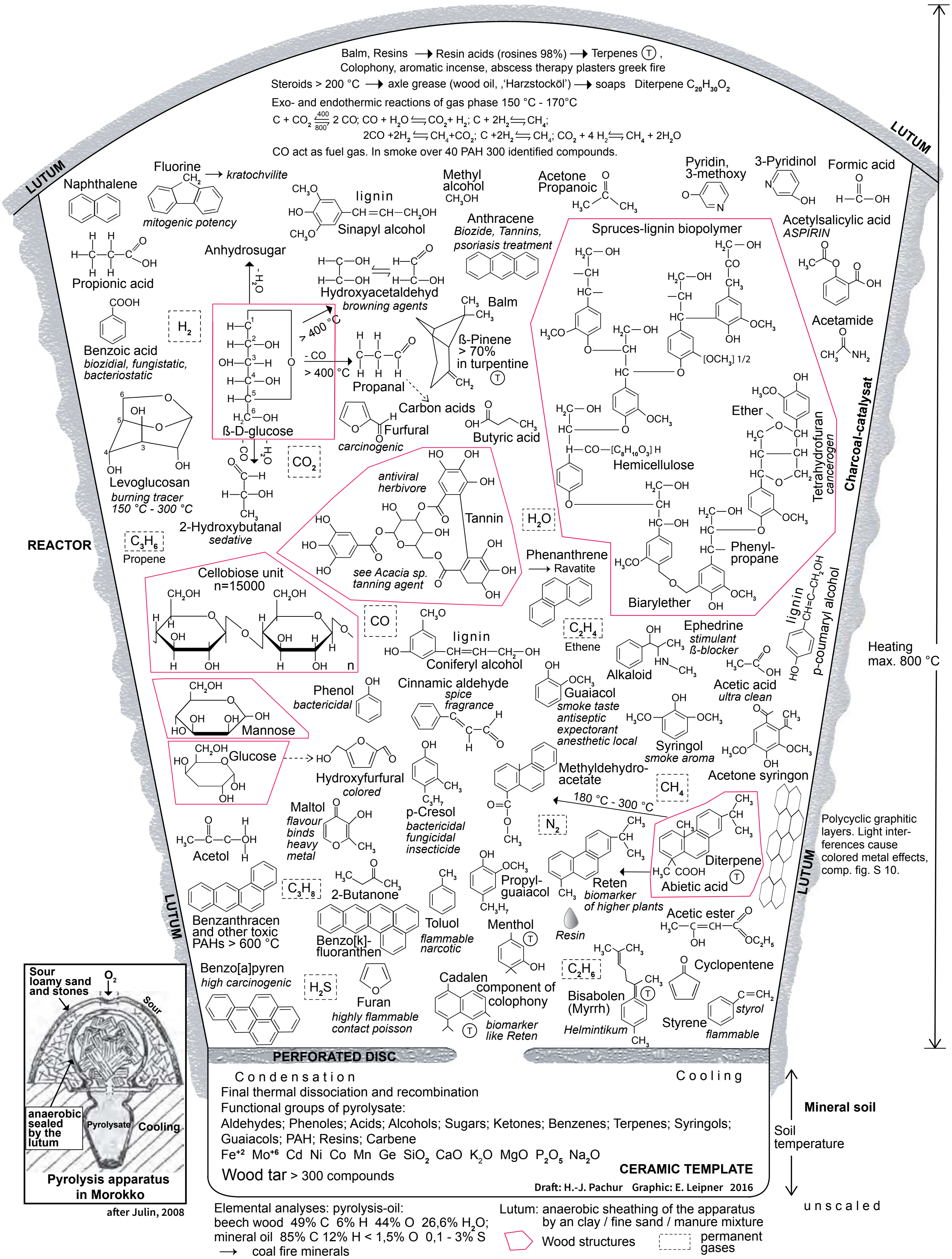


Fig. 5 Pyrolysis scheme.
Potential pharaonic allothermal pyrolysis of wood as a result of the thermochemical splitting of macromolecules and recombination of arising compounds.

Lignin, soft wood contains 26-32 %, hardwood 17-25 %. It is the most common organic substance in nature after cellulose and primarily comprises three phenolic alcohols - coniferyl-, sinapyl- and p-coumaryl alcohol (Fig. 5). It joins cellulose polymers to a compound polymer by means of hydrolysis polymerization. The pyrolytic decomposition of lignin at 320 - 380 °C primarily results in the generation of phenolic products, such as cresols, phenols with bactericidal, fungicidal and insecticidal for characteristics, for example guaiacol - an alcohol carrying a smoke aroma and functioning as an antiseptic and expectorant -, as well as resins under H_2O decomposition and, beginning at 400 °C, PAH formation.

The pyrolysis oil - after approx. 500 °C -contains decomposition products of the lignin, such as dihydrofurane - aerosol particles, biomass burning tracer - and cyclic unsaturated ethers like maltol (Fig. S-12) which generates a caramel aroma. Additional aromatic substances and dyestuffs develop in the presence of formic acid and reducing sugars as well as brown melanoidins that give roasted food products their characteristic color. It is possible that the tanning effect, lasting for approx. 14 days and emerging as a result of the reaction of the carotene of the skin with aldehydes and ketones contained in the pyrolysate, was also of interest to the pharaonic chemists/pharmacists.

A preferential goal of pyrolysis are the resulting plant secretions. The plant's gland cells produce these secretions in (partly) significant amounts as volatile and nonvolantile substances which attrackted human attention early on with their sticky consistency, their taste and smell as well as with multiple options of their medical application. Resin of the medical plant myrrh (Comiphora myrrha) functions as a disinfectant and helminthicum; compare the pervasive infections of the gastro-intestinal system in pharaonic Egypt (Caspary et al., 2006). These substances, also termed ointments, secretions of the balsam tree (myroxylon spec.) and mastic (Pistacia lintiscus), are complex farragoes of resin acids (diterpine, triterpene acids, phenylacetic-carboxylic-acids) or aromatic ester on the basis of terpenes (C_{10}-C_{40}) and essential oils (mono- and sesquiterpenes) with odors specific to plants as, for example, the lily-of-the-valley odor, which issue from the plant, oftentimes also stimulated by externally caused injuries. They are primarily produced from specific plant parts, such as the roots, from the pinewood of European conifers, sandarac and junipers in Mediterranea, and the Saharan tamarisk, among others. Resins from acacia (*Acacia spec.*) and tamarisk (*Tamarix spec.*) are collected by Bedouin children and immediately consumed, constitute current market - available products.

Colophony (rosin), named after the Ionian city Colophon, approx. 13^{th} cent. BC, in Asia Minor, Ismir region, forms the distillation residue from resin of the surrounding pinewoods. During heating of more than 130° C, combustible fumes develop; compare the incendiary weapon "Greek fire" from the 7^{th} century. Colophon is an effective drug in attempting to cure abscesses as well as for the use of incense with psychosomatic effects.

Wood Tar

After undergoing decarbonylation (-CO), de-carboxylation (-CO_2) and chemical dehydration (-H), with temperatures exceeding 400 °C and a long dwell time, the thermodynamically stable end products of the recombination configure wood tar - a highly viscose liquid and complicated mixture of several hundred substances - as well as flameless-burning wood coal and, in case of limited aerobic conditions, soot. In form of furan derivatives, wood tar contains aromatic flavor carriers. The aromatic alcohol guajacol (catechol monomethyl ether) carries a smoke flavor, Fig. 5. It masks unpleasant flavor components in drinking water from the Guirba, a drinking tube of a turned goat skin, which is coated with wood oil. In addition, it functions as a disinfectant and is used against bronchial diseases - the vaporizing pyrolysate was also inhaled in Morocco. It is likely that the axles of pharaonic chariots were tribologically maintained with an alloy of wood tar and wax (glazing agent); compare the resin oil "Harzstocköl" obtained at 200 °C.

In Tibesti, the clothing of women is exposed to the aromatic smoke of the smoldering pyrolysate during wedding ceremonies. In modern Sudan, installations of the "Hufret El Dukhan" (smokehole) are common.

Charcoal burning plants in Central Europe were visited especially by patients with bronchial-asthmatic conditions.

Soot

In addition to wood tar, which exhibits the highest potential for utilization, soot can develop as a pyrolysis product if air is added. Here, carbonizing resin-rich woods under oxygen-deficient boundary conditions stand at the center. Smoke is absorbed in textile fabrics or the soot is scraped off the sides of the reaction vessel. The resulting carbon black displays attributes which let its production appear rewarding even today. Much like graphite, primary parts form from a six-membered carbon ring which are movable against each other in layers; a pyrolysis product made up of up to 99 % carbon. Low molecular aromatic cyclic compounds may condense to larger ring-structures and become visible in the soot. These, for example benzo(a)pyrene, are cancerogenous.

Soot was in demand due to its dyeing ability as a black pigment in the coloration of pottery, as coating, ink and tattoo color. Since approx. 3.000 BC, papyri, similar to subsequent ostraca, were inscribed with ink containing soot, which, in addition, carried plant gums (exudate of the acacia) and plant-based proteins. This additional product of pyrolysis was possibly met with demand in pharaonic society; see also the black painted figures in some petroglyphs of the cattle rearing period.

During incineration, catalytically potent metals, such as Raney-Ni, Co, Mo, Fe, Cu, U and Ge, stay behind. They originate in the metal concentration of the plant and play a role in recombination. Prior to this recombination they appear as porphyrins in the gas chromatograph.

4. PYROLYSIS TRADITION IN THE SAHARA

Dry distillation of organic substances is widespread in the Sahara and part of the daily routine of Bedouins (Fuchs, 1961; Schatanek et al., 2006; Tubiana et al., 1977).

In the Bayuda/Nubia region, a marketable product - huile de cade "100 % naturelle BIO" (El-Toum, 2016) - is distilled in a modified two-pot apparatus.

In addition, it is stated: "Gatran was mainly used for small babies. The most frequent use to apply it on or under the nose, around the wrists, on the hands, temples and head of the baby."

Furthermore, throat, tonsils and eyes are treated with protective amulets are soaked in gatran.

Gatran therapy of psoriasis is the subject matter of medical research with critical results (Schoket et al., 1989).

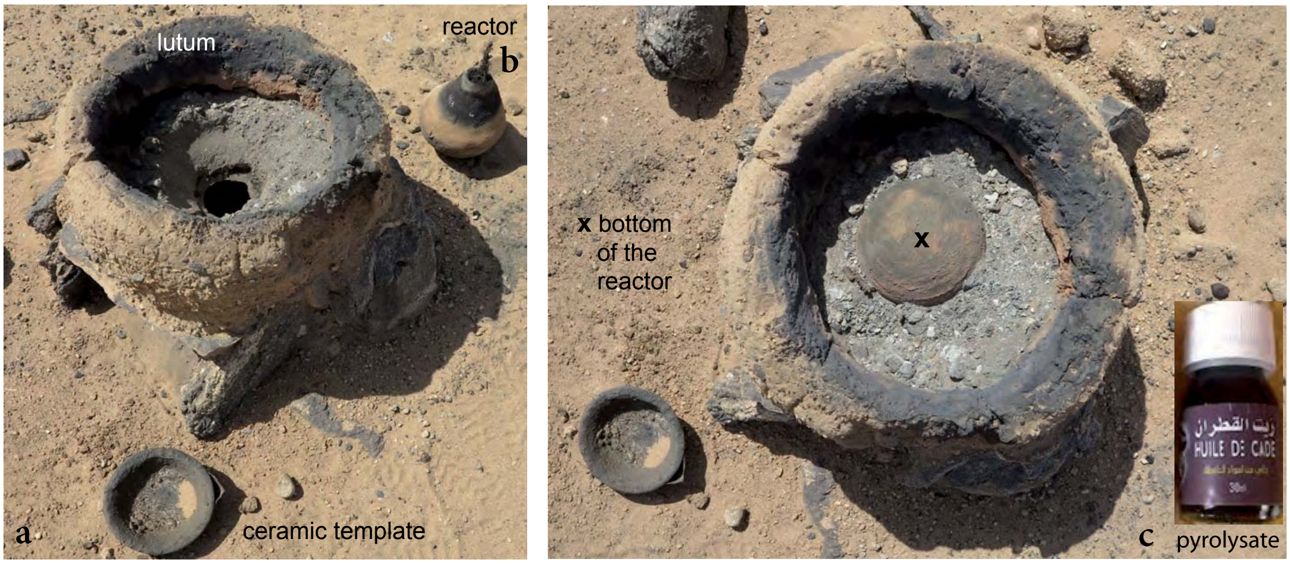


Fig. 6 Pyrolysis of small, 4 mm Ø kernels from Citrullus colocynthis after El-Toum (2016).
a: The reactor consists of a bulbous ceramic bottle.
b: Instead of the perforated disc a bundle of fibre is used.
c: The pyrolysate is a marketable dermatological product (Huile de cade, Bio 100 % naturel).

The tarry oils resulting from pyrolysis are currently used, among other applications, for the coating of drinking tubes made from goat skin (Guirba). Aside from improving the taste, the oils also demonstrate germ-killing properties due to, but not limited to, the propionic acid ester. In veterinary this medicine product is applied as a disinfectant to skin diseases and as an ointment during horseshoeing and clipping claws. A pyrolysis oil - gatran - generated from juniper roots (also connected to a significant devastation of juniper ecotopes) is at present still used as a pharmaceutical in Morocco and has been used until recently on the Mediterranean coasts of Spain, Portugal and France. After a survey in the Marrakesh region, Julin (2008) lists "the most frequent uses of medical tars in the Marrakesh region:"

- Hair and skin dominated
- Decoration of pottery
- Fumigation
- Baby care
- Snake repellent
- Black / white magic
- Animals
- Insect repellent
- Water disinfection and odor improvement
- Cold
- Hepatitis in cows.

Main consumers of the pyrolysis oil are, prior to the local market, international pharmaceutical and cosmetic enterprises; in the Marrakesh region this amounts to 50.000 l a^{-1}.

In the Tibesti mountains of the Eastern Sahara, the Tibbu practice the production of pyrolysis oils derived from a mixture of plant substances and bones. In 1961 Fuchs explains, probably in consensus with Le Couer (1950): "The tar in use is produced in the following manner: In a large pottery vessel bones, date stones, the fruits of the Acacia scorpioides and colocynth seeds are mixed. The vessel needs to have a narrow neck closed off by palm fibre. A smaller vessel, sealed with a metal sheet which only has one hole in it, is placed into a pit of 1½ m depth. On top, the larger clay pot is pulled over with the opening pointing downward. The construction is then fixated with loam. The pit is filled with camel and donkey dung then lit up and burned slowly for a duration of roughly 12 hours. The vessels are then excavated. In the smaller vessel there now is a malodorous, black, tar-like liquid. It is not only used for sealing of *guirbas*, but also as an inunction in cases of camel-mange." (Fuchs, 1961, S. 41 ff.). The neighbours, Zaghawa, produced tar from wild grass grains (e.g. Tribulus terrestris, containing saponins), see chapter 5.3.

Bergmann (2006) describes the production of a liquid (Gotran, handal tar) to be used for the dermatological application on animals and the impregnation of guirbas.

A dyadic ceramic - S 2-2 - was employed for roasting seeds from Citrullus colocynthis (handal) under atmospheric conditions.

Bedouins - also Zaghawa/Tschad - use the following plants for pyrolysis (i. a. Schatanek & Elkharassi, 2006):

- Thick - leaved Maerua crassifolia, a tree reaching heights of more than 10 m. Its very hard wood, adequate for use as projectiles, with a high energy value, is smoldered to form wood charcoal.
- From the wood of the shrub-like convolvulus trabutianus, a plant counting among the morning glory family, and the *Carophyllaceae polycarpaea* repens, wood tar is produced for human medical treatment in Southern Morocco if not enough wood of the chaste tree (*Vitex agnus-castus*) is available.
- *Citrullus colocynthis* - vine of sodom. The seeds of the initially juicy, pumpkin-like fruit, which moved by wind if dried, are surrounded by a capsule rich in bitter compounds - cucurbitalin. When removed in a water bath, the oily seeds are sold by Tubu women. In the Bayuda desert, pyrolysis oil is obtained from the seeds in an oven constructed of clay. The colocynth seeds, in combination with other plant parts, among which is *Zygophyllum gaetem*, are used for tar production. The latter is then employed dermatologically and as an insecticide in the coating of textiles and wood.
- Tamarisk, prevalent in wadis and other regions signalling the availability of groundwater, can be sedimented up to the lower end of the crown of the tree as a result of aperiodically rising sediment deposition in rivers. As a solitary it may exceed heights of more than 15 m. *Tamarix aphylla* can cause hills of > 8 m height. Its wood shows a high amount of resin, see manna exudation. For the wood tar extraction, ceramic pots filled with resin-rich plant parts are positioned within embers. The pyrolysate is gathered by means of a hose. Different plant mixtures yield pyrolysis oil for specific applications, among others for casting out ghosts, fumigating rooms and creating hallucinations (Γ - Butyrolactone). If gallnut (gallotannic acid) of the tamarisk is added, the product is used for the facial tattoos of Berber women.
- *Calligonum azel.* Tar extraction for treatment of dromedary camels infested with mange. Its wood charcoal is in as great of a demand as that of the *Ziziphus lotus*, measuring several meters in height and growing edible drupes. A soap and tanning substance can be produced from its bark. Populations besides *Ephedra alata* (see ephedrine) are disseminated across the Great Sand Sea of the Dakhla Basin, the area in which PYs were found.
- In addition to the unspecific share of acacia fruit (*Acacia nilotica,* Fig. 7*; A. scorpioides*) in the production of a pyrolysis oil (Fig. 5), tannic acid (tannin), a group name for polyhydroxyphenols, assumes a crucial role. It can also be utilized as a tanning substance, a dyestuff in the production of ink as well as in medical applications in form of an astrigent, antiseptic and hemostyptic. Tannin are an effective means against a variety of viruses. Finally, not to be forgotten, gum arabic from exudation also assumes an importment role in the production.

The pods of the *A. scorpiodes* were used for tanning skins directly by the Zaghawa blacksmith; other examples see chapter 5.3.

In the Marrakesh region, juniper roots are primarily used for the production of gatran in two apparatuses designed for different amounts. The smaller one is similar to the pharaonic pyrolysis apparatus (PY), which is verified by various findings (Fig. 8) in the Libyan Desert in, for example, the Eastern Desert; in this context first mentioned by Pachur & Altmann (2014). For its interpretation the biodiversity and net primary production of the ecosystem correspond to a Saharian Savanna around 5 *ka* BC.

Due to the remarable lack of pyrolysis activity in the Nile Valley, an interpretation suggests itself which implies that the geoecological boundary conditions, particularly the missing/rare plants, are unsuitable for the pyrolysis technique, especially since it is located just below the level of a developed on-site preflooder - a riparian, in part annually flooded ecotope with unfit plant species. This would, however, not meet the potential of the pyrolysis method. In the medical papyri p Ebers in Leipzig and Berlin P3038, distilled healing oils are explicitly appreciated. In Central Europe, frog oil was a demanded pharmaceutical (Rohland, 1992, p. 282).

Reference to Tarsian-ceramics in combination with the archaeological findings of PYs in the Nile Valley proximate to the Cave of the Wooden Peg in the Rayayna Desert needs to be considered (Darnell, ibid.).

Presumably, this reveals a lower societal esteem of those entrusted and familiar with pyrolysis; a low social status comparable to that of pottery makers whose object of work received highest consideration; comp. depiction of the creator deity Chnum with a pottery wheel.

A curiosity remains: sound evidence of an iconographic nature, for example on stelae, papyri and ostraca in earlier epochs, comparable to the description of other professions, specifically embalming - Herodotus (Book 2, The Histories) speaks of three class-dependent embalming techniques - that had become common practice with the introduction of the Book of the Dead in the New Kingdom (1550-1070 BC), is lacking.

Late Coptic papyri - published 1885 by L. Stern in Ermann & Krebs (1899) - impart knowledge on the tradition of the marketing of pyrolysis products. In a business letter from the Faiyum one can read: "And you have written to me: Send me cedar oil and stone… And what you payest for the natron.." [1] On the back, the address is written as: "To be delivered to Apiwein, residing in the bitumen merchant road. Sent by Pistene, the bitumen merchant. Peace be with you by God…. The Lord Jesus Christ my protect you." Germer (2002, p. 104) remarks that procedures for the extraction of aromatic, essential oils by means of distillation were not known during this time.

1 $NaHCO_3$ needed for embalming practices. It was inserted into body cavities in sachets for drying body tissue.

5. PYROLYSIS EQUIPMENT AND QUASI-MANUFACTORY PRODUCTION IN THE LIBYAN DESERT SINCE 5 *ka* BP

Interpreting the dyadic ceramic as a pyrolysis apparatus (PY) in light of the potential of the distillation method undergoes falsification simply by reference to the apparatuses employed; we reach close to 1.000.

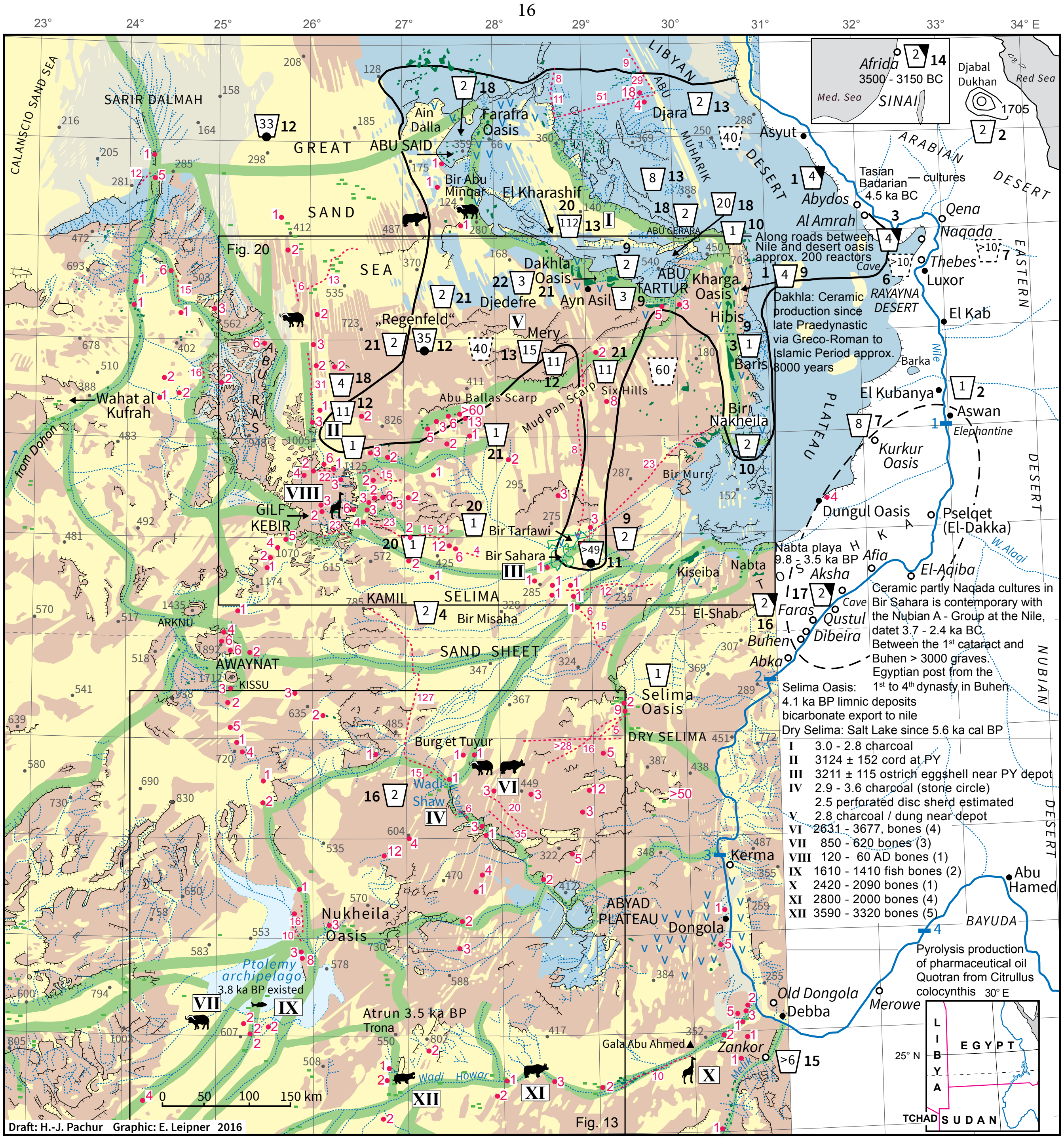
An estimate of the quantity of cylinders in the Libyan Desert, Fig. 8, including the documented funerary goods in the Nile Valley, reaches a number of approx. 400 pieces. Under consideration of the information by C. Bergmann (2016) and based on a multiplicity of expeditions, a total of 770 would be reached. 200 pieces have probably been registered in studies by Yale University (Darnell, 2002) between the Nile Valley and the western oases along the pharaonic transportation routes.

The estimates are likely correct, since PYs broken into shards or smaller units, such as single perforated discs, have not been taken into account.

Fragility lowers the half-life period of the apparatus and supports the representation of the count.

Therefore, the apparatus did not serve as an instrument of secret sciences in the temple areas or as a l'art pour l'art occupation. Rather, it was part of every day life of its users in the Libyan Desert, a land marked by dry savanna, being a pharaonic province and glacis, military buffer zone, in the timespan considered. Funerary goods in the necropolises of the Nile Valley (Fig. 8) demonstrate knowledge and appreciation of the pyrolysis apparatuses.

Fig. 7 Dakhla Oasis, photo Remelé, 1873/74. *Acacia nilotica*, specimen circumference 4.1 m after Rohlfs (1875: 235). Typical tree of the region with groundwater contact, spread in the grarets of the Libyan Desert plateau around 3 *ka* BC. High tannin content (tannery), very hard wood, water-resistant, low-smoke charcoal. Pyrolysis object, see chapter 4.



- Hamada on sandstone, crystalline and metamorphic rocks
- Sand sheet, dunes. Rainfall depending grass habitats, gizu
- Alluvial deposits. Medium to high NPP (net primary production)
- Limestone Hamada. Medium NPP in carstic depressions
- Playas,Grarets. Deposits of clay and silt. High NPP
- Palaeolakes. High groundwater level
- Phreatic-lacustrine dynamic. High NPP
- Drainage systems, interspersed sections of medium to high NPP
- Mainly ground water outlets
- Escarpment disintegrated into outliers. In front playa formation
- 607 Absolute elevation (m a.s.l.)
- Migration routes during dry phases, mainly ungulata
- Reactor of pyrolysis apparatus (PY), often associated by perforated disc
- Complete pyrolysis apparatus as burial objects
- Pyrolysis apparatus in depots
- Estimated number of pyrolysis reactors
- Area of itineration by C. Bergmann, approx. 350 PY
- 21 Sites are listed in references
- 2 Tethering stones
- 10 Route with number of tethering stones
- Cataract
- V [14]C dated material in year cal BC
- Ancient Egyptian: settlement / necropolis

Osteological remains:

- Giraffa camelopardalis (1)
- Fish (2)
- Syncerus caffer (3)
- Domestic cattle (4)
- Hippopotamus amphibius (5)

Fig. 8 Libyan Desert. Distribution of pyrolysis ceramic cylinder, tethering stones, palaeo-drainage systems, selected geomorphological elements. Chronological frame of an Sahelian Savannah by [14]C-data. Registration of the tethering stones near Dungul by J. C. Darnell (2002). Location of the pyrolysis reactors comp. Riemer (2011). Bos primigenius f. taurus (4).

5.1. LIBYAN DESERT PLATEAU, LIMESTONE HAMADA WITH HIGH NPP IN THE GRARETS

A main area of distribution, with more than 400 pyrolysis apparatuses (Bergmann, Exp. 2005/6), is the "Libyan Desert Plateau" - late Cretaceous period to Tertiary. In the northeast it is deeply eroded by the Nile. The area received local names such as Rayayana Desert, El Karashif, Farafra (Ta-Iht, cattle country, 5th Dynasty). It forms a cavernous sequence of cretaceous/paleogenic limestone and partly bituminous marl beds. The cave systems are close to the surface - in Djara they form a natural cistern - as well as in a depth of 274 m and up to 460 m on the northern edge of the Great Sand Sea. The karst relief resulting from subrosion and collapsed cave systems is subject to abrasive, aeolian erosion. The sand trajectory of the northeast trade wind, among others the Muharik Dune, also crosses the wind relief in the Jurassic/Cretaceous terrestrial sandstone and argillite beds of Abu Ballas and Six Hills in the Aptium. At Wadi Howar it reaches the wide-ranging Precambrian basement (Pachur & Altmann, 2006, chapter 2.6, map 3). In basin-like extended karst-depressions (grarets) with local hydrological drainage areas there was an increased potential net primary production leading to the growing of trees such as *Acacia spec.*, *Maerua crassifolia*, *Capparis decidua* and *Tamarix spec.*. A dry savanna with Mediterranean components existed; which is a general phenomenon of the northern Saharan Cretaceous-Tertiary limestone hamadas (comp. the high graret-density in the Hamada Al Hamra at 29°-30°N in Libya; Pachur & Altmann, 2014, fig. 13).

The following finds support the pyrolysis thesis. On a karst relict - "cheese cover hill, 1989" in Bergmann (2005) - Riemer (2011, table 10) counts multiple, parallel and equally sized PYs and vessels combinable to over 100 pyrolysis apparatuses. A few spouted bowls serviced the precise transfer of a precious liquid, such as the pyrolysis oil.

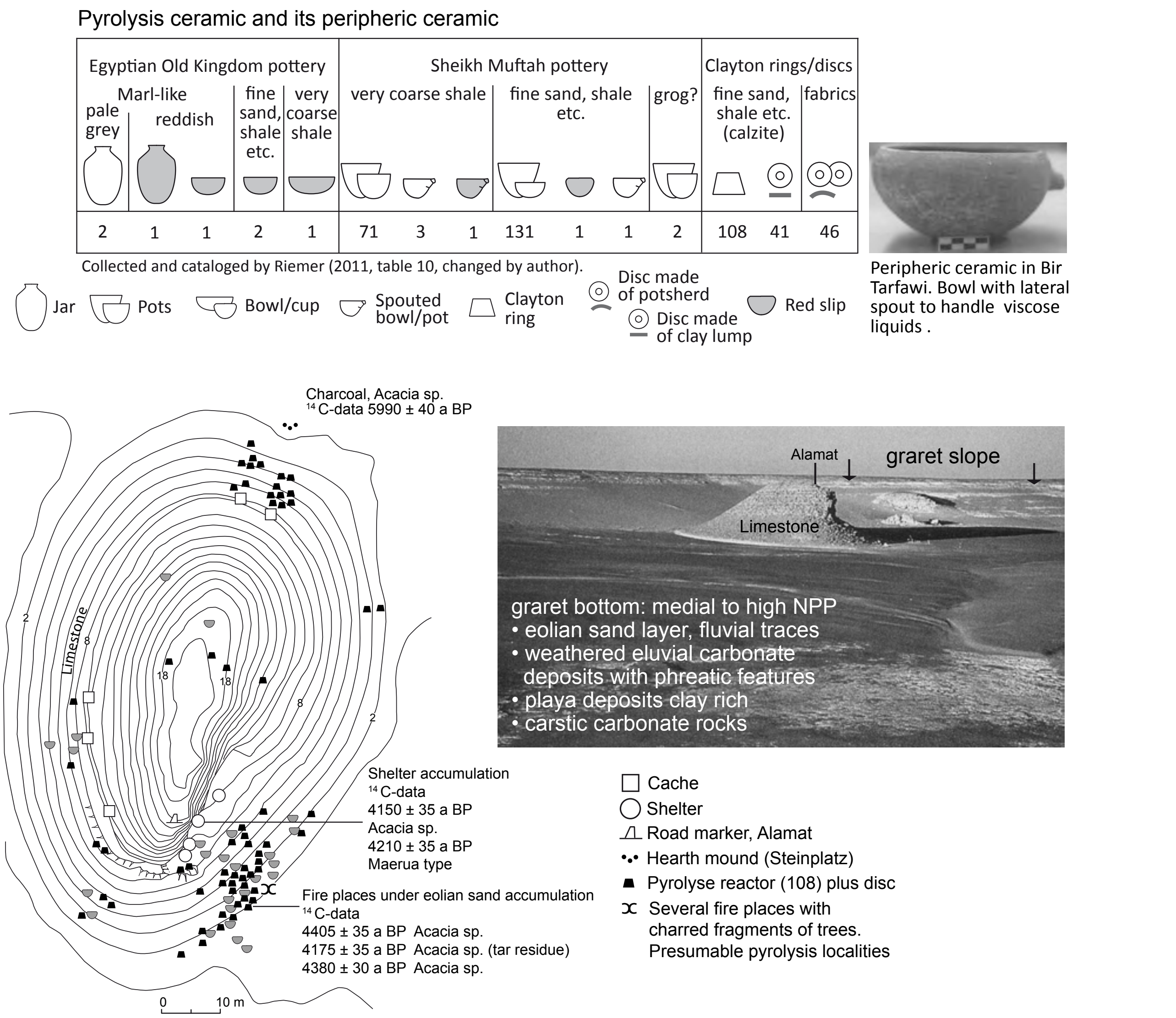


Fig. 9 Ceramic suitable for pyrolysis distributed over the surface - small shelters - of a carstic hill (90 m x 60 m); discovered by C. Bergmann (2006). Hills are located at the bottom of a graret with alluvial fine material. The collectives of peripheric ceramics and reactor-perforated discs are complementary to a complete pyrolysis apparatus of about one hundred.

The practice of pyrolysis with colocynthis seeds in the Bayuda teaches us the use of a flask-formed or narrow vessel - jar in Fig. 9 - as a reactor. The coexistence of karst depressions with sheet floods and an high level of ground water pressure, tree growth as well as over 100 PYs plus peripheric ceramics and charcoal fire pits substantiate the position of this locality as an exemplary production site of wood-oil in an organized group.

On the footslope, which is covered with aeolian sand, three fireplaces contain 92.8 % charcoal and carbonized fragments of Acacia spec. (Darius & Nussbaum, 2011).The following ^{14}C-Data were measured (Fig. 9):

4405 ± 35 a BP	3030 ± 70 a cal BC
4175 ± 35 a BP	2770 ± 60 a cal BC
4380 ± 30 a BP	3000 ± 60 a cal BC.

With regard to the youngest charcoal date the following has to be clarified: The adhesively fixated charcoal fragment - "adhering to the inner surface of the base part" (Riemer, ibid., p. 60) - comes from the inner side of a sherd of the template for a pyrolysis apparatus. The matrix fixating the fragment could be an aged, resin-containing pyrolysate. Unfortunately according to Dr. Riemer (May 2016), the material is not accessible for it undergoing a micro - analysis technique or a careful, ultra-sensitive gas chromatographic analysis. Dr. Nussbaum was not available for a differentiation of the matrix in which the charcoal fragments are embedded and which she retains in her private collection.

5.1.1 A CERAMIC ENSEMBLE WITH A SPECIAL FUNCTION

West of Farafra Oasis - also called Ta-Iht, land of cattle, 5th Dynasty 2475 - 2345 BC - on the limestone plateau El Guss Abu Said, C. Bergmann (expedition report 2005/6; 2006) found a remarkable group of pottery. Located on the banks of a local drainage system, a section of an ensemble of ceramic pieces - cylinder, perforated disc, half-cylinder - bearing ownership marks was uncovered (comp. chapter 2, Fig. S 8, Bergmann, ibid., fig. 33-42).

This was covered by a deep black matrix, probably containing charcoal, resulting from the firing of the construction. Between the latter and the ceramic one finds a burnt mineral grain mixture, likely the lutum, Fig. S 4. It is an "amorphous organic substance of brown colour being a decomposition product of oxidicing action (TC % 1,4; C % 0,25; TOC % 1,15)" (Bergmann, ibid.) which includes pollen of alder, sorrel, (cyperaceaen), birch, elm as well as fern spores and some algal cysts. It could therefore represent lacustrine sediment from the stillwater zone of the nearby channel, prepared for the lutum and used for the anoxic covering of the apparatus.

For the first time, the connection between a dyadic ceramic with attributes of the "lamp shades,""Clayton rings" etc. and high temperature firing as well as a burnt clay/sand mixture, interpreted as lutum, is created in situ.

The interior space of the intact conic ceramic cylinder is, in contrast to the known find, marked by a concentric, distinguishable inner configuration (Pachur & Altmann, 2014). The interstitial space of the lining (a carbonic fine-grained mixture, among which one finds microfossils) exhibits a concentration of allochthonous carbon according to REM (Pachur) and x-ray micro-analysis (EPMA) (Prof. R. Milke, FU Berlin).

Clarifying the functional purpose of this special pharaonic ceramic apparatus is currently the subject of a research association at the Freie University Berlin (FU Berlin). In a working hypothesis among other, the group examines whether a fluid from the reaction space was channeled into the template by means of a tube whose cross section was modified. This would mirror the model of the pyrolysis apparatuses in Morocco (Julin, 2008, fig. 3). Were there aspects that were already known about the influence of the reactor lining on the process of pyrolysis (comp. Alden et al., 1988)? We refer to upcoming results at this point.

Fig. 10 Ceramic ensemble near Farafra, Photo by C. Bergmann (2007).
A: Imprint of the removed cylinder (comp. chapter 2; Fig. S 1-3, S 8, S 11)
B: Residue of superheated lutum
C: Ash of the surrounding charcoal fire zone
D: Arranged perforated disc

5.2. PYROLYSIS APPARATUSES AS COMPARTMENTS OF AN SEMI-NOMADIC USED GRASS GATHERING ECOSYSTEM APPROX. 5 *ka* BP

Southwest of the edges of the Libyan Desert Plateau, the dissemination of PYs reveals a connection to the escarpments of the Dakhla geosynclines running in the northeast-southwest direction and partly breaking up into outliers with PY depots. Animal tracks and paths follow the subsequent depressions with semi-lacustrine sedimentation environments and high NPP as a result of surface water storage. The marshes / playas dating to the early- to mid- Holocene constitute in recent times the Yardang fields with Neolithic artifacts.

In 1931, Ball registered some PYs after Murray (1951). Especially the comprehensive depots of pyrolysis apparatuses lead us to anticipate a manufactory (used here to indicate comparably large-scale manufacturing in artisanal manner) production (Pachur & Altmann, 2014). Their archaeological site - next to a lake carbonate outcrop - is located in the Tarfawi basin in which one also finds the groundwater outlets Bir Sahara and Bir Tarfawi (comp. Fig. 8), roughly 300 km in distance of the Nile Valley.

The two depots BS21-with peripheric ceramic - and BS22 - PYs only - with up to 35 partly interlocking cylinders were found in 1973 (Gatto, 2002). The combination leads us to consider about the application of a double-pot apparatus fully composed of ceramic pieces. Among the peripheric-vessels two “Naqadian-Bowls” (Early Dynastic, 2920 - 2575 BC, necropolis of Qus in Naqada) with “spout” are perfectly fitted to handle a pyrolysate.

The ^{14}C-dating of an “eggshell-fragment” from the surface, close to the location of the finds, yielded the specification of predynastic period of 4510 ± 70 a BP; *cal.* BC 3211 ± 115 (Gatto, ibid.). It supports the age range deduced from the ceramic and belongs to a data collective that describes a high phreatic level as well as the existence of large mammals in West Nubia, see Fig. 20. A seasonal use of the pottery by A-groups living in the Nile Valley and even as lending material is discussed. Its use as a collector of honey, the during the production of cheese and salt or as a trap for small animals is also considered. At the same time it is stated that “For what purpose they needed the rings and to whom they wanted to sell them we do not know”, Gatto, ibid., p. 59.

The A - Group pottery - Nubian culture south of the 1st cataract- is dated to between 3.7 to 2.4 *ka* BC (Nordström & Olssen, 1972) in the villages of Dibeira, Halfa and Afia which are now flooded by the Lake Nasser reservoir. In the necropolises of Aksha and Faras, two complete apparatuses, among which are carefully repaired ones (Fuscaldo, 1999, fig. 1a), are described. Gatto (2006) mentions the A-ceramic grave and habitat finds, including pyrolysates required for “incense burner” in Nag El Qarmila.

If the contemporary distribution of pyrolysis potteries in the Nile Valley and Libyan Desert is evalated, contact of the ethnic groups using the apparatuses appears imperative when drawing on Gatto (2006).

The excellent geoecological position of the Bir Tarfawi basin needs to be mentioned (Fig. 8). It takes up the drainage channels from the Gilf Kebir and is marked by a hydrogeological anomaly - water occurs approx. 2 m below the surface-, a precambrian basement (granite-) outcrop.

Furthermore, the nomadic, cattle pastoralists and hunting ethnic groups in the Libyan Desert need to be taken into consideration. Their presence is verified by osteological evidence; women collecting seeds of wild grasses depicted in petroglyphs in Djebl Awaynat, Fig. 15 and the use of tethering stones as well as older, unadorned ceramics and finally stone circles, gathering fields and other stone arrangements.

Furthermore, in focusing on the inhabitants of the Nile-Valley, those ethnicities with a substantial tradition in the fertile depressions supplied with artesian water, from Farafra via Dakhla to Kharga (750 km !), remain unnoticed. Finds of lithic artifacts, often embedded in the tufa of spring vents, range from the Acheulian to the Neolithicum (Wendorf, F. & Schild, R., 1980). In the timespan under consideration here, this could have included Libyans (Baines et al. 1980). The temple of Hibis (ancient Egyptian “town of the plow”) that remains from the period 1100-300 BC in El Kharga Oasis was linked to a quay.

Fig. 11 Quasi-manufactory production. Photos by Gatto (2002)
A: Ensemble of cylinders, perforated discs and vessels suitable for pyrolysis, B21.
B: A nearby depot of 35 interlocking cylinders and perforated discs, B22. Based on this finding, Wendorf stated: “The pottery probably represents a high specialized function.” (Gatto, ibid.).

First of all, three depots will be mentioned each with eleven cylinders and perforated discs (chapt. 2, Fig. S 6) in an inter - dune corridor of the Great Sand Sea (Riemer & Kuper, 2000).

The locality is situated peripherally to Serir Dalmah, configured from the drainage systems with catchment areas in the Tibesti (Pachur & Altmann, 2014) and recently confirmed by remote sensing (Paillou et al., 2012).

It has to be regarded as contemporaneous to the freshwater lakes in Serir Calanscio visited by *Loxodonta africanus* around 3420 ± 230 a BP (3970 - 3390 *cal. a* BP), (Pachur & Altmann, 2006, p. 141). *Acacia spec.* and *Tamarix spec.* stands are situated peripheral to the drainage system of the Abu Ras into the Sand Sea (25° 07.0' N 25° 27.0' E); dated 5.4 *ka* BP by Neumann, in charcoal analyzed wood (1989) and 4.8 *ka* BP (Haynes 1982). The sharp ridged and hard to cross longitudinal dunes of the Sand Sea likely did not exist around 3 *ka* BC. They resembled the dunes in Mali and Arabia with ephemeral vegetation that can be highly productive in depressions (Hiernaux et al., 2009; Vesey-Fitzgerald, 1957) and the rainfall limited grass cover on the qoz dunes in North Dafur at 15° N.

There was a drainage system developed at the lenght of the Pharaonic Nile, a passage for nomadic groups from the Sirte to the west of Farafra.

At present, this part is peripheral to the transhumance range of groups familiar with the pyrolysis technique from the Tibesti Mountains. The sale of wheat in Kufrah was still one of the few sources of money for the Toubou in the 1960s. Their route leads northwards, as it did 5.000 years ago, along the drainage system equipped with a high NPP, with a catchment area on the east of the Tibesti, the Dohone with over 2.000 m high volcanoes.

From the outpost of the Farafra Oasis, Ain Dalla, the distance only measures 150 km, respective the radius of the southwestern foreland of Dakhla. The Farafra Oasis is also named cattle country (Ta-Iht) during the 5th dynasty and Ain Dalla served as a gate for the Libyan invasion during the rule of Mernptah 1212-1202. This pharaonic designation of the location, which contains a paleoclimatological aspect, is supported by osteological evidence of *Bos. spec.* and *Cyncerus caffer* at the periphery of the Great Sand Sea (Fig. 8).

The Sand Sea - comp. the Regenfeld location (16 mm/2 days rainfall, February 1875, Rohlf, p. 165) - at present migrates in form of isolated longitudinal dunes and sand fields into the extramontaneous area between the limestone plateau of the Libyan Desert and the sandstone plateau Abu Ras-Gilf Kebir (1125 m a. s. l.).

Next to finds of PYs, mostly in pairs, a depot of eleven cylinders needs to be highlighted, since it is embedded in a circular setting of stones , Fig. 20 A, located above swamp land.

As the review of numerous single stone circles shows, this is their typical position on the outcrops above landscapes marked by groundwater seepage, sheet floods and convoluted vegetation. These are observation posts of the grazing lifestock or wild animals.

Top	Sample	Sand (%)			Silt (%)			Clay (%)	
		c	m	f	c	m	f		
Sample every 20 cm	1	0	0.2	0.4	1.5	15.8	21.2	60.9	
	2	0	0.2	1	1.4	12.0	18.7	66.7	
	3	0	0	2	12	10	23	53	6.405 ± 325 a BP
	4	0	0	1	13	13	22	51	
	5	0	0	2	15	12	23	48	
	6	0	0	1	9	18	25	47	
	7	0	0	3	8	14	21	54	
	8	0	0	1	8	20	18	53	
	9	0	0	2	11	8	26	54	7.030 ± 435 a BP
	10	0	0.1	0.7	0.2	11.6	14.4	73.3	
	11	0	0	1	4	12	22	61	
	s*	0	4	85	0	1	1	9	
	12	0	2	1	0	19	17	61	7.560 ± 85 a BP
	13	0	0	1	4	14	21	60	
	14	0	0	5	9	9	23	54	
	15*	1	3	10	9	14	16	47	
	16	0	0	3	8	17	17	55	
Sample every 10 cm	17	0	1	20	16	15	11	37	
	18*	0	2.8	48.7	19.1	5.7	3.9	19.8	7.975 ± 75 a BP
	19	0	0	14	12	15	17	42	
	20*	0	0	14.3	46.2	16.2	11.7	11.6	8.110 ± 75 a BP
	21	0	0	11	18	18	16	37	
	22	1	2	7	7	16	19	48	
	23*	0	0	4	20	10	20	46	
	24	0	1	3	9	19	19	49	
	25*	0	1	37	5	15	10	32	8.370 ± 260 a BP
	26*	0	1	32	5	7	19	36	
	27	0	0.2	7.4	12.3	15.5	14.4	50.2	
	28*	0	0.2	11.8	13.0	13.8	15.1	46.1	9.510 ± 690 a BP
	29	0	0.1	9.4	23.1	20.0	17.1	30.3	10.100 ± 255 a BP
Base weathering sandstone	30	0	1	3.1	7.8	20.7	15.2	52.2	

Still water deposited (shaded) — Sheet-flood, aeolian deposited sand and clay particles (unshaded) — *Sand layer

Fig. 12 Semilacustrine thickly laminated sediment. Datable by charcoal remains. Because of low water stress, sand layers produce a root system - phragmites, tree seedlings. Absence of mollusca the lack of a limnic environment indicating. Hydrologically favoured environment by changing of argilaceous and sandy lavers. Idealized sequence of five $_{org}$C dated yardangs at the Abu Ballas Escarpment. The thickness of the pelite amounts 18 to 29 m depending of the windrelief (Pachur & Röper, 1984).

A second location, also including eleven cylinders and perforated discs - following documentation - is indirectly datable: A "twisted cord covered by the ceramic"revealed a radiocarbon-age of 4430 ± 80 BP; dating to the late predynastic period (Riemer & Kuper, 2000, p. 93).

On the outlier complexes Mery and Djedefre, hieroglyphs, according to Kuhlmann (2006) from the 4th Dynasty (2575 - 2465 BC), attest pharaonic control over today's desert. At Mery, charcoal and goat pellets in one of the multiple abris which were also used as PY depots were dated to 2790 ± 80 *cal.* BC, Fig. S 2-1, chapter 2.

Pyrolysis apparatuses, the use of different types of circular camps as well as tethering stones were, based on the radiometric data, contemporary cultural elements in contact with Nile Valley societies in this diversely used natural landscape (comp. Fig. 8, I-V).

Ayn Asil in Dakhla needs to be emphasized as it distinguishes itself due to manufactory production of pottery. Predynastic (3 *ka* BC) - Byzantine (640 AD) - to Islamic ceramic kilns occupy large areas of the oasis. This fact again underlines the extrazonal geoecological position of the oasis depressions and simultaneously the limited palaeo-ecologic/paleo-climatic diagnostic value of findings from this area demonstrated by the artesian wells.

Next to other utility-ceramics, the pyrolysis apparatuses fired from a fine-grained mixture were produced in Dakhla - the so-called Sheikh - Muftah-ceramics. Darnell describes the pyrolysis pottery between the Nile Valley and the Kharga Oasis as follows: "We have both purposes - made discs and cylinders, as well as discs and cylinders made from cut - down portions of Marl A 1 vessels" (2002 as well as letter notice 2016). Furthermore, Nubian A-Group ceramics from the Nile Valley in Bir Sahara (Gatto, 2006) need to be mentioned.

A system of intensive use of natural resources on an economically high level had been established. Securing the technical equipment on the basis of ceramic kilns, whose maintenance could only be organized by means of division of labor, took place in a consumer oriented manner, as particularly demonstrated at Ayn Asil. Yet, this does not exclude the utilization of ceramics created in the Nile Valley, as Kuhlmann (ibid.) documents by reference to the Mery example. Bergmann (2002, pict. 17) reports a PY made on a pottery wheel, a technique known in the Nile Valley since the 3rd millennium.

The distribution of the PYs, compliant with Fig. 8, is bound to the extra-mountainous area of the Libyan Desert and the accumulation of the run-off into the subsequent-depressions with phreatic lacustrine dynamics. The biological NPP may locally reach 600 g C/m^2. Typical locations are the Abu Ballas Scarp, Mud Pen Scarp and Six Hills.

Furthermore, the playas listed in Fig. 8, including the grarets at the top of the limestone plateau, were places of high net primary production and attractive pasture areas 5000 years ago comp. Table 1. According to Brentjes (1965, p. 33) hunting for wild cattle was taking place west of the Nile; see further cattle graves at 5.6 *ka* BC near Nabta playa described by Wendorf & Schild (2004, p.20).

Rock engravings showing ungulates, including large mammals of the savanna - *Giraffa camelopardalis* - as well as osteological evidence (comp. map 3 in: Pachur & Altmann, 2006), complement the picture of a sustainable, Saharian Savanna rich in ecological niches. Moreover, the actual number of PYs is underestimated. Riemer (2011, p.195) reveals and makes clear that the complete list "of the many rings and discs" exists in inaccessible magazines. This is taken into account by tentative recording of 60 PYs.

5.3 THE LIBYAN DESERT AS A TRAVERSABLE REGION FOR CATTLE PASTORALISTS AND TRANSHUMANCE USING SEDENTARY FARMERS

The previous chapter allowed an insight into the distribution of PYs. It becomes apparent that PYs were a measurable compartment of an ecosystem located above a desert and only accessible via caravan routes, if the fuel requirements are taken into consideration. If dung was the main fuel component, as partially used at present, domesticated animals would have had to exist with an ensuing high demand on the net primary production. Accordingly, it is reasoned that the Libyan Desert could not have been an hyperarid area around 3 *ka* BC, Table 1, but was instead used by ethnicities with a broad spectrum of activities:

- farming along an oasis strip - land of cow (Farafra) to plow town (Hibis) - of approx. 750 km by artesian water consumption
- production of ceramics
- trading with the Nile Valley
- production of wood oil by pyrolysis.

The southernmost evidence for proof PY ceramic - perforated disc from a ceramic shard - comes from the Wadi Shaw drainage system indirectly dated by 3 samples of charcoal to 2500 BC (Lange, 2006). This was excellently located in terms of geoecological considerations up to 2.5 *ka* BC. An unusual high frequency of tethering stones (Fig. 8) demonstrates a high anthropogenic intensity of utilization of the present-day hamadas. Osteological evidence of 18 animal species, among which are large mammals of the savanna and multiple fish species, are listed in the Wadi Shaw in late-Holocene sediments.

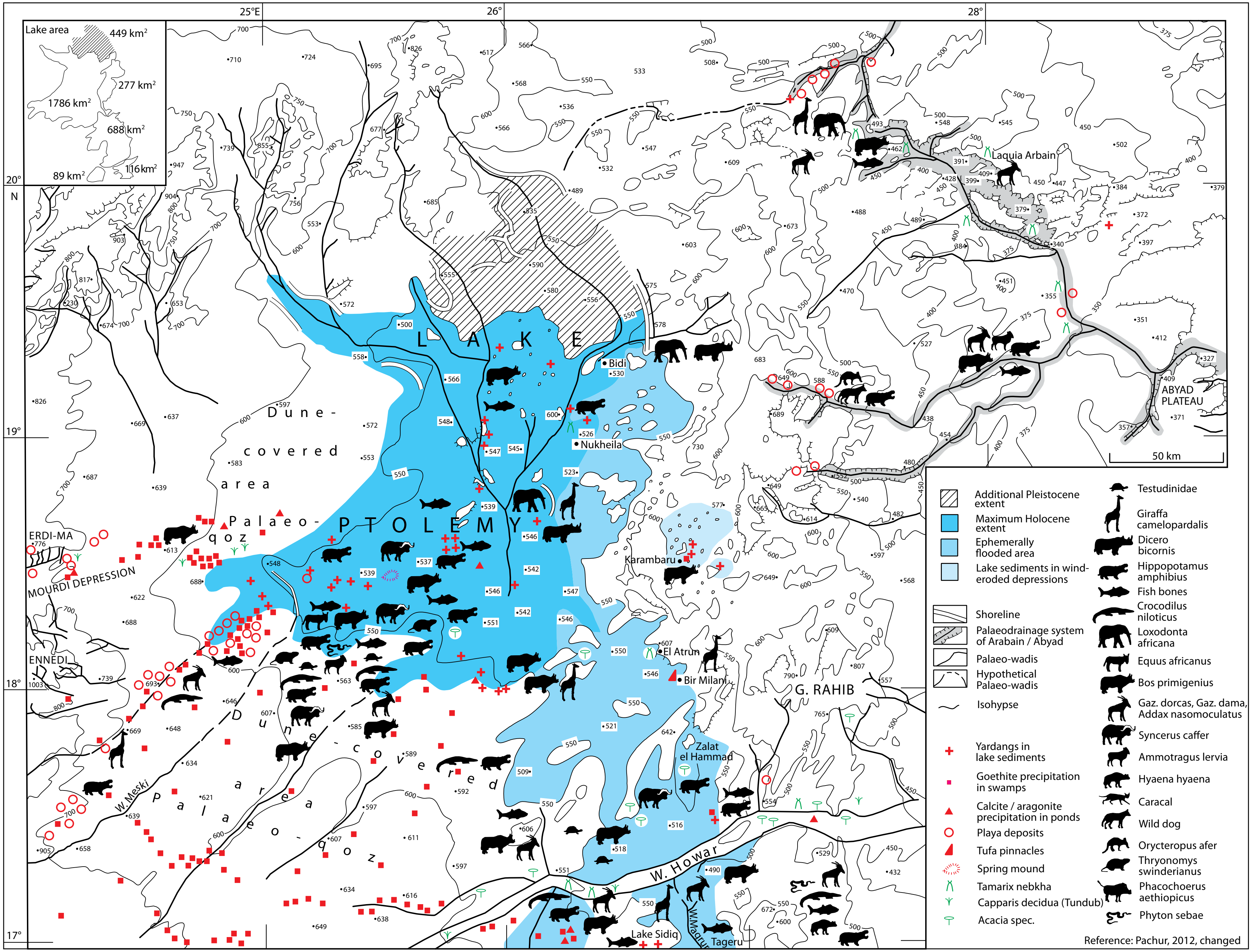


Fig. 13 Lake Ptolemy archipelago in the Sahelian Savanna. Southern boundary of known PY at Laquia Arbain. Paleofauna and paleohydrography of geoecological system of high net primary productivity around 3 *ka* BC; a zoogeographic migration potential northwards.

Lacustrine chalk		
Groundwater level still controls limnic eco-systems; chemically-biologically controlled sedimentation and a fish population in Nubia.		
(A 858-1)	„Lake Ptolemy" (Fig. 8)	3805 ± 65 a BP (inorg. c.), 4350 - 4080 cal a BP
(V 140)	„Lake Ptolemy" (Fig. 8)	3375 ± 105 a BP (charcoal), 3820 - 3470 cal a BP
(K 140-3)	Wadi Howar	3365 ± 305 a BP (charcoal), 4100 - 3250 cal a BP
(N 65-1)		3195 ± 135 a BP (inorg. c.), 3590 - 3250 cal a BP
(E 136)	"Eight ridges" (Nr.4) (16°19'N, 27°28'E)	3155 ± 175 a BP (org. c.), 3600 - 3050 cal a BP
(K 140-1)		3140 ± 380 a BP (charcoal), 3850 - 2850 cal a BP
Playa formation **as an indicator of not yet active aeolian ablation, which dominates in the present.**		
(U 604)	Selima (Fig. 8)	4465 ± 135 a BP (charcoal), 5300 - 4890 cal a BP
(G 3)	W. Akhdar, Gilf Kebir (23°12'N, 26°1.0'E)	4365 ± 95 a BP (treeroot, 3 m deep) , 4875 - 5193 cal a BP
(G 4)	W. Akhdar, Gilf Kebir (23°12'N, 26°1.0'E)	3830 ± 365 a BP, 3774 - 4746 cal a BP
(83/106)[L]	Wadi Shaw (20°26'N, 27°17'E)	3800 ± 55 a BP (wood, tundub), 4110 - 4295 cal a BP
(N 48)	Baheir Tageru (16°0.2'N, 27°0.7'E)	3085 ± 135 a BP, 3450 - 3080 cal a BP
(N 39-2)	Baheir Tageru (16°0.2'N, 27°0.7'E)	2505 ± 230 a BP, 2900 - 2300 cal a BP
Osteological remains. The NPP is still sufficient to enable mammals of the savanna to migrate.		
Loxodonta africana (82/57) [L]	Wadi Shaw (20°30'N, 27°32'E)	5130 ± 200 a BP (?), 3935 ± 221 cal a BP
Hippopotamus (U 502a)	N of the Wadi Howar (17°32'N, 26°52'E)	4720 ± 110 a BP (collagen.), 5590 - 5320 cal a BP
Hippopotamus (K 607-6)	Baheir Tageru (16°45'N, 26°55'E)	4460 ± 115 a BP (apatite), 5300 - 4960 cal a BP
Bos primigenius (82/38) (Long-horned breed)	Wadi Shaw (20°27'N, 27°31'E)	4350 ± 320 a BP (?), 2973 ± 423 cal a BP
Crocodil (K 607-3)	Baheir Tageru (16°45'N, 26°55'E)	4325 ± 100 a BP (apatite), 5250 - 4700 cal a BP
Hippopotamus*	Baheir Tageru (16°55'N, 26°54'E)	4210 ± 130 a BP (collagen), 4880 - 4520 cal a BP
Fish*	Wadi Howar (terrace, [dune])	4190 ± 120 a BP, (apatite), 4850 - 4530 cal a BP
Bos primigenius*	Gaborona (17°21'N, 26°28'E)	4120 ± 130 a BP 4830 - 4450 cal a BP
Fish*	Wadi Magrur (16°48'N, 26°45'E)	3980 ± 120 a BP, 4800 - 4200 cal a BP
Domestic cattle (K 146)	Wadi Howar (17°34'N, 28°25'E)	3915 ± 210 a BP (apatite), 4800 - 4000 cal a BP
Giraffa (A 63d)	Wadi Howar (17°45'N, 29°55'E)	3825 ± 115 a BP (collagen), 4420 - 4090 cal a BP
Hippopotamus (P 147)	„Lake Gureinat" (16°58'N, 27°18'E)	3705 ± 70 a BP (collagen), 4150 - 3920 cal a BP
Domestic cattle (K 617)	Baheir Tageru (16°45'N, 26°55'E)	3665 ± 250 a BP (apatite), 4450 - 3650 cal a BP
Bos primigenius*	Gabarona (17°21'N, 26°28'E)	3570 ± 110 a BP, 4070 - 3700 cal a BP
Domestic cattle (A 833)	El Atrun (18°10'N, 26°55'E)	3540 ± 180 a BP (apatite), 4090 - 3590 cal a BP
Fish (N 91)	„Lake Ptolemy" (18°24'N, 25°35'E)	3285 ± 70 a BP (collagen), 3610 - 3410 cal a BP
Syncerus caffer (P 194-9) (comp. Fig. 16)	„Lake Ptolemy" (18°14'N, 25°25'E)	2630 ± 65 a BP (collagen), 2850 - 2620 cal a BP
Wood species		
For a bovine pastoralism, combined with transhumance; men found conditions comparable to the ecotopes 10 latitude degrees south in the present.		
Wood of tree (J 121)	Great Sand Sea (25°57'N, 27°0.4'E)	2760 ± 85a BP (Acacia spec.), 2950 - 1770 cal a BP
	Abu Ballas (24°9.3'N, 28°6.9'E)	6880 ± 70 a BP, 7661 - 7800 cal a BP
(157)[N]	Great Sand Sea (25°0.7'N, 25°37'E)	5370 ± 65 a BP (Acacia spec., Tamarix spec.), 6049 - 6251 cal a BP
(206)[N]	Laquia Arbain (20°32'N, 27°30'E)	4990 ± 150 a BP (5 species), 5604 - 5899 cal a BP 3330 ± 110 a BP, 3460 - 3711 cal a BP
(85)[N]	W. Bakht, Gilf Kebir (23°12.4'N, 26°17.4'E)	4880 ± 390 a BP (A. albida), 5081 - 6030 cal a BP
Indirect dating of pyrolysis ceramics associate a contemporaneous use, probably with economic contacts to the Nile Valley cultures.		
BS 22 (Gatto, Fig. 13)	Near PY-depot, Bir Sahara	4510 ± 70 a BP (eggshell), 5046 . 5276 cal a BP
(02/50-1)	Mery (Fig. 8)	4190 ± 35 a BP (charcoal), 4660 - 4818 cal a BP
(02/5-1)	„ El Karashif" (Fig. 9)	4175 ± 35 a BP (charcoal), 4648 - 4807 cal a BP 4380 ± 30 a BP (charcoal [acacia]), 5501 - 5600 cal a BP 4405 ± 35 a BP (charcoal [capparis]), 4908 - 5038 cal a BP
(02/5-2)	Shelter layers (Fig. 9)	4150 ± 35 a BP (charcoal), 4621 - 4791 cal a BP 4210 ± 35 a BP (charcoal [maerua]), 4676 - 4831 cal a BP
	PY - depot	4430 ± 80 a BP (org. c. [cord]), 4931 - 5232 cal a BP
(02/5-1; 02/12)	Fire layer near Mery (Fig. 8)	4190 ± 35 a BP (charcoal [acacia]), 4660 - 4818 cal a BP 4175 ± 30 a BP (dung of goat), 4655 - 4808 cal a BP
82/52 (4 data; Lange, 2006)	Perforated disc, Wadi Shaw	3940 ± 140 a BP, 4168 - 4607 cal a BP to 4030 ± 50 a BP, 4452 - 4597 cal a BP
Circular camp. 39 stone circles with an entrance directed to SSW, distributed at the Zeugenberg plateau above the wadi floor.		
82/33-41(Schuck, 2006)	Laquia Arbain	4360 ± 60 a BP (charcoal), 4882 - 5037 cal a BP
[L] = Lange, 2006; * = Keding 1986; [N]Neumann 1989; not mentioned Pachur / Altmann, 2006		

Table 1 Conditions of a Sahelian Savanna defined by selected radiometric data.

The PY-user knew of the ungulate-herds of different species e.g. addax antilope, the seasonal visits of elephants (Loxodonta africana) in some sections of the valley, the daily sight of giraffes (*Giraffa camelopardalis*), ostriches (*Strutio camelus*), from whose eggshells bead chains were crafted, as well as occasional occurrences of the African buffaloes (*Syncerus caffa*) in the Wadi Sahal in the reed zones of small valley lakes. The latter were rich in mollusks and dated around 3610 - 3410 *cal. a* BP, fish, for example Lates niloticus, *Labeo spec.* and *Synodontis spec.* whose spikes on their fins were also used as trade goods (arrowheads). The region's cattle (*Bos primigenius f. taurus*, 2.9 *ka* BC) which could graze on the mounds of the aardvark (*Orycteropus afer*) was capable of long migrations. After less than 150 km in southwestern direction, before crossing the riversides and reed zones of Nukheila (Fig. 13) which were at the time, subject to the process of drying up and yet still invited the migrants to wallow (Pachur & Altmann. 2006, Kap. 2.5.3.9), they reached the large Ptolemy lake where buffalo (still present in 2850 to 2620 *cal. a* BP), cattle and hippopotamus (*Hippopotamus amphibius*; in 4150 - 3920 *cal. a* BP) sought-out the flooded sedge meadows. The lake, equal in the size to modern-day Lake Chad, configured lacustrine chalk from freshwater up to 4410 - 3980 *cal. a* BP. Fish bones are dated to 2320 - 2710 *cal. a* BP and 3410 - 3630 *cal. a* BP (comp. data Pachur, 1999 and Pachur & Altmann, 2006, chapter 2.5). Wood species - determinations by Neumann (1989) - of *Acacia sp.* , *Tamarix sp.*, *Capparis decidua*, *Salvadora persica*, *Boscia cf. senegalensis* and *Maerua crassifolia* were dated from charcoal 5.7 *ka* BP to 3.3 *ka* BP supporting the osteological finds. Considering the herb and grass flora to be deduced, biotopes with high NPP resulted , excellent conditions for a cattle pastoralism in the time range of known pyrolysis activities.

It becomes apparent that an unrealistically steep geo-ecological gradient would need to be assumed if an arid ecosystem were had been developed in the geographical location of the Western Desert oasis depressions around 4000 *cal. a* BC (Riemer, ibid. fig. 2). Instead the use of the PY is based on a herb-rich Saharian Savanna (after Schulz, 1994) ecotope streaked by trees and grass areas in which cattle were kept and drives of wild animals possible at larger intervals comp. Table 1. The praehistory dates an anthropogenic occupation with pastoral economy from 4.7 -2.9 *ka cal* BC including the use of A - Group ceramic and pyrolysis technology.

As an indicator for extensive and anthropogenic utilization of the Libyan Desert with high demands on local vegetation due to the fuel requirements, the pyrolysis apparatus is supplemented by the partly contemporary 1.240 tethering stones (Pachur,1991). Steiner (2016) anounced some hundred exemplares in the Western Desert, some of them includes hunting fences. These are artifacts with a length of 40-130 cm which the stone-striker either worked into trapezoid shape or, in case of hatches, left unaltered and in whose short axle a circumferential groove is added so as to hold a rope, Fig. 14. Their function is immediately extrapolated from petroglyphs. The legs of large mammals of the savanna - elephant, rhinoceros, giraffe, great bubalus (*Bubalus antiquus*) -, of ostriches as well as domesticated cattle are tied to the outstandingly heavy - > 200 kg - artifacts by rope. The stones are placed on sediments, the latter of which are dated to a range between 7.5 - 3.7 *ka* BP.

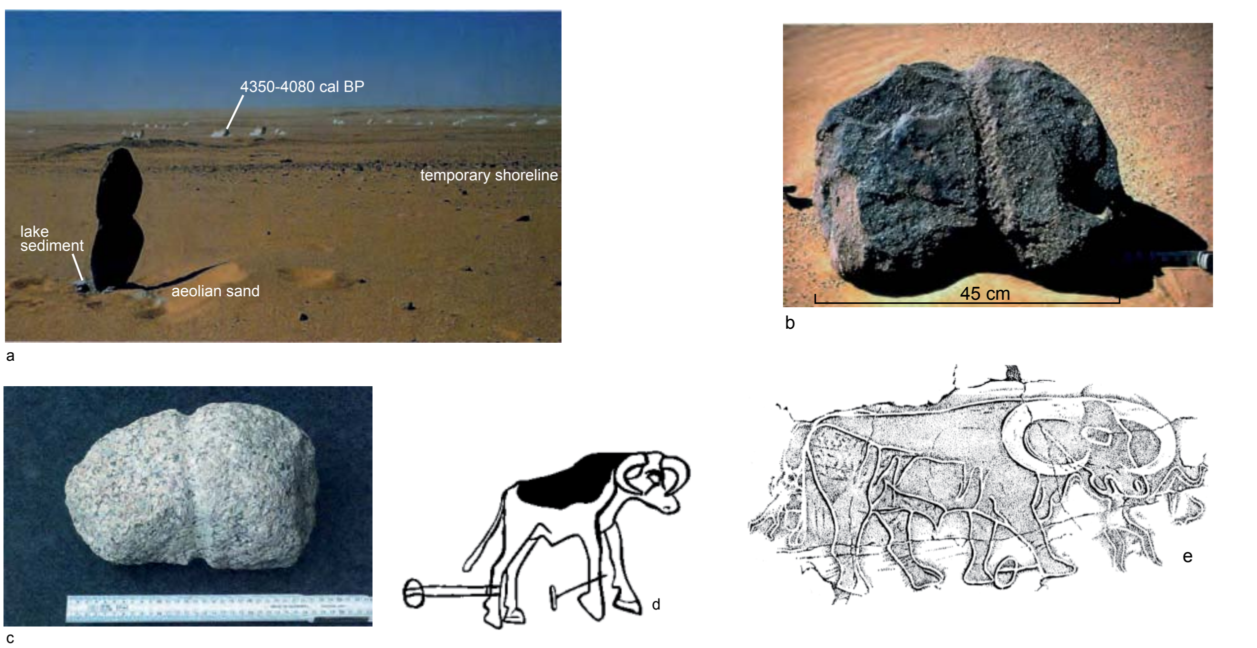


Fig. 14 Tethering stones (TS) as paleoecological indicator
a: Tethering stone, upright, at the lake bottom. Background lake carbonate yardangs of the Ptolemy archipelago, youngest layer dated 4.350 – 4080 *cal a* BP; postquem age of the artefact.
b: TS of coarse sandstone with punched slot. Pebble deflation lag. Great Sand Sea of Egypt (24°08' N; 26°05' E).
c: TS (grinded slot) from the gravel fan at the southern Djebl Arkenu
d: Petroglyph steer with TS. After Jelinek (1985) 6 *ka* to 1,5 *ka* BC. Messak Settafet/Murzuq-basin, area of cattle keeping ethnicity.
e: Steer with two TS. We suspect a method for keeping from running of semi-domesticated animal. In pharaonic Egypt wild bulls were not killed. See the Apis Taurus as symbol of regeneration. Wadi Geddis/ Messak Settafet (Castilioni et al., 1986).

There is a coincidence between the occurrence of tethering stones and anthropogenic stone settings. These are layouts of huts, young mammal pens, food storages facilities as well as stone lines for hunting and grazing techniques. Often, a circle is formed. Their existence serves as testimony of an organized ethnicity. They are repeatedly used structures, as deposits of PY (Fig. S 3-2; chapter 2; Fig. 9, Fig. 11, Fig. 20) and heavy grind stones shows. The variety of shapes is known from the Tibesti mountains (Rönneseth, 1982). The Teda (Toubou; Goran) practiced transhumance to the tarsos. With their small herds, among which are cattle, Toubou traditionally reached Kufrah. Already around 3.5 *ka* BC, the Tibesti, land of the Temehu, is considered the natural addition to the Egyptian Libyan Desert. Presumably, the burial mounds (Pachur & Altmann, 2006; Abb. 2.4.22), in accordance with their key area of distribution in the Tibesti, belong to the cultural testimony of the Toubou. This especially applies to lavishly designed tombs, comp. Pachur & Altmann, 2000; p. 171; Berger & Steiner, 2013/14; epistolary mentioned by Steiner, 2016. The comparison of the paleo-settlement structures with the current patterns of usage around 15° N encourages this functional interpretation.

The contemporary coincidence of tethering stones, PY and stone settings is justified as follows, table 1.

On the border to Nubia in Wadi Shaw, charcoal from two stone circles is dated to 2.9 *ka* BC and 3.6 *ka* BC (Schuck, 2006) and correlates to the indirectly dated pyrolysis apparatuses in the Regenfeld location with 3.1 *ka cal.* BC, Fig. 8 IV. Four circles (of 39) on the plateau of a small outlayer above the valley riverine floor - typical position - contain lithic artefacts, ceramics sherds, ostrich eggshell artefacts and small bone fragments. Between the huts grindstones were detected.
The age of a perforated disc fragment, among other ceramics, was dated to 2500 BC. Egyptian vessel sherds from the wider group of finds are associated with the 4th to 5th Dynasty - 2.6 to 2.3 *ka* BC (Lange, 1999). It can thus be assumed that stone circles and their organisation to circular camps were used in the 3rd millenium BC. Older systems are known.

At mud pans - 24° 9.3' N; 28° 6.9' E - a complex with 19 stone circles was dated by means of charcoal (2127 pieces were counted) 6.9 - 7.0 *ka* BP (Neumann, 1989). Schmidt (1991) assumes discontinuous usage between 500 - 700 years.

In the surrounding area of Regenfeld - where various PY were found (Fig. 8) - Steiner (2016, unpublished) and Berger & Steiner (2013, fig. 2; 2014) describe a high density of circular camps; they identified more than 780 throughout the Libyan Desert. These are indicators for a seasonal settlement of a nomadic ethnicity and / or the short path transhumance of members of the sedentary farmer families at the Kharga-Dakhla-Farafra oases. Also the Gilf Kebir has the potential to serve as a refugium during rainless years. The wadis of the Gilf Kebir carry tree stocks of *Acacia spec.*, T*amarix spec.*, *Ziziphus spec.* at 6.3 *ka* BP - 4.9 *ka* BP (Neumann, 1989). Playa formation (findings of *Giraffa camelopardalis* bones) were dated 4.4 - 3.8 *ka* BP in Wadi Akhdar and 4.9 - 2.3 *ka* BP in Wadi Bakht (Pachur & Altmann, 2006). See further the wild grass harvest of the cattle rearing nomades (Fig.15), based on a petroglyphe from the Djebl Awaynat (Pachur, 2012).

The paleobotanical background is the evidence of gramineae (*Urochlora*, *Panicum*, *Echinochloa colona*, *Bracharia, Setaria*) in the framing of Nabta Playa by Wasylikowa et al., (2001) and recently a glume of *Stipa grostis* in a cave near Djara (Darius et al., 2007). See further Gizu vegetation at 5.7 *ka* BP at Burg et Tuyur (Neumann, 1989). The scene (cattle period ~ 4.5 *ka* - 2.5 *ka* BC) shows female members of the group carrying a basket. Their body and arms bearing may correspond to collecting and plucking activities of wild grass. The illustration is expending the geoecological environment reconstruction in a very impressive way: "Its grains are very small; they are gathered (….) being knocked into a basket with a flattened branch"; this gathering practice of wild grasses by the Zaghawa is explained by Tubiana & Tubiana (1977, p. 16).

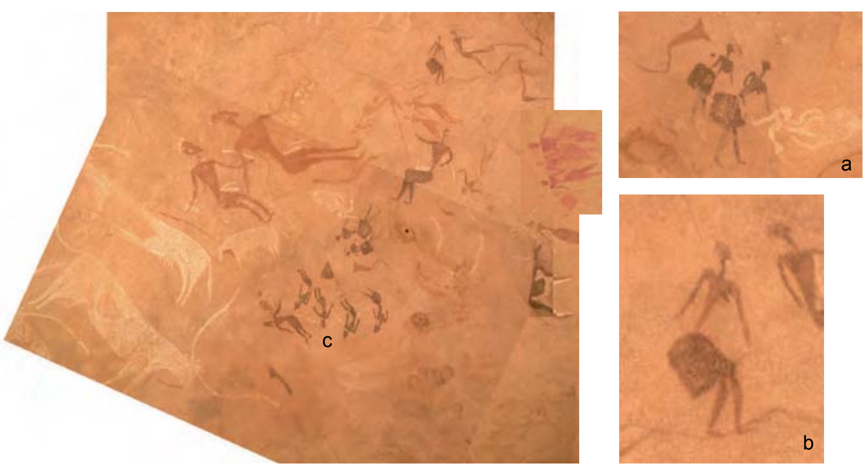


Fig. 15 Petroglyph on the cave ceiling at the Djebl Awaynat. A multiple period document of cattle pastoralists with subsidary competence, namely the harvest of wild grasses. We focus - see Pachur (2012) - on the filigree presentation of graceful females with a basket held lateraly below the waste with a slightly bent upper body. An arm makes a slightly sweeping movement. Obviously wild grass reaping women are shown in the tradition of the economically important subsidary performance of the Zaghawa girls and women at present times south of the 17th latitude. Women wearing skirts are visible at the lower edge of the image.
a: Two women with baskets and a flail or a special bag.
b: Female with basket in collecting position.
c: Bathing group - see "swimmer" at Gilf Kebir by Almasy (1939) - guelta flooding after a heavy rainfall.

The Zaghawa (Beri), Bideyat - a black African ethnicity in North Sudan, Northern/Chad - with their neighbours of the Teda, Toubou (Tibesti mountains and surrounding areas) and in the east the Arabic clans of Kababish are adduced as a model for the paleoenviron-mental conditions 10 parallels further north, see the following illustrations as the paradigma at 3 *ka* BC.

Current conditions by approx. 15° N are : average precipitation of 100 mm per year, episodic occurrence of intense rainfall along with the emergence of gizu herbs, and free of the tsetse fly (*Glossina morsitans*). During the rainy season the main wadis flow for a few hours, and overland flow reaches the structural depressions turning them into semi-permanent pools and fills the gueltas in the mountains - see Fig. 15, bathing persons.

Fig. 16 Winter rain flooded a flowering acacia population, 14° 13' N, near Um Badr. Paradigma at 3 *ka* BC, ten degree of latitude north. Wild animal tracks in front. Photo Pachur 13.1.1995.

Some days later the landscape will be occupied by different grass species as a function of the soil pattern.

Fig. 17 Sahelian Savanna in 14° N. A water saturated loamy arenosol, used as analogon, marked X in Fig. 20 B. Photo Pachur 13.1.1995.

The nomadic pastoralists (camels, cattle, donkeys, sheep, goats and horses at present times) practice an extremly diverse transhumant stock breeding; they migrate seasonally depending on the distribution of precipitation and the resulting grass cover e.g. *Aristida mutabilis* societies form valuable fodder grasses with a coverage of about 60 % and heights of > 50 cm (Krohmer, 2004). Trees and bushes (*Acacia ehrenbergiana*, *a. tortilis*, *Balanitis aegyptiaca*, *Capparis decidua*) present in depressions supply additional food. Ultimately, the allocation of the grass areas in detail depends on the rainfall. Only in the Tibesti regulary favored enneries (rivers) are existing, they are controlled by clans.

Fig. 18 Sahelian Savanna, cattle pasture of the Kababish nomades, North Kordofan 15° 15' N. Photo Pachur 8.1.1995. The grasses are far from each other valuable fresh and dry fodder. Termitarium with typical accompanying flora. Fossile examples at the Great Sand Sea 24° 39' N, 25°59' E.

When the nomadic group passes a potential collection area, the women stay behind in small groups. They defend the right of first arrival with their short knives and flails.

Following the Zaghawa model further harvest of wild grasses requires longer-term stays in grass-covered areas - harvesting starts October until December - and a minimum of infrastructure, huts, a threshing floor, a water source or milk producing life stock. The huts are built with a matting construction, like a typical settlement of shepherds. Circular placement of larger stones suggests itself for this practice, Fig. 20 A; 20 C. Some were used as observation posts for hunting and livestock grazing.

Echinochloa colona harvested twice at a monthly interval. Some grasses e.g. *Dactyloctenium aegyptiacum* are harvested by combing them out with a basket (comp. Fig. 15), others by using a sickle. A forked branch is employed as a threshing flail (comp. Fig. 15). The plant is beaten with a flattened branch before it has dried and the grains fall into a basket in which they are collected.

Preparation - (removal of husks by a simple form of wind winnowing) and storage of the poppyseed-sized seeds requires a ground as solid as possible - yet without stones - which is remote sensing identifiable as a distinct area, see Fig. 20. The following example shows an ideal threshing floor located in crystalline rock.

Fig. 19 Winnowing - enclosure prevents the accumulated seeds against animals (Tubiana et al., fig. 6, 1977). See the remote sensing detectable stone free circles, Fig. 20 B.

Securing the harvest from wild animals and own grazing domestic animals was achieved by means of an impenetrable enclosure of thorns firmly fixed in an accumulation of stones and it remains a remote sensing detectable nearly circular floor plan.

Thievery is meant to be prevented by the placement of a curse stone; divesting somebody of his property was punished by the clan.

The vegetation cover consists of wild grasses including wild rice, Quecel (1969) lits over 100 species in NW-Darfur.

According to Tubiana, ibid. (1977, p. 14) the yield of grass seeds seems to be effective: "one young woman or small groups" harvest up to four camel loads (lowland dromedar at 130 kg, Tibesti dromedar 100 kg) of the wild grass seeds which are roughly the size of poppy-seed.

Harvest of 250 kg per hectare in the middle Holocene are estimated by Schulz & Adamou (1988) in the Djebl Acacus (depression of Murcuq).

The Tuareg gather 50 kg per day and man by combing the grass with baskets (epistolary info. G. Jungstand, 2012).

In periods of shortage the ripping open of anthills can attain the size of a camel load (Tubiana ibid., p.17).

The Beri as well as the Tama (Janszky, 2007) harvest the ears of wild grasses, pick wild fruits, unearth tubers and more recently harvest the gum of *Acacia senegal*, furthermore they used to weave the wild cotton.Various types of honey were collected.

The harvest is stored at semi-permanent settlements in granaries the basis of which forms a circular arrangement of big stones at the centre of the temporary gathering camp, Fig. 20 C; see stone accumulation at the fundament (Tubiana, fig. 8, ibid.).

The production of tar for the dermatological and other purposes is known after Tubiana & Tubiana (1977).

Different species, also mixtures of them, are used:

- *Tribulus terrestris*, grass (saponins, tannin)
- *Dactyloctenium aegyptium*, grass (piscizide)
- *Eragrostis pilosa*, grass
- *Schouwia purpurea*, shrub, achebplant
- *Ricinus communis var minor*, shrub (ricin)
- *Commiphora africana*, tree exuding aromatic gum (flavonoide, triterpenoide).

Grains of *Tribulus terrestris* plus flour of *Ziziphus mauritiane* (castor oil plant).

Sugar extracted fruits of Grewia villosa - "the slave's date" - make tar together with grains of *Tribulus terrestris.*

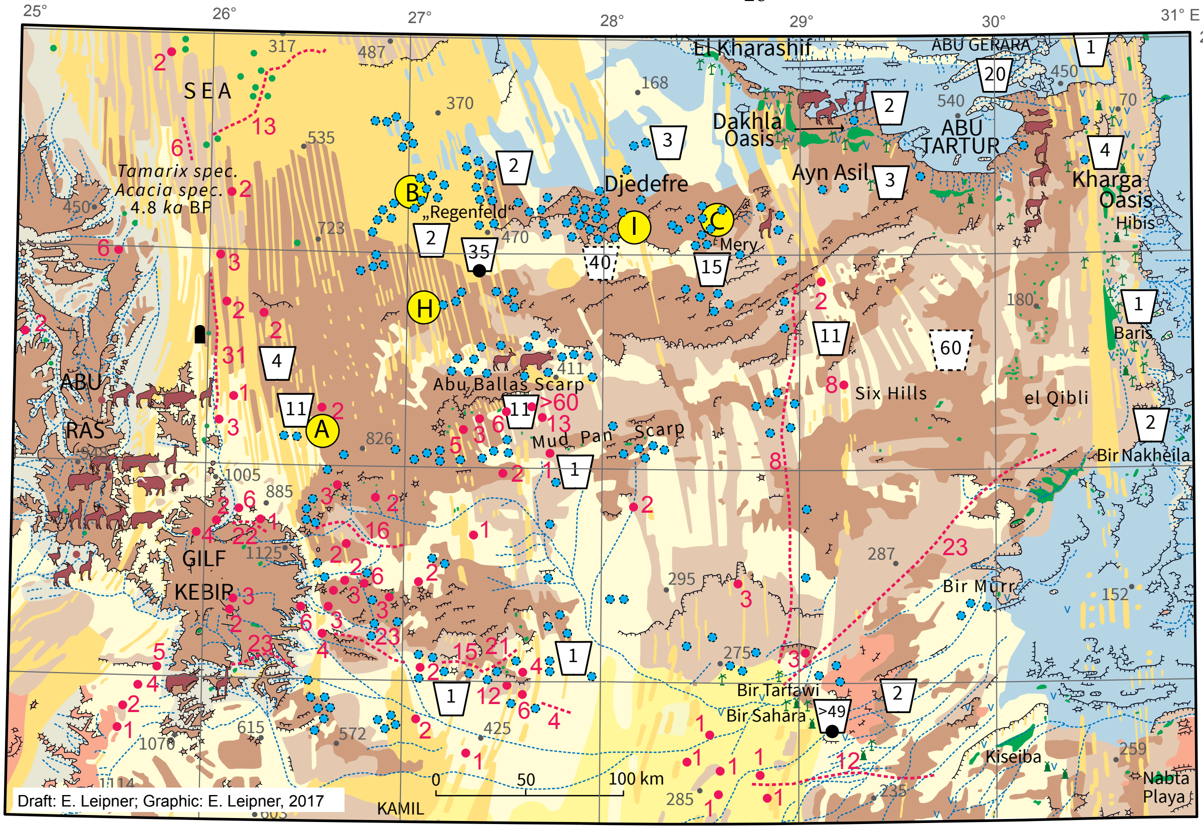
Colocynthis citrullus (Fig. 6) and seeds of *Hibiscus sabdariffa* are further used to produce tar. The dry sepals are exported to the pharmaceutical industry.

The Toubou employed a mixture of plants and bones by a "Doppeltopf" method (chapter 4 and Fig. 5).

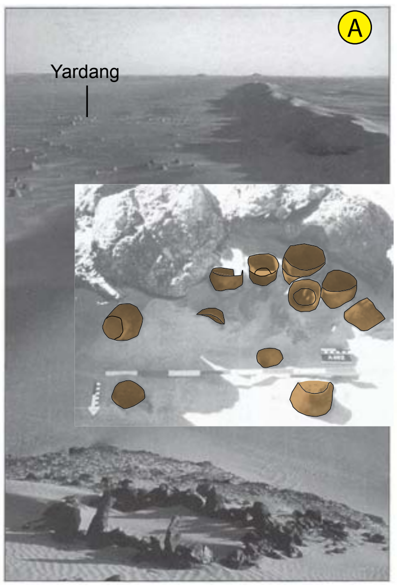
As a working hypothesis it could be formulated: the carriers of pyrolysis technology were the cattle-keeping and grass-harvesting ethnicity, which is represented in the Djebl Awaynat petroglyph in various trades (Fig. 15) and the transhumance using inhabitants of the Western Desert oases.

The comparison of the paleo-settlement structures with the current patterns of usage around 15° N encourages this functional interpretation.

Accordingly, the usage of the term "camp of the grass gathered cattle rearing nomads" is suggested for land using features, Fig. 20.



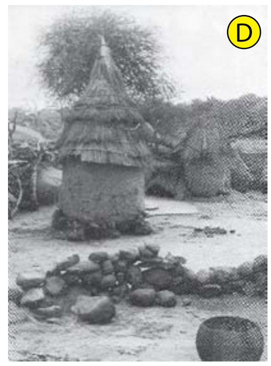
Pyrolysis apparatus (near Regenfeld). Photo Berger, Berlin.



Typical stone circle above run-off fed ponds. Inside 11 pyrolysis devices. (Riemer & Kuper, 2000, fig. 11 -12, changed by author).

Threshing floor Zaghawa women using flails. Floor with fence of thorns. (Photo Tubiana, epistolary info., 2014).

Foundation of an outdoor granary in contrast to the huts ground plans without entrance.



Analog : Boulder were used for the fundament of granary by the Zaghawa. Photo by Tubiana et. al., p. 8, 1977.

Accidental winter precipitation, dew - dry and cold season of the nomades - produce at sandy/gravelly alluvial soils some km² wide stocks of *Stipagrostis plumosa*. 25° N, october 1975, Photo Pachur.

Hypothetical environment at 5 *ka* BP used by transhumance cattle pastoralists, hunters, gatherers with connection to sedentary farming families and ceramic producers at the oasis belt.

Recent analogon. Peniplain with accidental rainfall produced grass cover. Active termitarien. 15° 15' N.Fossile termitarien at 24° 39' N; 25° 59' E. Photo Pachur 12.1.1995.

Depot of a pair of pyrolysis apparatuses (near Abu Ballas). Disc with owner ship mark. Photo Steiner, Zurich.

Fig. 20 Intense anthropogenic activity around 3 *ka* BC based on a high NPP in run-off catchment and in groundwater seepage areas s. l. playas, furthermore, the rainfall-dependent wild grass habitats are favored on the sandy soils. Osteological remains of vertebrates since 8 *ka* BP (Pachur & Altmann, 2006, map 3). Circular camps by Leipner i. pp.. Stone artefacts are described in the vicinity of the stone circles and in their interior (Schmidt, 1991; Schuck, 2006; Berger & Steiner 2013; 14), legend comp. Fig. 8.

6. MARKET-ORIENTED PYROLYSIS PRODUCTS

The pyrolysis hypothesis requires reflection on the amount produced: Was there a personal demand or did the ethnic group constitute a market? The ownership marks on the PYs were carved into the material after firing, suggesting individual property.

Information on belligerent activities is witness to economic potential. Snofru, first king of the 4th dynasty - 2543 to 510 ± 25 BC - , is praised in the Royal Annals of the Egyptain Old Kingdom (Palermo Stone) for the capture of 7.000 inhabitants and 200.000 livestock, led away from Nubia. 17.000 captive Nubians of the Nomarch are mentioned in the 6th Dynasty - 2323 - 2150 BC - in an inscription in Wadi Aqiba (Ziebelius, 1988). In Buhen, from the 1st to 4th dynasty, there was an Egyptian settlement probably used as a base for mining stretching from Buhen to the 20th parallel.

We adduce the interpretation of a hieroglyphic inscription (Fig. 21) in the Djebel Awaynat by Clayton et al. (2008); a high basement structure with preserved limestone ridges, circa 1.892 m a. s. l., 900 km east of Thebes. The rock carving includes the naming of the controversial country of Yam which known from in the tomb inscription of Harkhuf in Aswan and Weri in Abydos. Beneath a canopy, next to carving a cartouche, Mentuhotep is enthroned, bearing of the royal title “He who unifies the two lands;” Middle Kingdom, 11th Dynasty (Mentuhotep II, ca. 2009 - 1959 ± 16 B.C.). Drawing of inscription by Joseph Clayton & Aloisia De Trafford (2008, fig.1).

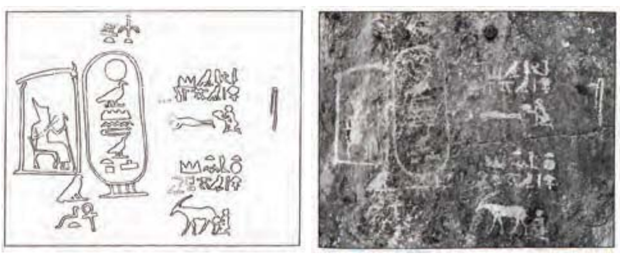


Fig. 21 Drawing of inscription by J. Clayton & A. de Trafford. Sahara 19/2008.

Two horizontal inscriptions read “Yam bringing incense” and Tekhebet bringing…”. In the first a kneeling man with a shell - ideogram A 115 - offers an abstract tribute, as the men lying on the ground in a submissive attitude allow to deduce. The meaning incense, because of the 3 points ideogram, excludes the frequently discussed interpretation as minerogenic products under the tributes of Yam. Incense (*Boswellia*) should be the only interpretation left for established phytogeographical reasons. Other resins, e.g. acacia (*Acacia spec.*) and tamarisk (*Tamarix spec.*) cannot be excluded.

But it could also be a pyrolysate whose aromatic scent would be aptly named due to the low vapour pressure of some components. The decoration of the burial chamber of Amenemone of the 19th Dynasty (1307 – 1196 BC), located in Western-Thebes, offers fumigation, burn incense ceremonies, mechanism for which pyrolysates are suitable (fig. 3). See further the incense burner in various graves of the Naqada culture.

That the performance of the province to the pharaoh is precisely described is shown by the second couplet. The ideogram captures the gift - a living oryx antelope - in detail. At the time, the half-domesticated gemsbok, is often depicted in Saharan petroglyphs and used for sacrificial purposes. The habitats of the gemsbok, Spießbock, (*Oryx dammah*) are the open landscapes of north Africa with reasonable gizzi-vegetation in winter and dispersed dense grass holdings after the monsoonal rainfalls. They are followed by small herds under additional grazing of shrubs and trees in competition with nomadic groups of people. At the Great Sand Sea, bones of antelope found in playa sediments were indirectly radiocarbon-dated 5905 ± 100 a BP (Pachur & Röper, 1984). The antelope (see “Einhorn der Alten”) was also in great demand since lightweight shields resistant to lances could be produced from its skin, the leather could be used for ropes and sandals and its horns were valued for agriculture. A grown animal provides approx. 100 kg of meat. It is also highly honored; the antelope does not flee from cheetah attacks, but instead defends itself with its horns.

The king’s hieroglyphs 900 km east in the Valley of the Queens in Thebes carries the territorial claim of pharaonic Egypt - provided the hieroglyph is real - far into the West of the Libyan Desert; comp. in this context the expedition note from the 4th Dynasty just west of Dakhla, Mery (Kuhlmann, 2005; Bergmann, 2006). The important potential of the territory at the time of the Middle Kingdom results from the still high NPP of the today arid desert area, its easy permeability for cattle-holders, huntable animals, the knowledge of minerogenous resources all the way to the Tibesti/Eghei - desert glass, obsidian, amazonite, flint, ochre, pumice stone, natron, sulphur – as well as the knowledge on habitats of specific plants. In light of the dissemination of PYs, the production of pyrolysis employing substances effective in the human-/veterinary medicine, cosmetics, insecticidal coating and use in ceremonial incense burning and embalming rituals of all societal classes since approx. 1500 AD was among the factors highlighting the importance of the territory. In the medical papyri p Ebers and P 3038 Berlin distilled healing oils are mentioned.

Fractioning of tar and bitumen led to their use in woodworking, the mounting of tools and weapons, and their tribological application in the deployment of chariots - when using tar-/oil-/wax lubrication an extension of the running time of wood axes has been proven by experiment (Kurzweil & Todtenhaupt, 1992). Whether small-scale PYs indeed supplied sufficient quantities for shipbuilding purposes remains an open question. Comprehensive use of the effective apparatus, independent of the caravan-trails, over a timespan in which pharaonic dry savanna and desert steppe provinces still existed, seems plausible. Exclusive attribution of PYs to specific subsistence strategies - roasting of locusts or moderate roasting of poisonous *Citrullus colocynthis* seeds (Bergmann, 2007)

- during travel in a hostile desert calls for a revision. Merely an aspect of ethnological utilization is passed on.

In fact, we do not yet know anything about the chemistry of the pharaonic pyrolysates; not even whether plant or animal - guaiacol is produced in the gut of the often roasted locust schistocera gregaria - material or a mix of substances, as in the case of the Tubu / Tedaga, were used for distillation. Questions regarding the specific maximum viability are therefore allowed, bearing in mind of the silphion-problem. Overuse appears unlikely, when considering the dimension of the area. The distribution of PYs known today reveals the recess of limestone- and crystalline plateaus. This could be an indication of to the limiting conditions for the spread of species used for pyrolysis. In addition, when taking into account the distribution of circular camps as ephemeral settlements and the tethering stone as a hunting and tending tools for larger ungulates, a discontinuous high density of anthropogenic users is revealed.

The assessment of the carrying capacity has to remain equally speculative when considering the fuel requirements posed by the distillation technique. Based on experiences made by the tar-smouldering group in Berlin that works on the basis of experiments, extracting one kilogram of tar-like wood oil with allothermal conduct of processing requires 110 kg of wood, including the processed wood (D. Todtenhaupt and A. Kurzweil, Berlin, personal communication).

For the latter, only specific parts of a plant, such as the resin-rich roots of the juniperus trees in the Mediterranean - chosen because of the odor and color - are usually suitable. For 30 liters of the distillation liquid, the use of 150 - 200 kg root wood is required in Morocco. Specific demands result in the mixture of different kinds of trees. The remaining parts of the tree provide process heat or are used as feed for animals. The surviving pyrolytic production of gatran in the Marrakesh region - at a scale of up to 50.000 liters per year - leads to a problematic devastation of the vegetation, particularly juniperus; a problem analogous to the occurrences during the late Middle Ages in the woods of Central Europe as well as during the Neolithic period in the entire Mediterranean forests and, most recently, the juniperus stocks on the coastal dunes of Southern France.

7. REFERENCES

Arabic numbers identify the PY findings. Roman numerals are ^{14}C data, comp. Fig. 8.

-14- Index in Fig. 5

ALDEN, H. ET AL. (1988): Conversion of tar in pyrolysis gas from wood using a fixed dolomite bed. - In: Bridgwater, A. A. & Kuestler, H. (edit.) : Research in Thermochemical Biomass Conversion. - Elsevier Applied Science.

ALMASY, L. E. (1939): Unbekannte Sahara - Mit Flugzeug und Auto in der Libyschen Wüste. - F. A. Brockhaus, Leipzig, 214 p.

AMBROSE, S. (2010): Coevolution of composite-tool technology, constructive memory, and language. Implication for the evolution of modern human behavior. In: Current Anthropology 51/ S1, 135-147.

BAINES, J. & MALEK, J. (1980): ATLAS OF ANCIENT EGYPT. - CAIRO, EGYPT, 240 P.

BAUMER, U. & KOLLER, J. (2002): Plinius und die nordeuropäische Pechsiederei. - In: Verfahren der Holzverschwelung und die Verwendung ihrer Produkte von der Antike bis zur Gegenwart. - Intern. Symp. i. Forst und Köhlerhof, Rostock-Wiethagen, vom 6.-9. September, S. 100-113.

BEADNELL, H. J. L. (1909): An Egyptian Oasis. An Account of the Oasis of Kharga in the Libyan Desert with Special Reference to its History, Physical Geography an Water Supply. - London: J. Murray. 248 p.

BECK, C. W.; C. STOUT & P. JÄNNE (1997): The Pyrotechnology of Pine Tar and Pitch inferred from quamtitative analysis by gaschromatography - mass spectrometry and carbon-13 nuclear magnetic resonance spectrometry. - p. 181-190. - In: Proceedings of the First International Symposium on Wood Tar and Pitch. – State Archaeological Museum, Warsaw, 1997.

-21-

BERGER, F. & STEINER, U. (2013): Rings of Stone Circles in the Western Desert of Egypt.- In: Les Cahiers de l'AARS 16, 45-56.

BERGER, F. & STEINER, U. (2014): Indications for an extension of the Donkey Trail beyond el-Uweinat. - In: Cahiers de l'AARS No.17, Décembre 2014, p.35-47.

-22-

BERGMANN, C. (2006): Results of Winter 2005/6 Expeditions - www.carlo-bergmann.de

-18-

BERGMANN, C. (2007): Results of Winter 2006/7 Expeditions - A solution to the Clayton Ring problem (continued). www.carlo-bergmann.de

-20-

BERGMANN, C. (2016): epistolary: Itineare in der Libyschen Wüste.

BEYERBACH, R. (2006): Über die Struktur der oligomeren Bestandteile von Flash-Pyrolyse-Ölen aus Biomase. - In: Diss. Univ. Hamburg.

BLIN, J.; GIRARD, P. (2006): Biotox - Bio - Oil Toxicity Accessment, Thermal Net Newsletter Feb., Issue 1.

BORCHARDT, L. (1911): Statuen und Statuetten von Königen und Privatleuten im Museum von Kairo, - Nr. 1-1294, Vol. 1. -Catalogue général des antiquités égyptiennes du Musée du Caire, Berlin.

-VIII-

BRAUN, E. & VAN DEN BRINK, E. C. M. (2008): Appraising south Levantine-Egyptian Interaction: Recent discoveries from Israel and Egypt. - In: B. Midant-Reynes, Y. Tristant, J. Rowland & S. Hendrickx (eds.): Egypt at its Origins 2. Proceedings of the International Conference "Origin of the State". Predynastic and Early Dynastic Egypt", Toulouse (France), 5th - 8th September, 2005. Orientalia Lovaniensia Analecta 172, Leuven: 643-688.

BRENTJES, B. (1965): Die Haustierwerdung im Orient. - Wittenberg.

CASPARY, W. F.; KUST, M.; STEIN, J. (2006): Infektiologie des Gastrointestinal-Traktes. - Springer.

-9-

CATON-THOMPSON, G. (1952): Kharga Oasis in Prehistory. - London.

-4-

CLAYTON, P. A. (1937): The South-Western Desert Survey Expedition 1930-1931. Bull. de la Soc. Roy de Géographie d'Egypte, XIX, 3: 241-265.

CLAYTON, J.; TRAFFORD DE, A.; BORDA, M. (2008): A Hieroglyphic Inscription found at Djebl Uweinat mentioning Yam and Tekhebet. – In: Sahara 19, 2008, p. 129-134.

COLOMBINI, M. P. & MODUGNO, F. (2009): Organic Mass Spectrometry. - In: Art and Archaeology, Whiley.

DARIUS, F. & NUSSBAUM, S. (2011): Late Holocene Plant Growth on the Libyan Plateau: The Vegetal Remains from El Karafish 02/5. - In: Africa Praehistorica 25: S. 306-332, Köln, Heinrich-Barth-Inst.

DARNELL, D. (2002): Gravel of the Desert and Broken Pods in the Road: Ceramic Evidence from the Routes between the Nile and Kharga Oasis. - In: R.Friedman (ed.), Egypt and Nubia. Gifts of the Desert. - London: 156-177.

DARNELL, J. C. (2002): Opening the Narrow Doors of the Desert: Discoveries of the Theban Desert Road survey. In: Friedman, R. (ed.), Egypt and Nubia. Gifts of the Desert. London, 132-155.

-7-

DARNELL, J. C. (2016): Briefl. Mtlg. 20. 07. 2016: Cylinders and discs.

EIGNER, D. (2002): Bauaufnahme der Räume 507-509 ("Heilige Hochzeit") der Großen Anlage von Musawwarat es Sufra. - In: Der antike Sudan, Mitteilungen der Sudan-Archäologischen Gesellschaft zu Berlin 13, Berlin 2002.

EL-TOUM, MOHAMMED (2011): The tar as traditional way of treatment. Case study: Bayuda Desert. Master thesis: Mohtom9@yahoo.com.

ERMANN, A. & KREBS, F. (1899): Aus den Papyrus der Königlichen Museen Berlin. - S. 281.

FRANCKE, U. (1986): Untersuchungen zur Keramik des 3. und 2. Jahrtausends v. Chr. aus dem Wadi Shaw, Nord-Sudan. - Magisterarbeit Köln, 1986.

FUCHS, P. (1961): Die Völker der Südost-Sahara: Tibesti, Borku, Ennedi. - 254 S., Wien (Braumüller). Veröff. Archiv Völkerkunde 6.

-17-

FUSCALDO, P. (1998): Pottery from the Nubian tombs (A- and C-Groups) at Serra West in La Plata Museum of Natural Sciences, Argentina. In: C. J. Eyre (ed.) Proceedings of the 7th International Congress of Egyptologists, Cambridge, 3. Bis 9. September, 1995. Orientalia Lovaniensia Analecta 82, Leuven: 409-417.

GABRIEL, B. (1970): Bauelemente präislamischer Gräbertypen im Tibestigebirge (Zentrale Ostsahara). - In: Acta Praehistorica et Archaelogica Berlin, 1: 1-28.

-11; III-
GATTO, M. C. (2002): Two Predynastic Pottery Caches at Bir Sahara (Egyptian Western Desert). - Sahara 13: 51-60.

GATTO, M. C. (2006): The Nubian A-Group: A Reassessment. - Archéo. Nile 16, 2006: 61-76.

GERMER, R. (1985): Flora des pharaonischen Ägypten. - Deutsches Archäologisches Institut, Abt. Kairo. Sonderschrift 14, Mainz, 1985.

GOSCHIN, M. (1984): Phosphate analysis of Neolithic sites. - Berliner Geowiss. Abh. (A) 50, p. 285-291.

GROOM, N. (1981): A Study of Arabian Incense Trade. - London, Longmann.

GRÜNBERG, H.; GRAETSCH, U.; BAUMER, J.; KOLLER, J. (1999): Untersuchungen der mittelpaläolithischen „Harzreste" von Königsaue. Ldkr. Aschersleben-Staßfurt. - Jahresschrift für Mitteldeutsche Vorgeschichte 81, 7-38.

HANSER, C. (2002): Strukturelle Untersuchungen, Reaktionen und Anwendung von Flash-Pyrolyse-Ölen aus Biomasse. - Dissertation Universität Hamburg, FB Chemie.

HAYNES, C. V. (1982): Great Sand Sea and the Selima Sand Sheet, Eastern Sahara: Geochronology of desertification. - Science 217: 629-633.

HOPE, C. A. (2002): Early and Mid-Holocene Ceramics from the Dakhla Oasis: Traditions and Influences. - In: R. F. Friedman (ed.), Egypt and Nubia: Gifts of the Desert. London: British Museum Press.

JANSZKY, B. (2015): Überleben an Grenzen. Ressourcenkonflikte und Risikomanagement im Sahel. Dissertation, Universität Köln.

JULIN, M. (2008): Tar production - traditional medicine and potential threat to biodiversity in the Marrakesh region: An ethnobotanical study. - 27, 6, 14 S. - Arbetsgruppen för tropics ecology, Uppsala University, Sweden (Minor Field Study 133).

KAUP, Y.; SCHMID, M.; TAYLOR, J.; WESER, U.(2003): Guaiacol, ein reaktiver Balsamierungsstoff des Pharaonischen Ägyptens. - In: Tagungsband Archäometrie und Denkmalspflege, Jahrestagung 2003, 134 ff.

KEDING, B. (1986): Djabarona 84/13. Siedlungsfunde des 2. und 3. vorchristlichen Jahrtausends im Wadi Howar (Ost-Sahara). Magisterarbeit Köln.

KLIK, A.; KAITNA, R.; BADRAOUI, M. (2002): Desertification Hazard in a Mountainous Ecosystem in the High Atlas Region, Morocco. 12th Conference. Beijing, 2002.

KOLLER, J.; BAUMER, U.; KAUP, Y; SCHMIDT, M. & WESER, U. (2003A): Ancient Materials: Analysis of a Pharaonic Embalming Tar. - Nature 425: 784; Doi: 10.1038/425784a.

KROHMER, J. (2004): Ethnoökologische, ethnobotanische und pflanzenphysiologische Untersuchungen in Sahel-Nord und Südsudan-Zone. - Diss. Universität Frankfurt a. M.

KUHLMANN, K. P. (2005): Der „Wasserberg des Djedefre" (Chufu 01/1) ein Lagerplatz mit Expeditionsinschriften der 4.Dynastie im Raum der Oase Dachla. - Mitteilungen des Deutschen Archäologischen Instituts, Abt. Kairo 61, 2005: 243-290.

KUPER, R. (2006): Zeitzeichen der Wüste. - Mensch und Umwelt im Wandel der östlichen Sahara. - In: Landesausstellung „Die Wüste" - www.primusverlag.de.

KUPER, R. (2007): Looking behind the scenes - Archaeological distribution patterns and their meaning.- Africa Praehistorica 21, Köln, p. 24-25.

KURZWEIL, A. & TODTENHAUPT, D. (1990): Das Doppeltopf-Verfahren - eine rekonstruierte mittelalterliche Methode der Holzteer-Gewinnung. In: Experimentelle Archäologie in Deutschland. Beiheft 4, p. 472-479.
KURZWEIL, A. & TODTENHAUPT, D. (1992): "Destillatio Per Descensum". - In: Archeologia Polski, t. XXXVII: z 1-2, p. 243-262.

KURZWEIL, A. & TODTENHAUPT, D. (2005): Chemische Technik im Mittelalter. - In: Experimentelle Archäologie in Europa, Sonderband 1, S. 143-146.

-16; IV; VI-
LANGE, M. (2006): Wadi Shaw - Wadi Sahal. Studien zur holozänen Besiedlung der Laquia-Region (Nord-Sudan). Africa Praehistorica 19, Köln.

LE COEUR, C. (1950): Dictionaire ethnographique téda: precede d'un lexique français-téda. - Mémoires de l'Institut Français d' Afrique noir 9: 211 S., Paris (La Rose).

-3-
MARCHAND, S. (2003): Le mobilier céramique. In: W. Mathieu, Travaux de l'Inst. Française de Archéologie orientale en 2002 - 2003: Bulletin de l'Inst. Française d'Archéologie orientale 103, 2003: 522-523.

MASUKO, C. P. (1990): Thermal reactions oft the bonds in lignin. III Thermolysis of alkylphenols. - In: Holzforschung 44, p. 469-475.

MAYDELL VON, H. J. (1990): Trees and shrubs of the Sahel. Their characteristics and uses. - Weikersheim, 1990.

MEIER ZU KÖCKER, H.; NELTE, A.; MANOS, G.; NOACK, R. & SCHMELTER, W. (1987): Flüssige Kohlenwasserstoffe aus lignocellulosischen Roh- und Reststoffen, Teil 1. - In: Holzforschung Vol. 41, Nr. 6, S. 351-358. E

-1-
MORGAN DE, J. (1897): Recherches soles sur les origins de l'Egypt. Etnographie préhistorique et tombeau royal de Négadah. Paris.

MURRAY, G. W. & HEINRICH, O. H. (1933): Some Pre-Dynastic Rock-Drawings. - Journal of Egyptian Archaeology 19, p. 129-132.

-2-
MURRAY, G. W. (1951): Perforated Discs and Pot-Stands. - Bulletin de Inst. Fouad I. du Désert 1, 1951: 157-160.

NEUMANN, K. (1989): Vegetationsgeschichte der Ostsahara im Holozän - In: R. Kuper (edit.): Forschungen zur Umweltgeschichte der Ostsahara. Köln: Heinrich-Barth-Inst..

NORDSTRÖM, H.-A. (1972): Neolithic and A-Group sites. - SJE 3 Uppsala: Scandinavian University Books.

NORDSTRÖM, H.-A. & BOURIAU, J. D. (1993): Ceramic Technology: Clay and Fabrics. - In: D. Arnold & J. G. Bouriau (edits.), An introduction to Ancient Egyptian Pottery. Mainz am Rhein: Deutsches Archäol. Inst., Abt. Kairo. Sonderschrift 17: 149-190.

PACHUR, H.-J. & RÖPER, H.-P. (1984): The Libyan (Western) Desert and Northern Sudan during the Late Pleistocene and Holocene. - Berliner geowiss. Abh. (A) 50, 249-284.

PACHUR, H.-J. & KRÖPELIN, S. (1987): Wadi Howar: Palaeoclimatic envidence from an exstinct river system in the south-eastern Sahara. - Science, 237: 298-300.

PACHUR, H.-J. (1991): Tethering stones as palaeoenvironmental indicators. - Sahara 4: 13-32.

PACHUR, H.-J. (1997): Der Ptolemäus See in Westnubien als Paläoklima-Indikator. - Petermanns Geogr. Mitteilungen, 141 (4): 227-250.

-VII; IX; X; XI; XII-
PACHUR, H.-J. & ALTMANN, N. (2006): Die Ostsahara im Spätquartär: Ökosystemwandel im größten hyperariden Raum der Erde.- XII, 662 p., Berlin, Heidelberg, New York (Springer).

PACHUR, H.-J. (2012): Palaeohydrology of the Eastern Sahara. - In: Geology of Southern Libya, Vol. 1: 293-314. Binghazi (Earth Science Soc. of Libya).

PACHUR, H.-J. & ALTMANN, N. (2014): Früh- bis mittelholozäne Nettoprimärproduktion in der Ostsahara als Kohlenstoffsenke. Early to Mid-Holocene Net Primary Productivity in the Eastern Sahara as a Carbon Sink. - Zbl. Geol. Paläont. Teil I, Jg. 2014, Heft 1, 5-53. Stuttgart.

PAILLOU, P.; TOOTH, S. & LOPEZ, S. (2012): The Kufrah Paleodrainage System in Libya: A past connection to the Mediterranean Sea? - Compt. Rend. Géosci. 344: 406-414. DOI: 10.1016/j.crte 2012. 07.002.

PENN, A. E. D. (1931): The ruins of Zankor. - Sudan Notes and Records 14, p. 179 ff.

PISKORZ, J.; SCOTT, D. S.; RADLIN, D. (1988): Composition of Oil Obtained by Fast Pyrolysis of different Woods. - Acs. Symposium, Series 376, p. 167-178.

PIOTROVSKY, B. B. (1967): La Nubie antique. - Résultats de travaux archéoologiques des expeditions de l'URSS á la Rau. - Moscow, Leningrad.

PLINIUS G. SECUNDUS, D. Ä. (O. J.): Naturkunde, Buch 16 (Botanik), Herausgegeben und übersetzt von R. König et al. (1991) - Wissenschaftliche Buchgesellschaft Darmstadt.

PROEFKE, M. L. & RINEHART, K. L. (1992): Analysis of an Egyptian Mummy resin by mass spectrometry. - In: J. Am. Soc. Mass. Spectrom. 3, 582-589.

RATSIMBA, V.; FERNANDEZ, J. M. G.; DEFAYE, J.; NIGAY, H.; VOILLEY, A. (1999): Qualitative and quantitative evaluation of mono- and disaccharides in D-fructose, D-glucose and sucrose caramels by gas-liquid chromatography-mass spectrometry….. - Journal of Chromatography A 844, p. 283-293.

-12; II-
RIEMER, H. & KUPER, R. (2000): "Clayton Rings": Enigmatic Ancient Pottery in the Eastern Sahara. - Sahara 12: 91-100.

-13; I; V-
RIEMER, H. (2011): El Karafish. - In: Africa Praehistorica 25, Köln.

RIEMER, H. (2016): New Results about the Clayton Rings - Earliest Desert Travellers in North - East Africa - www.uni-koeln.de/sfb389

RÖMPP (1999): Basis Lexikon Chemie. - Georg Thieme Verlag, Stuttgart. New York.

ROHLFS, G. (1875) : Drei Monate in der Libyschen Wüste. - Kassel: Fischer. p. 340.

ROLAND, I. (1982): Das "Buch von Altenschäden": Teil II, Kommentar und Wörterverzeichnis. - Würzburger Medizinisch-Historische Forschungen, Bd. 23.

SCHATANEK, V. & ELKHARASSI, H. (no date): Sahara, Kosmos Naturführer.

SCHMIDT, MARTIN (1990): Ein neolithischer Siedlungsplatz in der Ostsahara mit Hüttengrundrissen - In: Arch. Inf. 14/1, 1991, 129-132.

SCHOKET, B. ET AL. (1989): Formation of DNA adducts in the skin of psoriasis patients, in human skin in organ culture, and in mouse skin and lung following tropical application of coal tar and juniper tar. - In: The Soc. for Investgative Dermatology, inc., p. 241-246.

SCHOLZE, B.; MEIER, D. (2001): Characterization of the water-insoluble fraction from pyrolysis oil (pyrolytic lignin). Part I, PY-GC/MS, FTIR, and functional groups. Journal of Analytical and Applied Pyrolysis 60. S. 41-54

-VI-
SCHUCK, W. (2006): Wadi Shaw 82/82. Grabungen und Einzelfunde des 5.-3. Jahrtausends v. Chr. - In: Africa Praehistorica 19, 583-613.

SCHULZ, E. & ADAMOU, A. (1988): Die Vegetation des Air Gebirges in Nord-Niger und ihre traditionelle Nutzung. - Giessener Beiträge zur Entwicklungsforschung, 17: 5-86.

-21-
STEINER, U. (2016): epistolary: Koordinaten von Pyrolyse-Apparat-Funden und Dokumente von Fessel-/Fang-Steinen als Teile von Treibjagd-Einrichtungen.

STROUHAL, E. (1992): Life of the Ancient Egyptians. - The American University in Cairo Press. p. 279.

STREITWIESER, A.; HEATHCOCK, C. H.; KOSOWER, E. M. (1994): Organische Chemie. - VCH.

THOMAS, H. (2007): Determination of Cucurbitacins in untreated and roasted kernels of Citrullus colocynthis. - In: Veröff. BioChem Agrar, Labor für Biologische und Chemische Analytik GmbH, Machern. - www.biochemagrar.de

TODTENHAUPT, D (2017): Teergrubenmeiler. Fundpunkt 720 der archäologischen Grabung am Machnower Krummen Fenn. www.stadtentwicklung.berlin.de

TUBIANA, M. J. & TUBIANA, J. (1977): The Zaghawa from an ecological perspective. - Balkema, Rotterdam, p. 119. - Epistolary information. Photo documents 2014.

VESEY-FITZGERALD, D. F. (1957): The vegetation of Eastern and Central Arabia. - In: J. Ecol 45: 779-798.

WASYLIKOWA, K. BARAKAT, H. N., BOULOS, L., BUTLER, A., DAHLBERG, J. A., HATER, J. & MITKA, J. (2001): Vegetation and Subsistence of the Early Neolithic at Nabta Playa, Egypt, Reconstructed from charred Plant Remains. - In: F. Wendorf & R. Schild (Ed.): Holocene Settlement of the Egyptian Sahara. - Vol. 1: The Archaeology of Nabta Playa. Kluwer. S- 544-591.

WENDORF, F. & SCHILD, R. (1980): Prehistory of the Eastern Sahara. - Acad. Press Inc. (Studies in Archaeology): 414 p.

ZIEBELIUS, K. (1988): Die ägyptische Expansion nach Nubien - eine Darlegung der Grundfaktoren. - Beihefte zum Tübinger Atlas des Vorderen Orients, Reihe B, Nr. 78, Wiesbaden, 1988.

8. ACKNOWLEDGEMENTS

The analysis necessitated a demonstration of the nonexistence of organic compounds on the dyadic ceramic by means of different methods for which I want to express my gratitude.

The essential GC-MS analyses were carried out by, in alphabetic order:

DR. URSULA BAUMER, Doerner-Institute, Munich
DR. MICHAEL GOSCHIN, BEGA.Tec-Labor, Berlin
DR. ELENA GOMEZ-SANCHEZ, Berlin/Bochum
DR. TANIA OUDEMANS, Kenaz Consult Berlin, Fourier Transform Infrared Microspectroscopy and Direct Temperature-Resolved Mass Spectrometry
DIPL.-ING. CLAUS SCHALLENMÜLLER, ACL-GmbH, Rottenburg

In the aqueous phase of the pyrolysate resulting from the pharaonic pyrolysis simulation, DIPL.-CHEM. MICHAEL WINDT, Federal Research Institute for Rural Areas, Forestry and Fisheries, Hamburg, detected more than 60 chemical compounds.

PROF. DR. HENNING BOCKHORN, Institute for Combustion Technology, Karlsruhe, with great care verified our examinations based on REM- and microprobe imaging.

DR. MATTHIAS HÜLS, Leibniz Laboratory, Christian-Albrechts-University of Kiel, discussed contradictory radiometric dating results.

In addition to a GC-MS analysis ING. ANNEGRET FUHRMANN, HfBK, Dresden, conducted a Fourier Transform Infrared Microspectroscopy.

DR. BEATRICE ARNST, Ägyptisches Museum und Papyrus-Sammlung, Berlin, carefully and thoroughly revised this paper in its different drafts.

CARLO BERGMANN, Taucha-Sehlis, crucially supported the development of the analyses by readily making available his research findings from the Libyan Desert.

PROF. DR. HUGO DEBOER, Uppsala, Sweden, was most helpful with regards to the results of an examination in his research group.

DIPL.-GEO. ELLEN LEIPNER, FU Berlin, provided the graphics and layout with a high level of professionalism and dedication.

A methodological intensification with regard to the ceramic known from Farafra is planned with PD DR. RALF MILKE, FU Berlin.

DR. VERENA SCHATANECK, Wetzikon, put forth great effort to provide literature on relevant botanical issues.

URSULA STEINER, Switzerland, and ING. FRIEDRICH BERGER, Berlin, allowed insight into unpublished expedition results, including photo documents, from the Libyan Desert.

For the simulation of the pharaonic pyrolysis, I could trust in the extensive experiences of ING. DIETER TODTENHAUPT as well as DIPL.-CHEM. ANDREAS KURZWEIL's knowledge of the relevant literature; both Museumsdorf Düppel, Berlin.