Tagungsbeitrag zur DBG-Jahrestagung 2019: „Erd-Reich und Boden-Landschaften“, 24.-29.08.2019, Bern (AG Boden und Archäologie)
Berichte der DBG (nicht begutachtete Online-Publikation), http://www.dbges.de

Soils of ancient terraces in the southern Levant: archives of desert agriculture?

Bernhard Lucke[1], Jago Jonathan Birk[2], Paula Kouki[3], Rupert Bäumler[1], Nizar Abu-Jaber[4]

Introduction

The ancient city of Petra in southern Jordan was built in a valley hidden below deeply dissected sandstone cliffs. The scenery is spectacular and obscured and restricted access to the city. However, soils are poor, the location in the valley is prone to flash floods, and the arid climate poses severe limitations to cultivation. So far it is unknown how food supply of the ancient city was organized. The barren hinterland seems hostile to agriculture, but there are countless remains of terraces of so far unknown purpose. These terraces were apparently irrigated by collected runoff, similar to the systems found and reconstructed near the Byzantine cities in the Negev (Evenari et al., 1982). The experiments by Evenari et al. (1982) showed that runoff collection on terraces could have made agriculture in the desert possible, although it was a labour-intensive endeavour with frequent years of crop failures. Therefore the terraces may represent the former agricultural hinterland of Petra.

[1] bernhard.lucke@fau.de, rupert.baeumler@fau.de; FAU Erlangen-Nürnberg, Institute of Geography, Wetterkreuz 15, 91058 Erlangen, Germany.
[2] J.Birk@geo.uni-mainz.de; University of Mainz, Institute of Geography, Soil Geography, Johann-Joachim-Becher-Weg 21, 55099 Mainz, Germany.
[3] paula.kouki@hamina.fi; Ancient Near Eastern Empires Centre of Excellence, P.O. Box 3, University of Helsinki, 00014 Helsinki, Finland.
[4] nizar.abujaber@gju.edu.jo; German Jordanian University, School of Natural Resources Engineering and Management, Madaba, Amman 11180, Jordan.

However, construction of such a system was probably very labour-intensive and it seems questionable whether terracing of the sandstone slopes was worth the effort from an agricultural point of view. An alternative purpose could have been flood protection of the city of Petra. Al Qudah et al. (2016) showed that terracing of slopes and small valleys as carried out by the ancient systems would minimize runoff before a flood could develop, as many small walls were built covering wadis from the very top of the catchments till the lower slopes. In light of the massive engineering works applied for the water supply of Petra, and in the context of the potentially devastating power of flash floods that still pose dangers to tourism, a large-scale terracing effort of the hinterland appears possible in the context of the monumental development of the city.

We approached this question by investigating contents of plant-available phosphorus and biomarkers of faeces deposition in the sediments at two runoff-irrigated terraces on limestone and sandstone to the southeast of Petra.

The investigation sites

Although the hinterland of Petra seems barren and hostile to cultivation, the trained eye can spot remains of terraces (Figure 1). One of the largest runoff cultivation systems of the mountain is located at the western slope of Jabal Haroun below a high sandstone scarp, bordered by a dolomitic limestone ridge. The Wadi As-Saddat emerges between the sandstone and limestone, and hosts remains of sturdy barrages. We excavated one profile on the sandstone slope (Terrace on sandstone (Jh site 33), N 30.31404, E 35.39839), and one on the dolomitic limestone (Terrace on limestone (Jh site 60), N 30.31244, E 35.39476).

The terrace on sandstone (Jh site 33)

The upper 20 cm were sandy, had high stone content, were ploughed not long ago, and contained remains of a surface crust. Until a depth of 70 cm, the soil was dominated by sand and of friable structure. From 70-140 cm depth, however, the profile was compact and platy, poor of stones, and contained a significant share of silt. At the bottom, angular sandstone debris was met, probably of a former rock-covered slope.

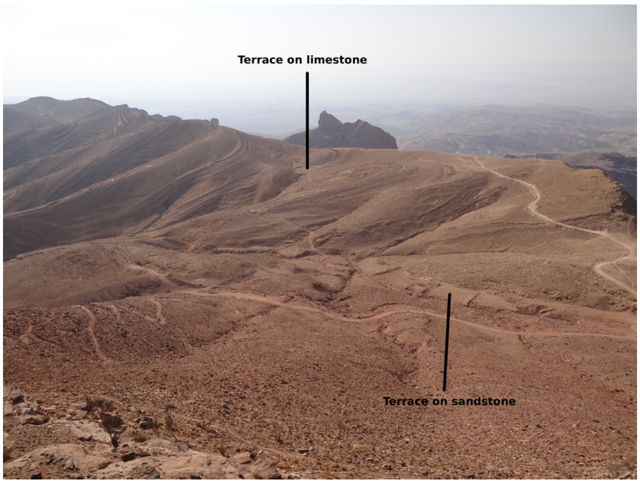

Figure 1: View from Jabal Haroun on the two investigated runoff-irrigated terrace remains.

Sediments had reached the top of the terrace wall, i.e. the construction had completely filled with sediment, The soil was classified as Protic Calcaric Arenosol (Colluvic) over Protic Calcaric Regosol (Colluvic) according to WRB (2015).

The terrace on dolomitic limestone (Jh site 60)

The profile was homogeneous and revealed a compact, silt-dominated substrate of 60 cm depth. Only the upper 10 cm were of friable structure, probably due to recent plowing by Bedouin today living in the area. They cultivate and graze the terrace remains opportunistically. Angular limestone debris was met in the bottom, and occasional small limestones in the profile suggest a contribution of the surrounding, weathered rock. The soil was classified as Protic Calcaric Regosol (Colluvic) according to WRB (2015).

Methods

Plant-available phosphorus was extracted by sodium bicarbonate at pH of 8.5 according to Olsen et al. (1954) and concentrations determined colorimetrically with blue ammonium molybdate (using a photometer DR 5000 by Hach-Lange).

Stanols and Δ5-sterols were extracted as faeces biomarkers following the method of Birk et al. (2012). Extracts were saponified in 3.5 ml 0.7 M KOH in methanol and reaction was allowed overnight (~15 h) at room temperature. After saponification, 10 ml water was added to the extract and the neutral fraction including the stanols and Δ5-sterols extracted by liquid–liquid extraction with chloroform. The chloroform extracts were concentrated by rotary-evaporation and dried.

The acidic fraction was methylated in 1 ml dry 1.25 M HCl in methanol at 80 °C for 2 h. The methyl esters were extracted after addition of 1 ml water by liquid–liquid extraction with hexane. Both the neutral and acid fractions were purified by solid phase extraction (SPE). Purification of the neutral fraction was carried out with columns packed with 5% deactivated silica gel and preconditioned with hexane. Less polar substances (aliphatic and aromatic compounds etc.) were eluted with 5 ml hexane and discarded. The fraction containing alcohols including stanols and Δ5-sterols was first eluted with 3 ml dichloromethane and afterwards with 2 ml dichloromethane/acetone. The dichloromethane and dichloromethane/acetone eluates were combined and dried.

Purification of the acid fraction was carried out with columns packed with activated silica gel and preconditioned with dichloromethane/hexane. Less polar substances (fatty acid methyl esters, etc.) were eluted with 5 ml dichloromethane/hexane (2:1, v/v). The hydroxy acids were eluted with 5 ml dichloromethane/methanol and dried.

For silylation of stanols and Δ5-sterols, 37.5 µl BSTFA+TMCS (99:1 v/v) and 12.5 µl pyridine were added and the mixture heated at 90 °C for 1 h. Excess silylation reagent was evaporated and dry toluene and 5α-cholestane as second internal standard (IS2) were added. The fraction containing bile acids was silylated in 50 µl dry toluene, 98 µl BSTFA and 2 µl TSIM. After heating at

80 °C for 1 h, 5α-cholestane (dissolved in dry toluene) was added.

External standard solutions of the relevant biomarkers and first internal standard (IS1) were prepared in methanol and derivatized using the same methods which were used for the soil extracts. All substances were analysed via gas chromatography-mass spectrometry (GC–MS) with an Agilent 7000D mass spectrometer connected to an Agilent 7890B gas chromatograph. A DB-5ms Ultra Inert (Agilent) 30 m fused silica column with 0.25 mm I.D. and 0.25 µm film thickness was directly coupled with the mass spectrometer. The injection port was equipped with a split/splitless liner (5183-4711, Agilent), and He (99.9999% purity) used as carrier gas at a constant column flow of 1 ml/min. The transfer line temperature was 250 °C, electron ionisation carried out at 70 eV, and measurements in scan mode done to verify peak identity. Measurements in selected ion monitoring mode (SIM) were performed for quantification. The injection port was set to 250 °C and 1 µl was injected in pulsed splitless mode (pulse pressure: 180 kPa, pulse time: 1.01 min) for analyses of derivatives of stanols and Δ5-sterols.

Results

Table 1 shows results of three stanols ratios and contents of plant-available phosphorus. We calculated the following ratios from the measured concentrations of stanols that indicate faeces remains from omnivores and herbivores:

Stanols ratio 1 = (5β-cholestan-3β-ol + 5β-cholestan-3α-ol)/(5α-cholestan-3β-ol+5β-cholestan-3β-ol + 5β-cholestan-3α-ol)

Stanols ratio 2 = (5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)/(5α-stigmastan-3β-ol + 5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)

Stanols ratio 3 = (5β-cholestan-3β-ol + 5β-cholestan-3α-ol)/(5β-stigmastan-3β-ol + 5β-stigmastan-3α-ol)

Elevated values of stanols ratio 1 indicate the presence of faeces from omnivores, and stanols ratios 2 mark the presence of faeces from herbivores. Stanols ratio 3 represents the relative contribution of omnivore faeces against herbivores, with higher values pointing to a stronger contribution of omnivore faeces (Prost et al. 2017).

Biomarker ratios should not be affected by dilution with mineral sediment, as ratios are compared. Relatively high values of stanol ratios 1 and 3 suggest the presence of excrements with high share of omnivore faeces. These are present in the central part of the profiles.

Plant-available phosphorus contents of various samples are 1 – 2 mg/kg, which is similar to the natural soils in the vicinity. However, some samples show higher values of 2.5 – 6.3 mg/kg, and the surface samples fall out with 15.7 and 20.8 mg/kg, respectively. The lowest contents are present in the sand-rich layer of the terrace of sandstone.

Sample No.	Stanols ratio 1	Stanols ratio 2	Stanols ratio 3	Plant -av. P [mg/kg]
Terrace on sandstone				
Jh site 33 10 cm	**0.65**	**0.48**	**0.16**	**15.7**
Jh site 33 30 cm	**n.a.**	**n.a.**	**n.a.**	**0.8**
Jh site 33 50 cm	**0.56**	**0.40**	**0.75**	**0.9**
Jh site 33 75 cm	**0.60**	**0.23**	**0.85**	**1.4**
Jh site 33 100 cm	**n.a.**	**n.a.**	**n.a.**	**1.9**
Jh site 33 130 cm	**0.43**	**0.31**	**0.70**	**2.5**
Jh site 33 150 cm	**0.50**	**0.45**	**0.64**	**6.3**
Terrace on limestone				
Jh limestone 0 cm	**0.61**	**0.34**	**0.31**	**20.8**
Jh limestone 20 cm	**0.71**	**0.19**	**0.55**	**3.9**
Jh limestone 40 cm	**0.62**	**0.26**	**0.61**	**2.1**
Jh limestone 60 cm	**0.47**	**0.36**	**0.28**	**1.8**

Table 1: The calculated stanols ratios and plant-available P according to Olsen et al. (1954).

Discussion

Faeces of herbivores dominate at the surface and at the bottom of the profiles, while a higher presence of omnivore excrements can be stated for the central parts of the profile. These contain high shares of silt, which are derived from aeolian sedimentation (Lucke et al., 2019) and were thus probably deposited when fluvial erosion from slopes was reduced. This scenario could match well-functioning terrace systems during antiquity. While herbivore faeces could be derived from grazing and extensive use of the terraces, possibly mainly for runoff control, the presence of human faeces suggests planned manuring. In this context, ancient papyri uncovered in the Petra church suggest systematic collection, treatment, and application of excrements (Kaimio, 2011). That makes it very probable that systematic manuring was applied near Petra, and the presence of remains of human excrements on fields could be expected. However, there is no connection of omnivore faeces biomarkers with contents of plant-available phosphorus.

Plant-available phosphorus builds up if not consumed by crops. Strongly elevated contents of plant-available phosphorus in the topsoils indicate that the terraces continued to be used agriculturally when walls were no longer built higher. Therefore organic matter from stubble, dung from grazing, and possibly also manure continued to accumulate whereas sedimentation of mineral soil diminished. With the exception of the topsoils and the lowermost sample of the terrace on sandstone, contents of plant-available phosphorus in the runoff-irrigated terraces are not significantly higher than in natural soils, and the lowest contents with less than 1 mg/kg are present in the sandy layers in the upper part on the terrace on sandstone. This seems due to rapid deposition of sand poor in organic matter from the sandstone slopes, probably when terraces were not well maintained any more. It could have been associated with fluvial deposition from probably poorly vegetated slopes, leading to higher sedimentation rates and thus greater 'dilution' of phosphorus.

Conclusion

Faeces biomarkers suggest that omnivore excrements, probably from humans, were deposited in the central part of the profiles of the investigated runoff-irrigated terraces. These are associated with relatively high silt contents from aeolian sedimentation, suggesting reduced slopewash, probably when terraces were well-maintained during antiquity. This points to planned application of manure and an agricultural purpose of the system.

Herbivore faeces biomarkers increase during a later stage of sedimentation, apparently associated with increasing slope-wash. This is consistent with current extensive use mainly for grazing.

There is no direct connection of contents of plant-available phosphorus with certain types of faeces. Plant-available phosphous seems highest in current topsoils, probably due to minimal dilution of organic matter by mineral substrate as terraces continued to be used while sedimentation rates were probably strongly reduced when walls had filled completely.

References

Al Qudah, K., Abdelal, Q., Hamarneh, C., & Abu-Jaber, N. (2016). Taming the torrents: The hydrological impacts of ancient terracing practices in Jordan. *Journal of hydrology*, *542*, 913-922. doi:10.1016/j.jhydrol.2016.09.061

Birk, J.J., Dippold, M., Wiesenberg, G.L.B., Glaser, B., 2012. Combined quantification of faecal sterols, stanols, stanones and bile acids in soils and terrestrial sediments by gas chromatography-mass spectrometry. *Journal of Chromatography, 1242*(1), 1–10. doi:10.1016/j.chroma.2012.04.027

Evenari, M., Shanan, L., Tadmor, N., & Shkolnik, A. (1982). *The Negev: the challenge of a desert* (2nd edition). Cambridge, MA: Harvard University Press.

Kaimio, J. (2011). Terms connected with houses in 39 and other Petra Papyri. In A. Arjava, M. Buchholz, T. Gagos & M. Kaimio (Eds.), *Petra Papyri IV* (pp. 9-22). Amman: American Center of Oriental Research (ACOR).

Lucke, B., Roskin, J., Vanselow, K., Bruins, H., Abu-Jaber, N., Deckers, K., Lindauer, S., Porat, N., Reimer, P., Bäumler, R., Erickson-Gini, T., & Kouki, P., 2019. Character, rates, and environmental significance of dust accumulation in archaeological hilltop ruins in the southern Levant. *MDPI geosciences, 9*(190), 1-60. doi:10.3390/geosciences9040190.

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimation of available phosphate in soils by extraction with sodium bicarbonate. *Circular, 939*(19). Washington, DC: US Department of Agriculture.

Prost, K., Birk, J. J., Lehndorff, E., Gerlach, R., Amelung, W. (2017). Steroid Biomarkers Revisited – Improved Source Identification of Faecal Remains in Archaeological Soil Material. In: *PLoS ONE, 12*(1), e0164882. DOI: 10.1371/journal.pone.0164882.