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Communicated by Oliver Nakoinz

Received September 9, 2016

Revised November 28, 2016

Accepted December 2, 2016

Published March 22, 2017

Edited by Gerd Graßhoff and Michael Meyer,
Excellence Cluster Topoi, Berlin

eTopoi ISSN 2192-2608

<http://journal.topoi.org>



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Quantifying Chronological Inconsistencies of Archaeological Sites in the Petra Area

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Numerous archaeological surveys have already contributed to the research of the surroundings of the ancient Nabataean capital Petra (Jordan). The provided dataset forms the basis for further studies on the landscape organization of the Petraean hinterland. However, a reevaluation of the data revealed, in some cases, greatly differing and inconsistently defined chronological specifications of archaeological sites. Researching the general landscape organization of spatial strategies in the Petraean hinterland throughout time, such fundamental inconsistencies within the core archaeological dataset is a very critical methodological issue that needs to be addressed before following up larger research questions. This contribution therefore quantifies such uncertain chronological information and aims at offering definitions of the evidenced cultural periods that make the chronological uncertainties inherent to the base dataset transparent for future research.

Petra hinterland; chronology; chronological uncertainty; dating probability; archaeological surveys.

Etliche archäologische Surveys haben bereits zur Erforschung des Umlandes der antiken Nabatäerhauptstadt Petra (Jordanien) beigetragen. Die erhobenen Daten bilden die Grundlage für weitere Studien zur Landschaftsorganisation des peträischen Hinterlandes. Allerdings macht eine Neuauswertung der Daten zum Teil stark abweichende und unscharf definierte chronologische Angaben der archäologischen Fundplätze deutlich. Für eine diachrone Untersuchung der allgemeinen Landschaftsorganisation und räumlichen Strategien im Peträischen Hinterland sind solche grundlegenden Unsicherheiten in dem archäologischen Kerndatensatz ein fundamentales methodisches Problem, das bearbeitet werden muss, bevor weiterführende Forschungsfragen verfolgt werden können. Dieser Beitrag quantifiziert diese unscharfen chronologischen Informationen und zielt darauf ab, Definitionen der belegten kulturellen Perioden zu liefern, die die chronologische Unschärfe der zugrundeliegenden Daten für weitere Forschungen transparent machen.

Petra Hinterland; Chronologie; chronologische Unschärfe; Datierungswahrscheinlichkeiten; archäologische Surveys.

I Introduction

Every archaeological study dealing with large datasets faces basic methodological challenges that must be dealt with before it is possible to engage in further research. The archaeological study of the ancient landscape organization of the Petra hinterland in modern-day Jordan is no exception. Numerous survey expeditions have already been car-

The authors would like to express their gratitude to O. Nakoinz for offering valuable methodological advice at the initial stage of the quantification process of the chronological inconsistencies and for communicating this paper. Also, many thanks to L. Tholbecq who kindly provided the preliminary catalog of the Jabal Shara Survey for this study. We would also like to thank to the Excellence Cluster Topoi for accepting this paper for publication. Last but not least, we owe the two anonymous reviewers great gratitude for their immensely valuable comments on the original draft of this paper.

ried out in the immediate environment of the ancient Nabataean capital, Petra, documenting rural archaeological sites ranging from the Iron Age to the Byzantine and Early Islamic Periods. In her seminal work for further understanding rural Petra, P. Kouki was able to aggregate the various survey results.¹ Since her work focuses on rural settlements and land use strategies in the Petra region only, a more detailed study of other archaeological sites within Petra's surroundings should aim at more comprehensively researching overall, military and non-military, strategies of spatial organization in and around Petra. Following this research perspective, a re-evaluation of the original survey data has revealed two major methodological issues. First, the various survey data follow immensely differing site typologies. Without fitting the various site types into a more rigid and consistent site classification system, any comparative analysis would offer only crude results. Second, the dating of archaeological sites within the Petra area is based on the sometimes greatly differing chronological systems defined by the different surveys. The issue of varying chronological systems appropriated by different archaeological base datasets is not unique to the survey data available for the Petraen hinterland, but is a rather common methodological problem faced by other regional landscape archaeological studies as well and these offer various solutions to this fundamental methodological challenge.²

As part of F. Hahn's comprehensive study on the various surveys carried out in the environs of Petra, the main focus of his work was particularly concerned with the chronological information provided by the original survey data.³ By applying the method of chronological shift, Hahn was able to expose an alarming chronological distortion within the dating of the numerous archaeological sites. Although the various chronological systems of the original surveys seem to roughly follow conventional historical datings of cultural periods, the surveys' dating of the same cultural period can, in some cases, vary by centuries. When researching the spatial organization of archaeological sites and features in the Petra area throughout time, the uncritical appropriation of dating information provided by the original surveys would result in an extremely distorted archaeological model of rural Petra chronologically.

The aim of this study is therefore to propose a methodology that is not only able to work out the various chronological inconsistencies and temporal uncertainties of the original survey data, but also to present a more transparent and valid definition of the different cultural periods evidenced within the Petra hinterland.

2 Previous Research

In the past decades, Petra has been the focus of vast archaeological research. However, such studies have focused mostly on Petra's urban environment alone and the immediate surroundings of the ancient city were, until recently, of no primary interest to modern archaeological research projects.⁴

1 Kouki 2012. Since then, both Hahn 2014 and Wenner 2015 also researched aspects of Petra's hinterland based largely on survey results.

2 For an example dealing with ancient Crete, see Gkiasta 2008, 161–167. Also see Farinetti 2011, 35–39, for how she dealt with the issue within her study on ancient Boeotia. For an insightful methodological contribution on how to tackle problematic issues of site contemporaneity within larger settlement-pattern studies, see Dewar 1991 as well as the discussion that followed between Kintigh and Dewar (Kintigh 1994 and Dewar 1994). Finally, for another project studying regional archaeological landscapes in the Middle East and facing similar chronological inconsistencies within the archaeological dataset, see Lawrence, Bradbury, and Dunford 2012.

3 Hahn 2014.

4 Kouki 2012, 15, 46–54.

From the 19th century onwards, however, the earliest explorers of Petra extensively travelled and researched the archaeological heritage of the immediate surroundings of

Survey	Date	Total Amount of Sites Surveyed	Selected Literature
Petra and environs (conducted by Alois Musil)	1896–98, 1900–1902	v?	Musil 1907
Petra and environs, Bayda, Udruh, Sadaqa, Ma'an (conducted by Rudolf Brünnow, Alfred von Domaszewski)	1897–98	?	Brünnow and Domaszewski 1904
Petra and environs (conducted by Gustaf Dalman)	Early 20th century	?	Dalman 1908
Petra urban center, Jabal Haroun area (conducted by Theodor Wiegand and the Deutsch-Türkisches Denkmalschutz-Kommando)	1914–1918	?	Bachmann et al. 1921
Petra region (conducted by Nelson Glueck)	1930s	?	Glueck 1934; Glueck 1935; Glueck 1939; Glueck 1945
Petra region including Sabra, Abu Kusheibeh, Saddaqa, Umm Rattam etc. (conducted by Manfred Lindner)	Since the 1970s	?	Lindner 1987; Lindner 1992; Lindner and Zeitler 1997; Lindner, Hübner, and Hübl 2000; Lindner 2003
Edom Survey (conducted by Stephen Hart)	1984–1985	115	Hart and Faulkner 1985; Hart 1987
Udruh Region (conducted by A. Killick)	1980s	200	Killick 1983, Killick 1986, Killick and Hadidi 1987
'Aqaba – Ma'an Survey (conducted by W. J. Jobling)	since 1980	?	Jobling 1982; Jobling 1983; Jobling 1984; Jobling 1985
Beidha Ethnoarchaeological Survey (E. B. Banning and Ilse Köhler-Rollefson)	1983	63	Banning and Köhler-Rollefson 1983; Ullah 2003
Hisma, Ras an-Naqb, 'Aqaba (conducted by David Graf)	1978	?	Graf 1979; Graf 1992
Petra – 'Aqaba (conducted by David Graf)	1986–89	?	Graf 1992; Graf 1995

(continued on next page)

Survey	Date	Total Amount of Sites Surveyed	Selected Literature
Southeast Araba Archaeological Survey (SAAS) (conducted by Andrew M. Smith II)	1994, 1996, 1998	330	A. Smith II. 2010
Dana Archaeological Survey (DAS) (conducted G.M. Findlater)	1994–1996	400	Findlater 2003
Jabal Shara Survey (JSS) (conducted by Laurent Tholbecq)	1996–97	160	Tholbecq 2001; Tholbecq 2013
Archaeological Survey of the Wadi Musa Water Supply and Wastewater Project (WMWS) (conducted by Khairieh ‘Amr et al.)	1996, 1998–2000	132	‘Amr, al-Nawafleh, and Qrarhi 1996; ‘Amr, al-Momani, et al. 1998; ‘Amr and al-Momani 2001
Bir Madkhur Project (BMP) (conducted by Andrew M. Smith II)	since 1997	25	A. M. Smith II. 2007; A. Smith II. 2010
Udruh Region (conducted by F. Abudanh)	2003–2004	336	Abudanh 2006
Finnish Jabal Harun Project (FJHP) (conducted by J. Frösen)	1998–2005	189 (Core Area); 172 (Extended Area)	Kouki and Lavento 2013
Ayl to Ras an-Naqab Archaeological Survey (ARNAS) (conducted by B. Macdonald)	2005–2007	389	MacDonald 2015; MacDonald, Herr, Quaintance, Clark, et al. 2012
Shammakh to Ayl Archaeological Survey (ShamAyl) (conducted by B. Macdonald)	2010–2011	366	MacDonald, Clark, et al. 2016; MacDonald, Herr, Quaintance, al-Haja, et al. 2011; MacDonald, Herr, Quaintance, and Lock 2010
Udruh Archaeological Project (UAP) (conducted by M. Driessen and F. Abudanh)	2011–2014	?	Driessen and Abudanh 2015
Petra Area and Wadi Slaysil Survey (PAWS) (conducted by S. Alcock and A. Knodell)	2010–2012	1032 “Features”	S. E. Alcock and Knodell 2012
Petra Hinterland Survey Project (PHSP) (conducted by W. M. Kennedy and S. G. Schmid)	2016	165	Forthcoming

Tab. 1 | List of archaeological surveys conducted in the Petra area since A. Musil.

the city.⁵ Shortly after the rediscovery of the ancient ruins of Petra by the Swiss explorer J. L. Burckhardt in 1812⁶, various expeditions were carried out in the larger Petra area

5 Kouki 2012, 54. Such travels were often embedded within the emerging branch of biblical archaeology at the time.

that can be considered as the first archaeological and ethnological “surveys” of the region. Within the core research area of the study region (see below) a total number of 24 surveys starting from the late 19th century to the present day can be listed (table 1).⁷

As P. Kouki already worked out, research interest in rural Petra ceased after N. Glueck’s explorations in the 1930s.⁸ Only with the work of M. Lindner and his team starting in the 1970s, did archaeological research extend the city limits of urban Petra. The various surveys applied different methodologies, adopted different detailed chronologies and were interested in various time periods ranging from the Palaeolithic to the Islamic Period. However, all surveys generally aimed at determining political, economic and social changes over time within the specific survey areas. They were interested in defining changes in land use, property situations, changes of the natural environment and the climate and – particularly in the case of surveys interested in the Nabataean-Roman Period – attempted to clarify the process of Nabataean sedentarization.⁹ In total, over 3000 archaeological sites were documented.¹⁰

However, no attempt was made to comprehensively study the various survey data and synchronize the different survey results before P. Kouki in 2012.¹¹ Kouki’s work forms a major contribution to the study of rural Petra, Nabataean-Roman settlement patterns and ancient land use strategies in the region within a 20km radius around the city that Kouki defines as the scope of the Petraean hinterland¹². This definition is based on the fact that the 6th century AD Petra Papyri mention both Udruh (Augustopolis) as well as Sadaqa (Kastron Zadacathon) being within Petraean jurisdiction in terms of taxation, which corresponds well with Lindner’s earlier proposition of the extent of “Greater Petra” supposedly having a radius of at least 20km around the city in Nabataean-Roman times.¹³ While realizing that this suggestion for the Petraean hinterland is problematic, it nevertheless is taken as the core study area for this paper.¹⁴

3 Methodological and Analytical Issues

While Kouki’s work remains an extremely important contribution to the understanding of Nabataean-Roman settlement strategies, her study deals with settlement patterns without offering an in-depth contextualization of the various other archaeological sites

6 Stucky 2012.

7 This list excludes smaller private travel ventures to the region. Also note that it is impossible to give a complete and detailed description of each survey in this format. Table 1 shall serve only as a general overview with the most important literature cited.

8 Kouki 2012, 46.

9 For a more detailed overview on the specific research aims of the various surveys, see the literature cited in table 1.

10 This count excludes the approx. 1000 features documented by the Petra Area and Wadi Slaysil Survey (PAWS) between 2010 and 2012 (see https://brown.edu/Departments/Joukowsky_Institute/fieldwork/bupap/8497.html (visited on 15/02/2017)) since these are not yet published. So far, the published results of PAWS mostly deal with pottery densities and highlight singular archaeological features only (compare S. E. Alcock and Knodell 2012). Also, it is not possible to give an exact number of sites documented by the early travelers’ within the Petra region. However, most of these are also covered by the more recent surveys.

11 Kouki 2012.

12 Kouki 2012, 17.

13 Kouki 2012, 17; Lindner 1992, 266.

14 For further thoughts on defining the limits of Petra’s hinterland, see Kennedy 2016. Generally, however, the described rationale for defining the 20 km radius as the study area has to be considered carefully and the so called *edge effect* it may have on the observed pattern of archaeological sites recognized. Without being able to go into too much detail in this contribution, it should be noted that the general site pattern of the Petra area fundamentally remains the same once leaving the limits of the 20 km radius.

that were documented within the Petra area.¹⁵ In order to continue Kouki's work, it is necessary to comprehensively study overall strategies of spatial organization in Petra's immediate surroundings, thus allowing a general reassessment of its actual political, economic and social areas of influence.¹⁶ However, there are very basic methodological issues that must be considered before conducting such studies. These issues concern mostly the problem of the differing site classifications and chronologies within the original survey data. In order to perform comparative spatio-temporal analyses and to receive results going beyond simple site distribution maps, it is first necessary to create a consistent base dataset.¹⁷ Otherwise, a comprehensive comparison and archaeological or historical contextualization of site types throughout time is not possible. Since it would overreach the limits of this contribution, the issue of differing site classifications can only be touched very briefly: Based on the various surveys listed above, almost 800 original site types were documented within the Petra region. Seemingly, no standardized site classification system was established. Each survey follows its own site definitions, and even these are not always consistent. This is a major problem when attempting to study the various survey results together.¹⁸ Additionally, the same inconsistencies can be observed for the chronological periodizations of the various surveys. The problem of the differing chronological information of archaeological sites as well as the general difficulties when researching diachronic trends of large spatial datasets is therefore apparent.

Attempting to meet similar issues, S. Alcock analyzed aspects of chronological shifts as well as chronological continuities within her study on Roman Greece.¹⁹ In order to clarify the different chronological shifts from one cultural period to the next, Alcock considered each larger cultural phase separately and counted the total amount of sites dating to subdivisions of that cultural phase.²⁰ Additionally, she researched chronological continuities by evaluating how many sites are evidenced in two or more cultural periods.²¹ Taking on Alcock's approach for Roman Greece, F. Hahn researched the various survey data of the Petra region in terms of chronological shifts as well and established that 12,27% of all evidenced sites date to the Iron Age II Period, 32,64% to the Nabataean Period, 28,36% to the Roman Period, 23,75% to the Byzantine and only 2% to the Early Islamic Period.²² A more detailed subdivision of these cultural phases appeared to be difficult. For

15 Although Kouki was able to incorporate the surveys listed in table 1, the full data of the JSS, ARNAS, ShamAyl, the UAP, PAWS and the PHSP were not yet available at the time of the publication of her work in 2012. More importantly, however, Kouki interpreted archaeological sites as settlements only if the building remains were structurally significant and if they could be dated by surface pottery. Furthermore, structures that suggested cultic, funerary or military use were excluded from her analysis (see Kouki 2012, 78–79).

16 This study is currently part of a larger, on-going research project by W. M. Kennedy.

17 On how Kouki dealt with this problem and how she created her dataset, see Kouki 2012, 77–84.

18 This site classification will be presented in detail in the final publication of Kennedy's doctoral research project. It shall be noted, however, that for the purpose of this paper the differing site classifications were not important. For the quantification of chronological uncertainties inherent to the original survey data, the various chronological information of all archaeological sites were evaluated – independent of site type – since the differing site classifications had no impact on the dating of the sites.

19 S. Alcock 1995, 56–58; 56, Table 4. For other examples on how to deal with chronological uncertainties, see footnote 2 above.

20 S. Alcock 1995, 56–58; 56, Table 4. For example, there might be 15 sites that date to the Iron Age. However, two of these sites actually date to the Iron Age I Period, 13 to the Iron Age II and one site to the Iron Age III Period.

21 S. Alcock 1995, 56–58; 56, Table 4. For example, how many (Late) Nabataean sites were also occupied in the (Early) Roman Period.

22 Hahn 2014, 29–36. Reaching a total number of 1777 sites, Hahn considered sites from the Edom Survey, the Beidha Ethnoarchaeological Survey, Southeast Araba Archaeological Survey, the Dana-Showbak-LH2E Survey, the Jabal Shara Survey, the Archaeological Survey of the Wadi Musa, the Bir Madhkur Project; F. Abudanh's Survey, the Finnish Jabal Harun Project based on P. Kouki's settlement model from 2012 and the Ayl to Ras-an-Naqb Archaeological Survey.

example, only 31% of all Roman sites are further differentiated chronologically between Early and Late Roman. For the Byzantine Period, only 17% of all respective sites were further distinguished between Early and Late Byzantine.²³

In terms of chronological continuities, the inherent inconsistencies within the survey data allowed to evaluate only an unrepresentative 10% of the total amount of survey sites.²⁴ Based on this, only 0,9% of Iron Age II A–B sites continued to exist in the Iron Age II C Period, only 2,2% from the Iron Age II C Period to the Hellenistic Period, only 3,45% from the Hellenistic to the Nabataean Period, 58,19% from the Nabataean to the Roman Period, 29,7% from the Roman to the Byzantine Period and, finally, only 6,9% from the Byzantine to the Early Islamic Period.²⁵ Due to the above mentioned inconsistencies within the original survey data, however, such analyses can only offer limited and problematic information on chronological shifts and continuities. Additionally, only the evidenced cultural phases were considered, without taking the differing chronological phasings of the individual research projects into account. This is a major issue since, in some cases, the definition of cultural phases can vary significantly: Highlighting only the Nabataean and Roman phases, Fig. 1 shows that Abudanh, the Ayl to Ras an-Naqab Archaeological Survey (ARNAS) and the Shammakh to Ayl Archaeological Survey (ShamAyl) define both periods to run at least from the mid-first century BC to the end of the 3rd/ beginning of the 4th century AD.

Other surveys define the Nabataean Period to mostly cover the 1st century BC and AD and the Roman Period to begin with the early 2nd century AD and ending in the late 3rd century AD following more conventional historical chronologies.²⁶ Any attempt to synchronize these chronological systems faces huge methodological problems. For her study of 160 settlement sites, Kouki's solution was to transform culturally defined chronological phases into their respective centuries when possible.²⁷ However, Kouki bases her chronological analysis of sites in the Petra hinterland only on settlement data from the Archaeological Survey of the Wadi Musa (WMWS), Abudanh's Survey as well as from the Finnish Jabal Harun Project (FJHP), where both cultural periods as well as the respective time spans of these periods are mentioned in the original survey reports.²⁸ While the approach of associating cultural periods to respective centuries is valid, Kouki's analysis is, first, limited to settlement sites only and therefore does not cover other site classes. Second, survey data from other survey reports which date sites by cultural periods only are not included, thus potentially leading to an over-simplification of the chronological development of site distributions within the Petra region. It was therefore necessary to develop a new and more refined methodology in order to reconstruct a more methodologically coherent archaeological model of the Petra hinterland throughout time.

4 Quantifying Chronological Inconsistencies

Without approaching these problematic methodological issues mentioned above, any large-scale research on spatial and chronological developments of rural Petra is methodologically questionable at best. The chronological inconsistencies within the surveys of the Petra region may even question the scientific validity of diachronic analyses of

23 Hahn 2014, 36.

24 Hahn 2014, 36.

25 Hahn 2014, 36.

26 Parker 2006, 5–24, 332, Table 2.1; Fiema and Jansson 2002; Homès-Frederique and Hennessy 1986; Sauer 1973, 1–5.

27 Kouki 2012, 80–82.

28 Kouki 2012, 80–82.

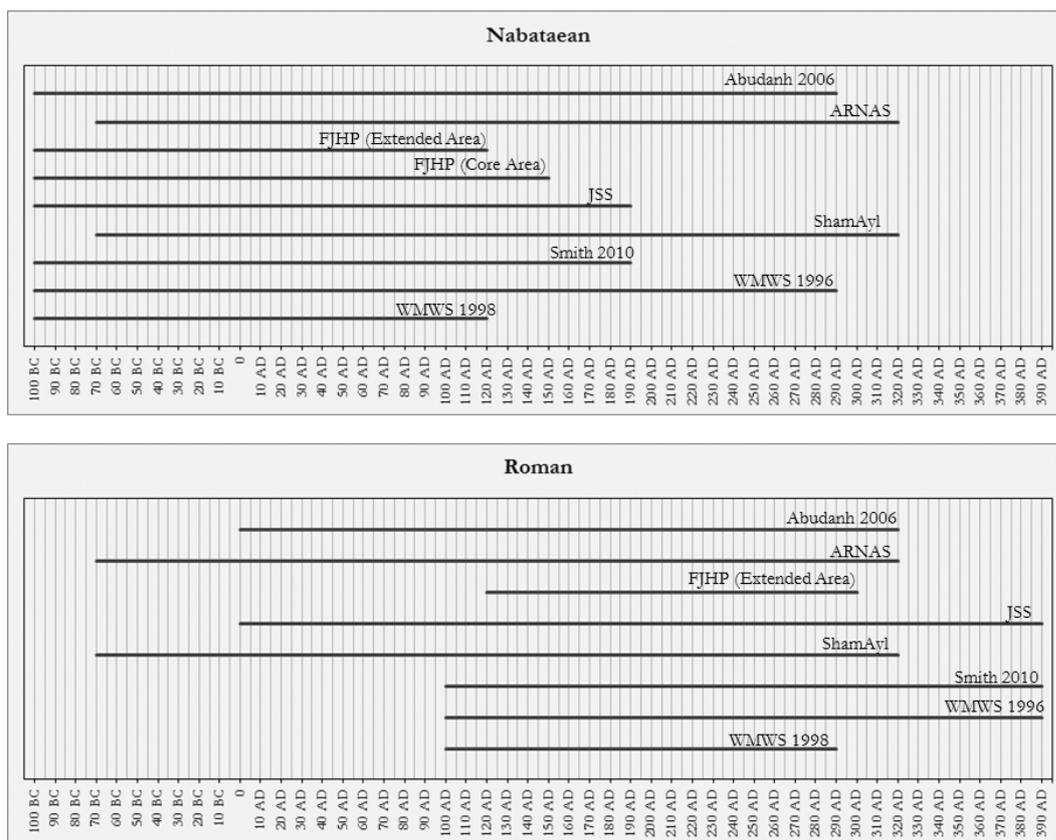


Fig. 1 | The varying range of the Nabataean and Roman Periods as defined by the different surveys.

site distributions. This is a methodological challenge that many archaeological research projects face, particularly when dealing with large spatial datasets as in this study.²⁹ The larger and more diverse the dataset grows, the more difficult it becomes to deliver a comprehensive chronological and site typological system. Particularly with large spatial datasets, archaeological periods are often broadly defined, with the consequence that accuracy and precision is relatively low. Also, the dating of sites is often primarily based on diagnostic archaeological artifacts such as surface pottery (which is mostly the case in this study). This is, in itself, already problematic, as it inherently causes a certain amount of *fuzziness* into the dating quality of sites.³⁰ It is therefore impossible to establish an exact start and end point for chronological periods. The distinguished archaeological periods (*time spans*) are often unsubstantiated or follow imprecise definitions.³¹ Additionally, these time spans are then correlated with loosely defined cultural periods or categories such as “Early Roman” or “Late Byzantine” (see below). These temporally blurred or *fuzzy periods* are defined in order to offer more detailed information on the dating of archaeological sites and to guarantee temporal comparability for further research.³² However, the limits of such chronological sequencing as explained above are only rarely recognized by

29 Crema 2015; Nakoinz 2012, 189–190. For further references also see the literature cited in footnote 2.

30 Crema 2015, 315; Lyman and O’Brien 2006. That being said, there are nevertheless other dating elements that were considered for a site’s dating. In addition to surface pottery, archaeological sites recorded by the various surveys were also dated by numismatic, architectural as well as epigraphical and literary evidence. For a brief overview on the challenges of dating archaeological sites according to surface material see e.g. Kouki 2012, 28–29.

31 Crema 2015, 315.

32 Nakoinz 2012, 190.

archaeological research projects.³³ Since the primary aim is to conduct methodologically responsible diachronic spatial analyses for the Petra hinterland, it was first necessary to create a consistent spatio-temporal system into which the available survey data (see table 1 above) was classified. Subsequently, the survey data was categorized into three classes:

Survey Class A: Survey data giving coordinate information³⁴, pre-defined time spans of archaeological (cultural) periods with start and end point as well as the respective periods per archaeological site

Survey Class B: Survey data giving coordinate information, but mentioning cultural periods per archaeological site only (without pre-defined time spans)³⁵

Survey Class C: Survey data without coordinate information and mentioning cultural periods per archaeological site only.³⁶

The particular problem for this study is first, that the relevant surveys of Class A share common or similarly defined cultural periods such as “Nabataean”, “Roman” or “Byzantine”; on the other hand however, the respective time spans differ sometimes significantly (see above Fig. 1).³⁷ Therefore, a diachronic comparison of site distributions would entail a disturbing chronological blur. Secondly, as the time spans of these defined cultural periods vary from survey to survey, it is impossible to fit the purely culturally defined periods of Class B survey data into a respective time span from Class A surveys.³⁸ However, without determining time spans for Class B survey data, these datasets cannot be integrated into spatio-temporal analyses in a methodologically responsible fashion. Thus, without recognizing and tackling these inherent chronological problems within the base dataset, any spatio-temporal analysis will offer flawed or misleading results (see above). The following section therefore elaborates on how these methodological issues may be confronted:

1. *Acquiring the Base Dataset.* Acquisition of spatio-temporal information of all survey classes. In this step temporal information is also provided with dating *values* (see below).³⁹

33 Crema 2015, 314–315.

34 This study conducts all spatial analyses in an UTM 36N environment.

35 Survey data of Class B may sometimes also give information on the time spans of the respective cultural periods per archaeological site. In such cases, these count as Class A.

36 This paper will be dealing with Survey Classes A and B only. However, if survey data of Class C would mention pre-defined time spans of archaeological periods with start and end point as well as the respective periods per archaeological site, these survey data would then count as Class A. Naturally, these data would not provide spatial information.

37 The same applies to site classifications. The relevant surveys rarely follow a consistent and uniform site classification. In order to compare the relevant datasets functionally however, it was necessary to create an own site classification, to evaluate all sites manually and fit them into the greater classification. As described above, the results of this paper are not affected by differing site classifications and are therefore also valid if other research projects introduce a different site classification system. Additionally, while reevaluating the sites functionally, the original site classification was also listed in order to guarantee transparency.

38 An alternative – and significantly easier – option would have been to predefine a new generally valid chronological system for this study and simply fit the survey data into that greater system. However, not only would this have not solved the problem of temporal fuzziness, instead it would have increased it and rendered further spatio-temporal analyses faulty.

39 At this point it is necessary to define a temporal resolution or scale. In this study, the century-based temporal resolution was broken down to decades in order to receive a better temporal resolution and to better grasp cultural periods such as “Early Roman” or “Late Nabataean” as well as temporal overlaps. The important issue of temporal resolution deserves a more detailed discussion than can be provided in this contribution and must be followed up in farther-reaching studies on the subject matter. For now, the reader should be aware that the choice of temporal resolution or the scale of the chosen time spans can have a significant impact on the general result of any diachronic quantitative analysis. E.g. this is very insightfully highlighted by Wilson 2014, 147–155 and his reevaluation of studies on Mediterranean ship wrecks.

2. *Selection Process*. Class A survey data is filtered according to cultural periods and their respective time spans as stated in the original survey data.
3. *Quantifying Chronological (Un)Certainties*. The dating values of each stated cultural period and respective time spans are quantified.
4. *Creating the Quantified Spatio-Temporal Base Dataset*. The quantified time spans of Class A survey data are applied to the cultural periods from Class B data.

(a) *Acquiring the Base Dataset*

There are various approaches on coding temporal information.⁴⁰ However, one particular coding method was conducted in this study which suited the available information best. Within the Class A survey data, archaeological sites can either be assigned to one cultural period (e. g. “Nabataean”), consecutive periods without interrupted temporal intervals (e.g. “Nabataean to Roman”) or various periods with interrupted temporal intervals (e.g. “Iron Age”, “Nabataean”, “Byzantine”). Particularly for the latter example, the best coding method for Class A survey data was O. Nakoinz’ “Stufenbelegung mit unterbrochenem Intervall”⁴¹ This method simply assigns Boolean values for each evidenced cultural period and its respective time span as defined by the different Class A surveys. The unit of a time span is termed here as a “time block” (*tb*) and is measured in decades. The Boolean value “0” signifies “Period not evidenced” and “1” equals “Period evidenced”.⁴² The same principle applies for the respective time span of all cultural periods as stated in the Class A survey reports. For example, a site might be dated to the Nabataean period (N [= Nabataean]: 1), which was predefined as ranging from 100 BC to 106 AD.⁴³ Since a time span’s time block is measured in decades, this would mean that the decades 100 BC, 90 BC, 80 BC...100 AD would receive the Boolean value “1”. For sites that are dated to consecutive cultural periods, e.g. from the Nabataean to Roman Periods (N:1, R [=Roman]:1), the entire time span of both periods would simply receive the Boolean value “1”. However, for sites that are dated to various periods with interrupted temporal intervals, e.g. sites dating to the Iron Age, Nabataean and Byzantine periods (IA [=Iron Age]:1, N:1, B[=Byzantine]: 1), the time spans of each evidenced period receive the value “1” and the time spans which are not evidenced simply receive the value “0”.

However, some sites reported in the available Class A surveys could not be dated into a cultural period (and thus also into the period’s defined time span) with certainty. In the survey reports, this is signified by expressions such as “probably Iron Age”, “possibly Nabataean” or “Roman (?)”.⁴⁴ In order to meet these concessions from the original

40 For a discussion on the various coding options, see Nakoinz 2012, 191–194. In addition to the method described here, Nakoinz proposes four other options for coding chronological information. One, termed “Herkömmliche Datierung”, structures data that date to one cultural date only. Therefore, this approach is too simplistic for the data analyzed in this study. Nakoinz’ “Stufenbelegung” also defines Boolean values for evidenced cultural periods, but only assigns them to data that are continuously evidenced in consecutive cultural periods. Basically, the applied “Stufenbelegung mit unterbrochenem Intervall” is the same, the only difference being that it also takes non-evidenced cultural periods into account. Another option would be to code chronological information by defining real dating probabilities. While this would be the ideal solution, the various inconsistencies within the original survey data of this study – particularly the dating qualities – do not allow defining a precise probability value of a site dating to a particular period without previous analysis. As described above, the chronological information at hand firstly follows a Boolean logic of true or false. Therefore any further coding options based on dating probabilities, as also proposed by Nakoinz, are not applicable for the data of this study.

41 Nakoinz 2012, 193.

42 Nakoinz 2012, 192.

43 Abudanh 2006, 201.

44 See for example Abudanh 2006, 418–419: Abudanh Survey Site Nr. 042 is “probably Nabataean?” and Abudanh Survey Site Nr. 043 “Nabataean?”

surveyors, aspects of *fuzzy logic* were followed that was first developed by L. A. Zadeh.⁴⁵ Zadeh recognized that it is not always possible or necessary to apply absolute Boolean values of “true” or “false”.⁴⁶ *Fuzzy logic* allows us to use uncertain or so called *fuzzy* values. In such so called *fuzzy* cases described above, the original surveys were not able to give an exact dating for archaeological sites, however the provided information nevertheless suggest an inclination towards a specific cultural period. Still, the dating of these sites obviously could not be given with absolute certainty in terms of “Period evidenced” or “Period not evidenced”, i.e. when the Boolean values of “0” and “1” would apply. Absolute Boolean statements of “true” or “false” are not possible in such cases and these fuzzy cases must receive different dating values. Therefore, “0,5” was defined as a *fuzzy dating value* signifying chronological uncertainties stated in the original survey reports.⁴⁷ The fuzzy dating value “0,5” was chosen since it expresses a 50–50 chance that the respective sites are dated in the stated cultural period, therefore meeting the concessions of the original surveyors best in our opinion. It was then possible to assign these fuzzy values in the same manner as giving Boolean values for cultural periods and their respective time spans.

The dating values “0”, “0,5” and “1” were thus assigned to the cultural periods and their respective time spans for each dated archaeological site of Class A survey data (table 2). This process corresponds to the second step 4.2. *Selection Process* as stated above.

Survey Specifics			Cultural Phases			Respective Time Spans of Cultural Phases (century-based)			
Survey	Site Nr.	Site Type	N	R	B	1st century BC	1st century AD	2nd century AD	...
[Class A Survey]	[Class A Survey]_Nr. 001	[Site Type A]	0	1	0	0	1	1	...
[Class A Survey]	[Class A Survey]_Nr. 002	[Site Type B]	1	0	0	1	1	0	...
[Class A Survey]	[Class A Survey]_Nr. 003	[Site Type C]	0	0	1	0	0	0	...
[Class A Survey]	[Class A Survey]_Nr. 004	[Site Type C]	0,5	0	0	0,5	0,5	0,5	...
[Class A Survey]	[Class A Survey]_Nr. 005	[Site Type A]	1	1	1	1	1	1	...
[Class A Survey]	[Class A Survey]_Nr. 006	[Site Type B]	1	0	0,5	1	1	0	...
...

Tab. 2 | Example showing how to define the fuzzy and Boolean dating values to Class A survey sites according to cultural periods and their respective evidenced centuries (only showing from the 1st century BC to the 2nd century AD). N= Nabataean; R= Roman; B= Byzantine.

45 Zadeh 1965. Other landscape archaeological studies also applied aspects of fuzzy logic for deconstructing chronological inconsistencies. See for example Farinetti 2011, 35–39 and Farinetti, Hermon, and Niccolucci 2010.

46 Nakoinz 2012, 197–199; Crema, Bevan, and Lake 2010, 1120; Zadeh 1965.

47 The fuzzy dating value of “0,5” therefore lies between “0” for “Period not evidenced” and “1” for “Period evidenced”.

4.1 Quantifying Chronological (Un)Certainties

In addition to establishing an exact time span for each cultural period of survey data that includes a start and end point, the aim was to define the temporal range of (un)certainty of the existence of an archaeological site at a particular time block (decade) and not simply stating the presence or absence of an archaeological site with absolute certainty.⁴⁸ This allows us to further quantify the differing chronological information of the available survey data and use these results as the basis for the definition of cultural periods for further studies. Based on the assigned fuzzy and Boolean dating values, a cultural phase (p_x) should state the existence or frequency value (f) of each time block for each given cultural period expressed somewhere between “0” (“absolute certainty of non-existence”) and “1” (“absolute certainty of existence”) as *probability* values.⁴⁹ The definition of a cultural phase therefore no longer follows a binary (Boolean) logic, but is rather based on fuzzy logic as explained above.⁵⁰

At this stage, other studies propose applying the so-called *aoristic weighting method* or *aoristic analysis*. Aoristic analysis was first developed in criminology by Ratcliffe and underlies similar principles of fuzzy logic.⁵¹ The method was later adopted for archaeological research purposes by Johnson, enabling archaeologists not only to define the linear length or duration of a fuzzy dating period, but also to further quantify it.⁵² The advantage of the aoristic method is that chronologies are not considered relatively, but encompass an absolute time scale, allowing the combination of chronological information from both scientific and typology-based dating methods.⁵³ However, the method requires a predefined time span with fixed start and end points.⁵⁴ In this study, the aoristic method may be applied for the different cultural phases of Class A surveys, but (a) the dating probability of cultural phases of singular surveys is of minor interest for this study since the aim is to achieve a *cumulative* probabilistic dating of cultural phases based on *all* Class A survey data, and, more importantly, (b) even Class A survey data have numerous exceptions within their definitions of cultural periods, which exceed and/ or fall behind the predefined time span stated in the survey reports. Therefore, the required predefined time spans are inherently fuzzy and do not meet the prerequisites for applying the aoristic method. Instead, this study calculated the cumulative probabilistic dating of cultural phases as follows:

Once the fuzzy and Boolean dating values were assigned to all Class A survey data, each evidenced cultural period (and its respective time span) were selected (compare step 4. 2. above) and evaluated individually. The sum of all fuzzy and Boolean dating values ($SumDV_{tb}$) for each time block (tb) evidenced per cultural phase for all Class A survey data was then calculated. Each time block per cultural phase thus first received summed dating values. Subsequently, the existence or frequency value f per time block (tb) of each cultural phase was defined as the proportion per cultural phase. More precisely, it was calculated by first multiplying each existence or frequency value f with the one percent value of the total number of sites evidenced for a phase (S_x). Each result was then divided by 100:

$$f_{tb} = \frac{(SumDV_{tb} * S_x)}{100}$$

48 Bevan, Crema, et al. 2013, 40; Crema 2012, 448; Crema, Bevan, and Lake 2010, 1120.

49 Nakoinz 2012, 193; Crema, Bevan, and Lake 2010, 1120.

50 Nakoinz 2012, 193.

51 Bevan, Crema, et al. 2013, 40; Crema 2012, 448; Nakoinz 2012, 193; Crema, Bevan, and Lake 2010, 1120; Mischka 2004; Ratcliffe 2000.

52 Johnson 2004.

53 Nakoinz 2012, 193.

54 Nakoinz 2012, 193; Crema 2012, 448; Crema, Bevan, and Lake 2010, 1120.

The existence values f_{tb} signify the probability values for the dating of a phase p_x within each time block (decade) of that phase, expressed by values ranging from 0 (“absolute certainty of non-existence”) to “1” (“absolute certainty of existence”). Each cultural phase p_x evidenced by Class A survey data was then simply defined as the maximal temporal range of the f_{tb} values for each given phase:

$$length_{p_x} = max. temporal range (f_{tb})$$

In order to facilitate the understanding of the steps necessary to quantify the chronological uncertainties within Class A survey data and defining the quantified range of each cultural phase, the process shall be briefly highlighted with the Nabataean Period as an example.

Survey	Site Nr.	N	100 BC	90 BC	80 BC	70 BC	...	0	10 AD	20 AD	30 AD	...	320 AD
Abudanh 2006	Abudanh 2006_003	1	1	1	1	0	...	1	0
...
FJHP (Exterior Area)	FJHP Ext_003	1	1	1	1	0	...	1	1	1	1	...	0
...
FJHP (Core Area)	FJHP S_004	1	1	1	1	0	...	1	1	1	1	...	0
...
ARNAS	ARNAS_001	1	0	0	0	1	...	1	1	1	1	...	1
...
ShamAyl	ShamAyl_001	1	0	0	0	1	...	1	1	1	1	...	0
...
	<i>SumDV_{tb}</i> :		202,5	202,5	202,5	479,5	...	555	554	555	555	...	277

Tab. 3 | Simplified example for calculating the summed fuzzy and Boolean dating values for the Nabataean Period based on Class A Survey data.

As shown in table 3, four Class A surveys define a maximal temporal range for the cultural period “Nabataean” from 100 BC to 324 AD⁵⁵: Abudanh defines the Nabataean Period to run from 100 BC to 106 AD⁵⁶, the Finnish Jabal Harun Project (FJHP) from 100 BC to 125 AD⁵⁷ and MacDonald et al. define for both the Ayl to Ras an-Naqab Archaeological Survey (ARNAS) and the Shammak to Ayl Survey (ShamAyl) the Nabataean phase as ranging from 63 BC to 324 AD (compare also Fig. 1 above).⁵⁸ It becomes obvious that the chronological definitions differ up to two centuries, making simple chronological sorting of these archaeological sites extremely difficult. It was therefore necessary to assign the fuzzy and Boolean dating values “0”, “0,5”, “1” to each evidenced time block (decade) for all recorded sites of these four Class A surveys. For example, a FJHP site may be dated to

55 Note that since the majority of sites documented by ARNAS are not within the defined 20km radius set as the study area (see above), only ARNAS sites within the radius were considered for calculating the dating probabilities of the various recorded cultural phases.

56 Abudanh 2006, 201.

57 Silvonen 2013, 129–130. Note that the Nabataean Period was subdivided into “Nabataean B.C.” and “Nabataean A.D.”: Silvonen 2013, 130, table 9 states that the latest date of “Nabataean A.D.” is roughly set to the “early second century A.D.”: In contrast to statements such as “mid-2nd century A.D.,” which corresponds to 150 A.D., “early 2nd century A.D.” must equal 125 A.D. (first quarter of the 2nd century A.D.).

58 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

the Nabataean Period. According to the FJHP's definition, the decades from 100 BC to 120 AD (the end date of the Nabataean period being 125 AD) receive the Boolean dating value "1". If a FJHP site would be dated to "probably early second century AD", the decades from 100 BC to 90 AD receive the Boolean value "0" and the decades from 100 to 120 AD receive the fuzzy dating value "0,5". This process is then applied to all four Class A surveys dating to the Nabataean Period and corresponding to steps 4.1. and 4.2., as explained above.

After the base data for all Class A survey sites dating to the Nabataean Period is clarified, step 4.3 (see above) is devoted to calculating the dating probability values for each decade-based time block (tb) within the total temporal range as pre-defined by the surveys. In this case, the maximal temporal range of the Nabataean phase (p_N) runs from 100 BC to 324 AD. The sum of all fuzzy and Boolean dating values per time block (tb) is then calculated (see also table 3). With a total number of 625 Class A survey sites dated to p_N , the one percent value S_N is 0,16. According to the formula above, the frequency value for each time block (f_{tb}) is calculated by multiplying the summed Boolean values of each time block by S_N . The results are then divided by 100. To be more precise, the frequency values for each time block (f_{tb}) of Class A survey sites belonging to the Nabataean phase (p_N) are calculated as follows:

$$f_{tb} = \frac{(SumDV_{tb} * 0,16)}{100}$$

Once the frequency values of the four Class A surveys are established, these can be assigned as dating values to Class B survey data, where sites are dated by non-defined cultural phases only. This corresponds to step 4.4. *Creating the Quantified Spatio-Temporal Base Dataset* as explained above. In the case of the Nabataean Period, the Class B surveys are the Archaeological Survey of the Wadi Musa 1996 and 1998 (WMWS), the Jabal Shara Survey (JSS) and Andrew Smith's survey of the Wadi Arabah, adding another 107 sites to the total count.⁵⁹ The sum of the survey Class B Boolean values per time block are then added to the sum of the values of the Class A surveys. The new results of each time block within the temporal range of the Nabataean phase (p_N) (100 BC–324 AD) is then multiplied by the new one percent value S_N being 0,1366 (the new total amount of both Class A and B sites is 732) and divided by 100. Therefore, based on Class A and Class B survey data, the existence value f per time block (f_{tb}) of phase p_N is calculated and expressed in decimal numbers from "0" ("absolute certainty of non-existence") and "1" ("absolute certainty of existence"). For example, the results of these calculations can be plotted as simple bar charts or histograms as shown in Fig. 2 for the Nabataean Period. The graph shows the probability or existence values f on the y-axis and the single time blocks (decades) evidenced for the Nabataean Period on the x-axis.⁶⁰

The entire process as exemplified for the Nabataean Period is repeated for all evidenced cultural periods. The following presents the results of the dating probabilities calculated for each cultural period by Class A and B survey data.

Based on the survey reports of the Petra hinterland, more than 1800 sites formed the basis of the analyses conducted in this study, that belong to the following cultural periods⁶¹: Iron Age, Iron Age 1, Iron Age 2, Iron Age 2a, Iron Age 2b, Iron Age 2c, Iron Age 3, Hellenistic, Early Nabataean, Nabataean, Late Nabataean, Early Roman, Roman, Late

59 Tholbecq 2013; A. Smith II. 2010; 'Amr, al-Momani, et al. 1998; Tholbecq 2001; 'Amr, al-Nawafleh, and Qrarihi 1996.

60 All analytical steps were conducted mostly with the use of the statistical computing software R. An exemplary script highlighting the workflow of the individual steps described above is included at the end of this paper.

61 Other cultural periods such as the Palaeolithic, Neolithic, Bronze Age, Early Islamic, Middle Islamic, Late Islamic/ Ottoman, Umayyad, Abbasid and Transitional Periods were also defined and recorded by

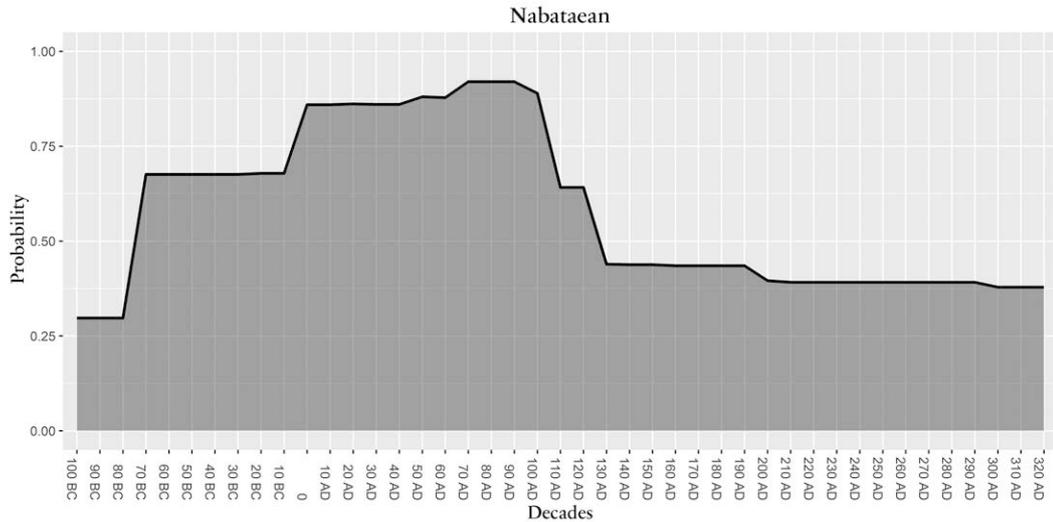


Fig. 2 | Dating probability graph for the Nabataean Period evidenced by Class A and B survey data.

Roman, Early Byzantine, Byzantine, Middle Byzantine and Late Byzantine. As can be seen below, the resulting probability graphs (Figs. 3–8) are structured by the superordinate cultural periods such as the Iron Age or Nabataean Periods. The dashed vertical lines represented in the graphs signify the limits of a more accurate definition of the respective periods based on a qualitative assessment of the analyses' results presented below.

5 Results

5.1 The Iron Age Periods

Abudanh defines the Iron Age Period as running from 1200 BC to 539 BC.⁶² He does not differentiate the Iron Age further chronologically, but equates it with the Iron Age II and Edomite Periods.⁶³ Both ARNAS and ShamAyl differentiate between Iron Age I and II. Iron Age I is set to 1200–1000 BC and Iron Age II between 1000 and 539 BC.⁶⁴ Only the Edom Survey further subdivides the Iron Age II Period into Iron Age II A–C. All three are roughly set between 700 and 500 BC.⁶⁵

For Abudanh, the Iron Age III Period is synonymous with the Persian Period, which he defines as running from 539 to 332 BC.⁶⁶ Both ARNAS and ShamAyl define the Persian Period as Abudanh.⁶⁷

In total, only 24 sites, including Class B survey sites giving cultural periods only, are dated to the Iron Age Period without any further specification. The maximal temporal range runs from 1200 BC until the end of the sixth century BC. Since 22 sites are recorded by the ShamAyl (Iron Age I and II defined to run from 1200 to 539 BC), the high probability values along the entire temporal range as shown in the dating probability graph (Fig. 3), is of no surprise.

the surveys. See Abudanh 2006, 222, 225, 229; Silvonen 2013, 130; Sinibaldi 2013. However, these periods do not fall in the chronological focus of this study.

62 Abudanh 2006, 196.

63 Abudanh 2006, 196.

64 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

65 Hart – Faulkner 1985, 256.

66 Abudanh 2006, 198.

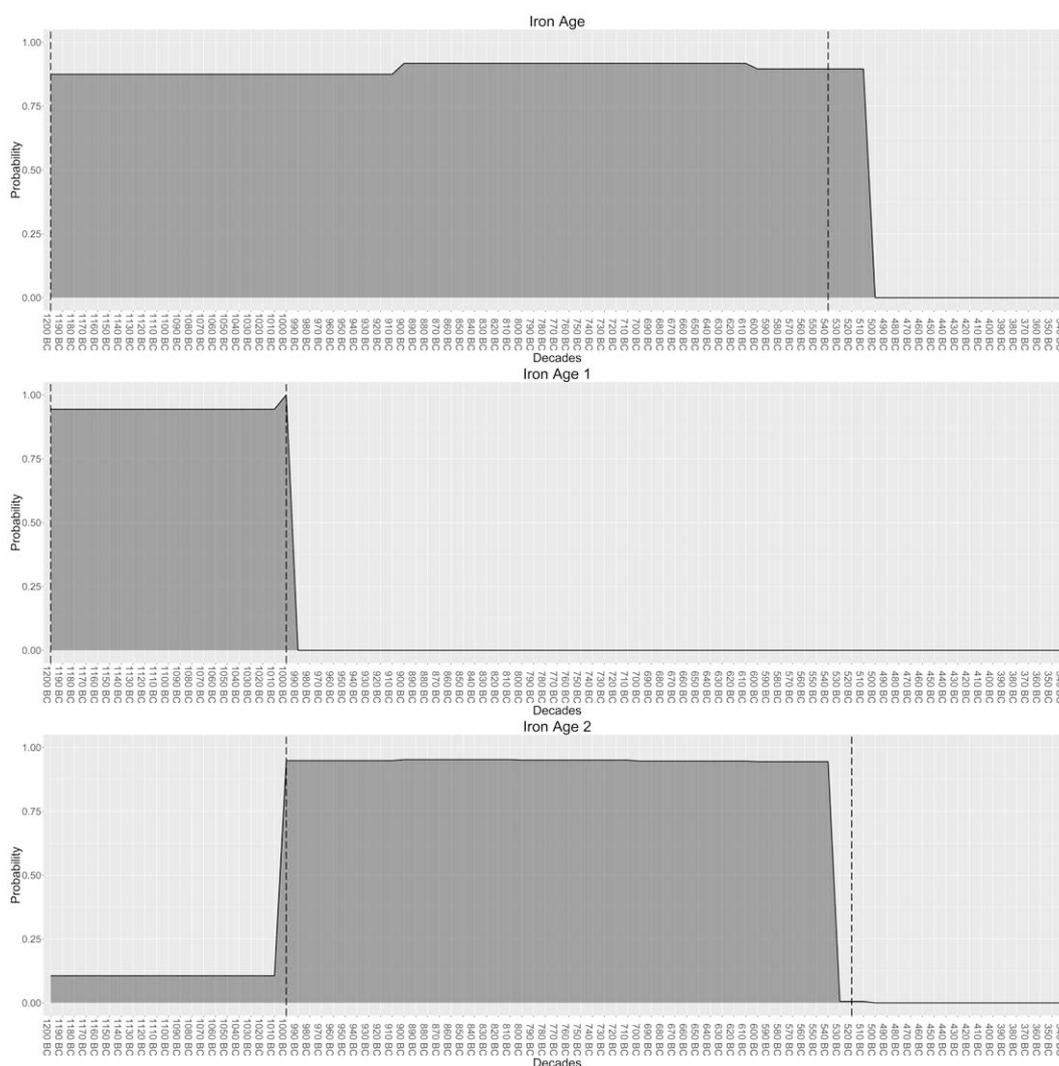
67 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

Only 22 sites date to the Iron Age I Period. Since the evidenced sites are all recorded by ARNAS and ShamAyl, the maximal temporal range from 1200 to 1000 BC as well as the high dating probability values is expected (Fig. 3).

In total, 254 sites date to the Iron Age II Period. The maximal temporal range runs from 1200 BC until the end of the sixth century BC. Since almost half of the evidenced sites were recorded by ARNAS or ShamAyl (Iron Age II defined to run from 1000 to 539 BC), the high dating probability values between 1000 and the 530s BC comes as no surprise (Fig. 3).

Only three sites date to the Iron Age II A and B Period and 60 sites date to the Iron Age II C Period. The maximal temporal range of all three periods begins with the seventh century and ends with the beginning of the fifth century BC. All three periods are evidenced by the Edom Survey only, which explains the stable dating probability of 100% (Fig. 3).⁶⁸

Only 2 sites are dated to the Iron Age III or Persian Period, both of which were recorded by Abudanh.⁶⁹ This explains the stable probability of 100% (Fig. 3) throughout the entire maximal temporal range between 539 and 332 BC.



(continued on next page)

68 Hart 1987.

69 Abudanh Survey Site Nr. 047 and 138.

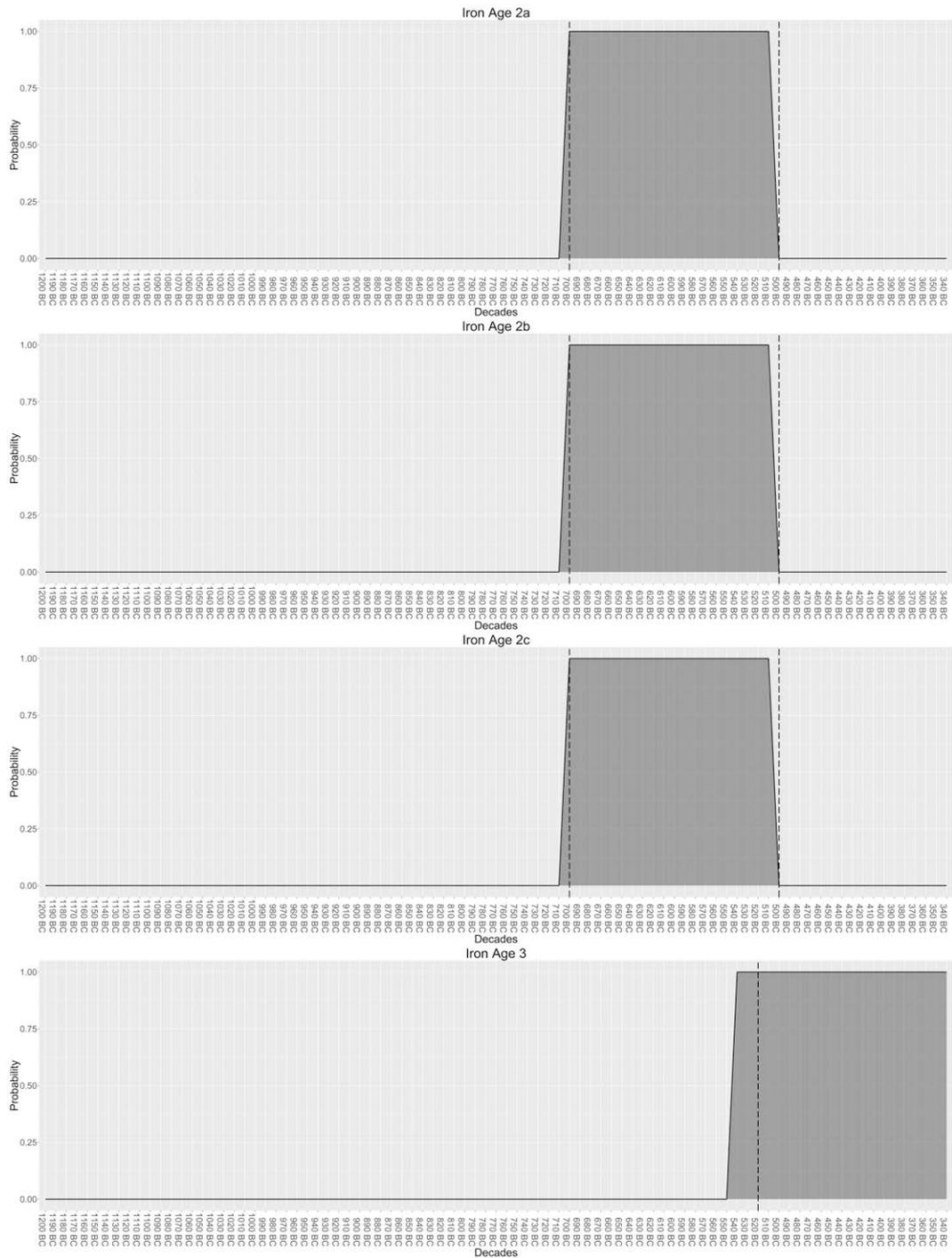


Fig. 3 | Dating probability graphs of all Iron Age Periods evidenced by Class A and B survey data.

5.2 The Hellenistic Period

Both Abudanh and the WMWS 1996 mention only one site dating to the Hellenistic Period. Abudanh sets it to the first three and the WMWS 1996 to the first two centuries BC.⁷⁰ The JSS also sets the period to the first two centuries BC.⁷¹ The FJHP limits it to

⁷⁰ Abudanh 2006, 567; ‘Amr, al-Momani, et al. 1998, 529.

⁷¹ For example JSS Site Nr. 117: unpublished survey catalog provided by the courtesy of L. Tholbecq.

the first century BC.⁷² ARNAS and ShamAyl define the Hellenistic Period from 332 to 63 BC.⁷³

In total, 42 sites, including Class B survey sites giving cultural periods only, are dated to the Hellenistic Period. The maximal temporal range is defined as the first three centuries BC, although the dating probability graph (Fig. 4) shows a very small probability for Hellenistic sites dating to the first half of the fourth century BC and second half of the first century BC. The highest probability (between approx. 75 and 90%) falls within the 340s and 60s BC. This corresponds to the conventional dating of the Hellenistic Period starting with the death of Alexander the Great in 323 BC. The end date is due to the high amount of ARNAS and ShamAyl sites (combined 79%), where the Hellenistic Period is defined to end at 63 BC. Although the authors do not present an argument for this precise date, it may be associated with Pompey the Great's campaigns in the Near East.⁷⁴

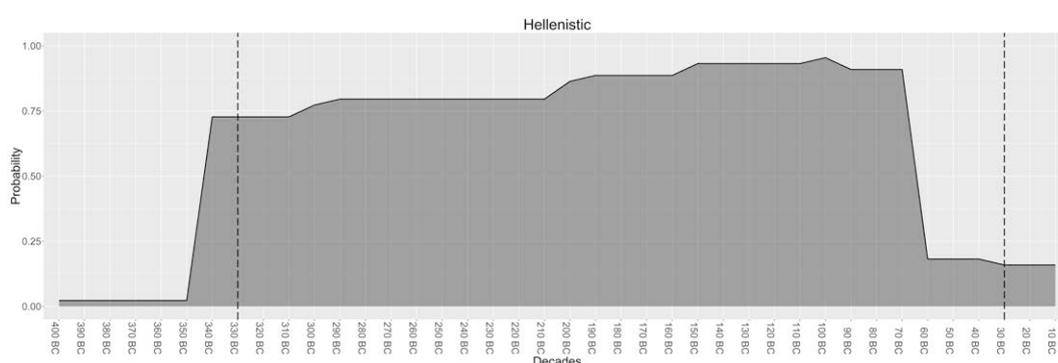


Fig. 4 | Dating probability graph of the Hellenistic Period evidenced by Class A and B survey data.

5.3 The Nabataean Periods

According to Abudanh, the Nabataean phase dates between 100 BC and 106 AD.⁷⁵ The FJHP defines the Nabataean Period as running from 100 BC to 125 AD.⁷⁶ Abudanh also dates sites to the Late Nabataean Period which he does not define further.⁷⁷ It was therefore necessary to artificially define this period in order to incorporate it into the study: Sites dated to the Late Nabataean Period by Abudanh were thus assigned the Boolean value “1” for the first century AD and the Boolean value “0,5” for the second century AD. For both ARNAS and ShamAyl, the Nabataean Period is not differentiated from the Roman Period and runs from 63 BC to 324 AD.⁷⁸ Only the WMWS 1996 recorded one site that is dated to the Early Nabataean Period, which is defined as the first two centuries BC.⁷⁹ The survey also differentiates a Late Nabataean phase running from 170 to 320 AD.⁸⁰

72 Silvonon et al. 2013, 373: FJHP Site Nr. S085 actually states “Late Hellenistic”.

73 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quintance, Clark, et al. 2012, xvi.

74 Bowersock 1983.

75 Abudanh 2006, 201.

76 Silvonon 2013, 129–130. On the FJHP's subdivision of the Nabataean Period into “Nabataean B.C.” and “Nabataean A.D.” see footnote 57.

77 See for example Abudanh Survey Site Nr. 063.

78 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quintance, Clark, et al. 2012, xvi.

79 ‘Amr et al. 1998, 529: WMWS 1996 Site Nr. Wadi Musa 23.

80 ‘Amr et al. 1998, 535: WMWS 1996 Site Nr. Tayyiba 12.

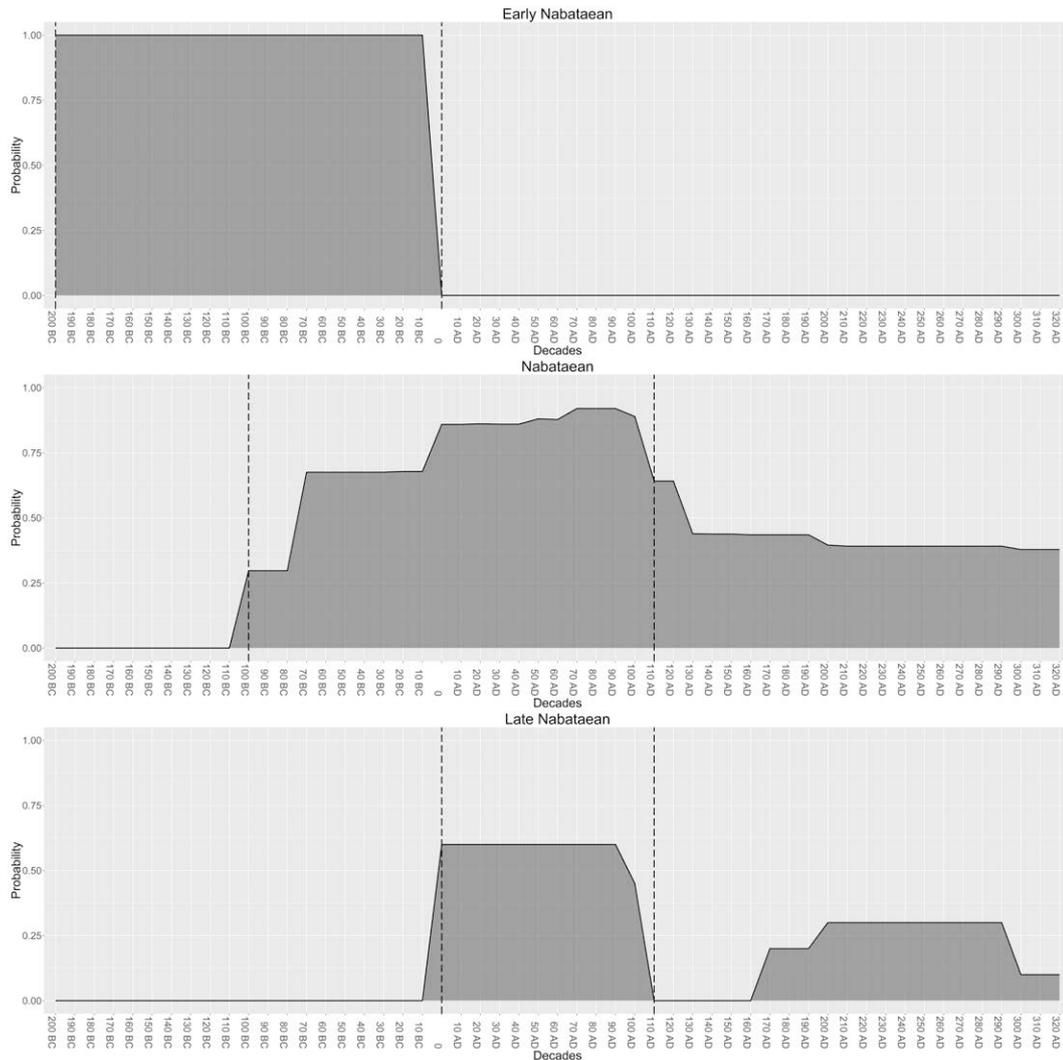


Fig. 5 | Dating probability graphs of the Nabataean Periods evidenced by Class A and B survey data.

In total, only one site is dated to the Early Nabataean Period. It is therefore not surprising that the dating probability is set at 100% (Fig. 5). The maximal temporal range begins at 200 BC and ends with the last decade of the first century BC. However, with only one evidenced site, this period is negligible.

Representing the most evidenced cultural phase, 732 sites, including Class B survey sites giving cultural periods only, are dated to the Nabataean Period. The maximal temporal range is set between 100 BC and the 320s AD. As the dating probability graph (Fig. 5) shows, the dating probability is relatively low during the first three decades of the first century BC. However, a sudden rise to a dating probability of almost 70% can be observed during the 70s BC. This upward trend continues during the first century AD peaking around 70 AD. With the turn of the century, there is a sudden drop again, which eventually stagnates shortly below 40% by the third century AD. While the observed drop during the beginning of the second century AD fits very nicely with the Roman annexation of the Nabataean realm in 106 AD, the continuation of the Nabataean Period into the fourth century AD seems very far stretched. This can be explained by the relatively large number of sites recorded by ARNAS and/ or ShamAyl (38% combined), where, as stated above, the Nabataean Period is synonymous with the Roman Period both running

from 63 BC to 324 AD.⁸¹ However, the irregularity of such a dating of the Nabataean Period is shown by the expected drop at the beginning of the second century AD. The probability values for the Nabataean Period after the first quarter of the second century AD must therefore be considered critically.

Only 10 sites date to the Late Nabataean Period. The maximal temporal range runs from the beginning of the first century AD and ends in the 320s AD. While the relatively high dating probability in the first century AD (approx. 60%) seems to correspond well with the decades before the Roman annexation in 106 AD (Fig. 5), the probability values for the second to early fourth centuries must be due to dating irregularities of the surveys (being Abudanh and WMWS 1996 only). This is supported by the sudden drop at the end of the first century AD, after which no sites are evidenced for half a century. Particularly concerning the Late Nabataean Period, it is interesting to note the complete overlap with the Nabataean Period as exemplified in Fig. 6 showing the Nabataean Period defined by WMWS 1996 and the Late Nabataean Period as defined by Abudanh. This fact also impacts the course of the dating graph for the Late Nabataean Period.

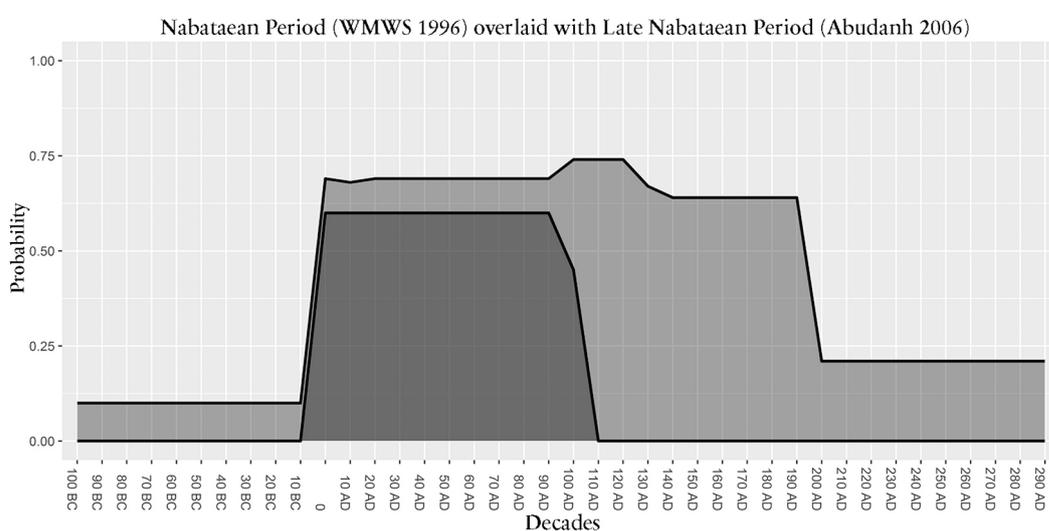


Fig. 6 | Dating probability graphs of the Nabataean Periods evidenced by Class A and B survey data.

5.4 The Roman Periods

The Roman Period is dated by Abudanh between 106 and 324 AD.⁸² Abudanh also dates sites to the Early and Late Roman period which he does not define further.⁸³ It was therefore necessary to artificially define these periods in order to incorporate them into the larger study. Sites dated to the Early Roman period by Abudanh were thus assigned the Boolean value “1” for the second century AD and the Boolean value “0,5” for the third century AD. Sites dated to the Late Roman period were assigned the Boolean value “1” for the fourth century AD and the Boolean value “0,5” for the third century AD. The FJHP only acknowledges the Late Roman Period which is set between 150 and 300

81 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quintance, Clark, et al. 2012, xvi.

82 Abudanh 2006, 208.

83 As an example for the Early Roman Period, see Abudanh Survey Site Nr. 026. For the Late Roman Period, see Abudanh Survey Site Nr. 002.

AD.⁸⁴ While both ARNAS and ShamAyl do not differentiate between the Nabataean and Roman periods (both running from 63 BC to 324 AD), they also distinguish between Early and Late Roman. Early Roman is set between 63 BC and 135 AD, Late Roman runs from 135 to 324 AD.⁸⁵

In total, only 18 sites, including Class B survey sites giving exclusively cultural periods, are dated to the Early Roman Period. The maximal temporal range is set between 70 BC and the last decade of the third century AD. The dating probability graph (Fig. 7) shows a very small probability for Early Roman sites dating between 70 BC and 100 AD. This is due to the unconventional dating of the period by ARNAS (see above) as well as two sites recorded by Smith's survey of the Wadi Arabah.⁸⁶ The highest probability (85%) is set during the second century AD corresponding well with the annexation of the Nabataean realm by the Romans in 106 AD. The relatively high probability for the Early Roman Period dating to the third century can be explained by the high amount of sites recorded by Abudanh (89% of all Early Roman sites).⁸⁷ As stated above, since Abudanh does not give a definition for this period, the Boolean values were assigned subsequently and artificially in this study. The high probability of the Early Roman Period dating to the third century AD is therefore questionable.

In total, 485 sites date to the Roman Period. The maximal temporal range is set from 63 BC to the end of the fourth century AD. While dating probabilities for the first centuries BC and AD remain stable around 62%, a sudden rise up to almost 100% can be observed with the beginning of the second century AD (Fig. 7). The probability values stay above 87% until the first quarter of the fourth century AD, when the dating probability reaches almost 0 around 320 AD. Again, the rise in the dating probability can be associated with the Roman annexation of the Nabataean realm and the drop after 320 AD may be explained with the conventional beginning of the Byzantine Period at 324 AD. The lower dating probability from 70 BC to 100 AD is most likely due to the relatively high amount of sites recorded by ARNAS and/ or ShamAyl (61% combined) where, as stated above, the Roman Period is synonymous with the Nabataean Period (both running from 63 BC to 324 AD).⁸⁸ However, the irregularity of such a dating of the Roman Period is shown by the expected rise at the beginning of the second century AD. The probability values for the Roman Period before the first quarter of the second century AD must therefore be considered critically.

Sixty-six sites date to the Late Roman Period. The maximal temporal range runs from 130 AD to the end of the fourth century AD. A rise in the dating probability (Fig. 3) can be observed with the beginning of the third century AD which remains stable during the entire course of the century until the probability values drop again during the first quarter of the fourth century AD. This may correspond to the conventional beginning of the Byzantine Period in 324 AD.

84 Silvonon 2013, 129–130. Silvonon 2013, 129 mentions that this period is synonymous with the so called “Nabataean-Roman” Period.

85 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

86 A. Smith II. 2010, 75 and 76 : BMP/ CAS Site Nr. 016 and 019.

87 In total, Abudanh associates 238 sites with the Early Roman Period.

88 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

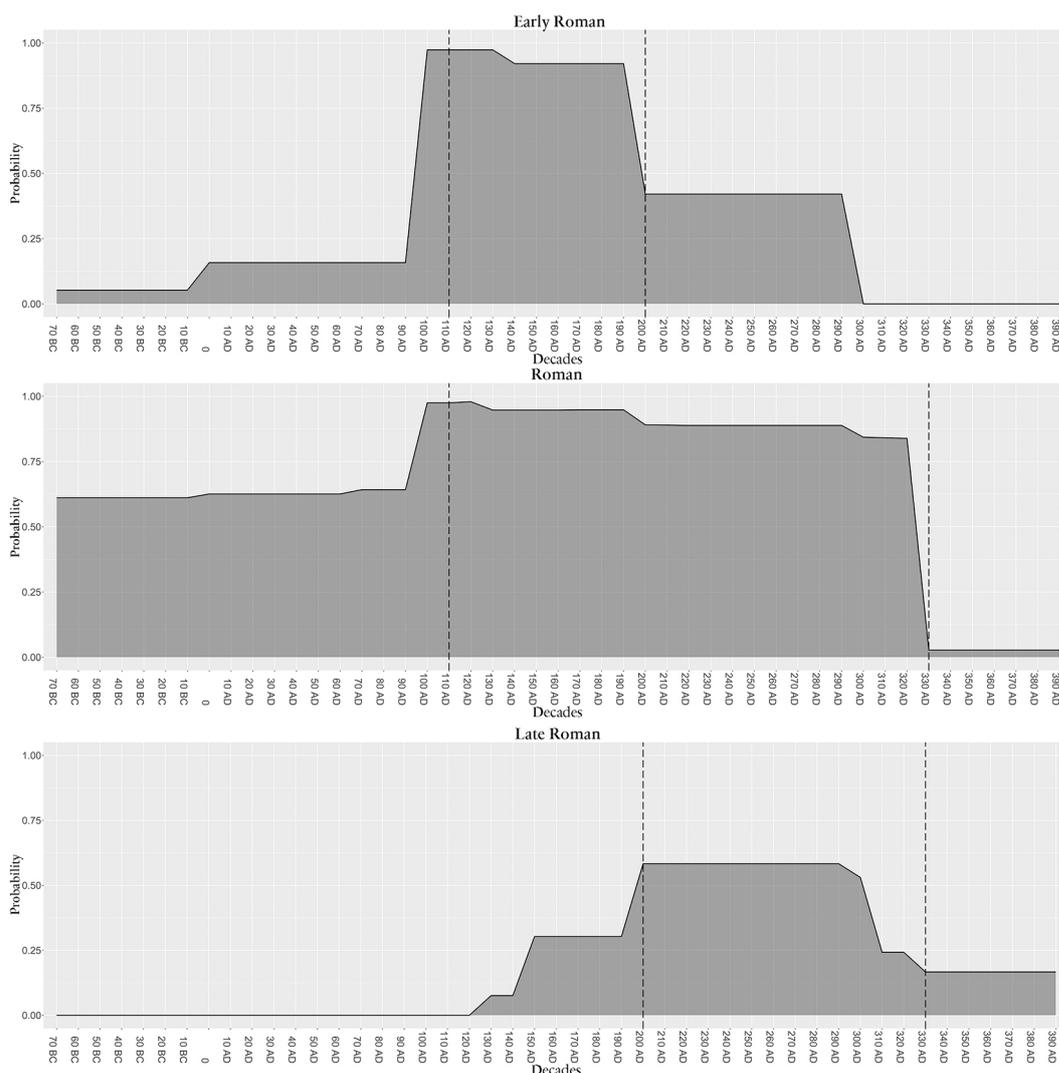


Fig. 7 | Dating probability graphs of the Nabataean Periods evidenced by Class A and B survey data.

5.5 The Byzantine Periods

Abudanh sets the Byzantine Period between 324 and 636 AD.⁸⁹ He also dates sites to the Early, Middle and Late Byzantine Period without any further definition.⁹⁰ It was therefore necessary to artificially distinguish these periods in order to incorporate them into the larger study. Sites dated to the Early Byzantine Period by Abudanh were assigned the Boolean value “1” for the fourth century AD and the Boolean value “0,5” for the fifth century AD. Sites dated to the Middle Byzantine Period were assigned the Boolean value “1” for the fifth century AD and the Boolean value “0,5” for the sixth century AD. Sites dated to the Late Byzantine Period were assigned the Boolean value “1” for the seventh century AD and the Boolean value “0,5” for the sixth century AD. The FJHP also divides the Byzantine Period (375–525 AD) into “Early Byzantine” (300–400 AD)

89 Abudanh 2006, 215.

90 As an example for a site dating to the Early Byzantine Period, see Abudanh Survey Site Nr. 006. For a site dating to the Middle Byzantine Period, see Abudanh Survey Site Nr. 089 and for a site dating to the Late Byzantine Period, see Abudanh Survey Site Nr. 017.

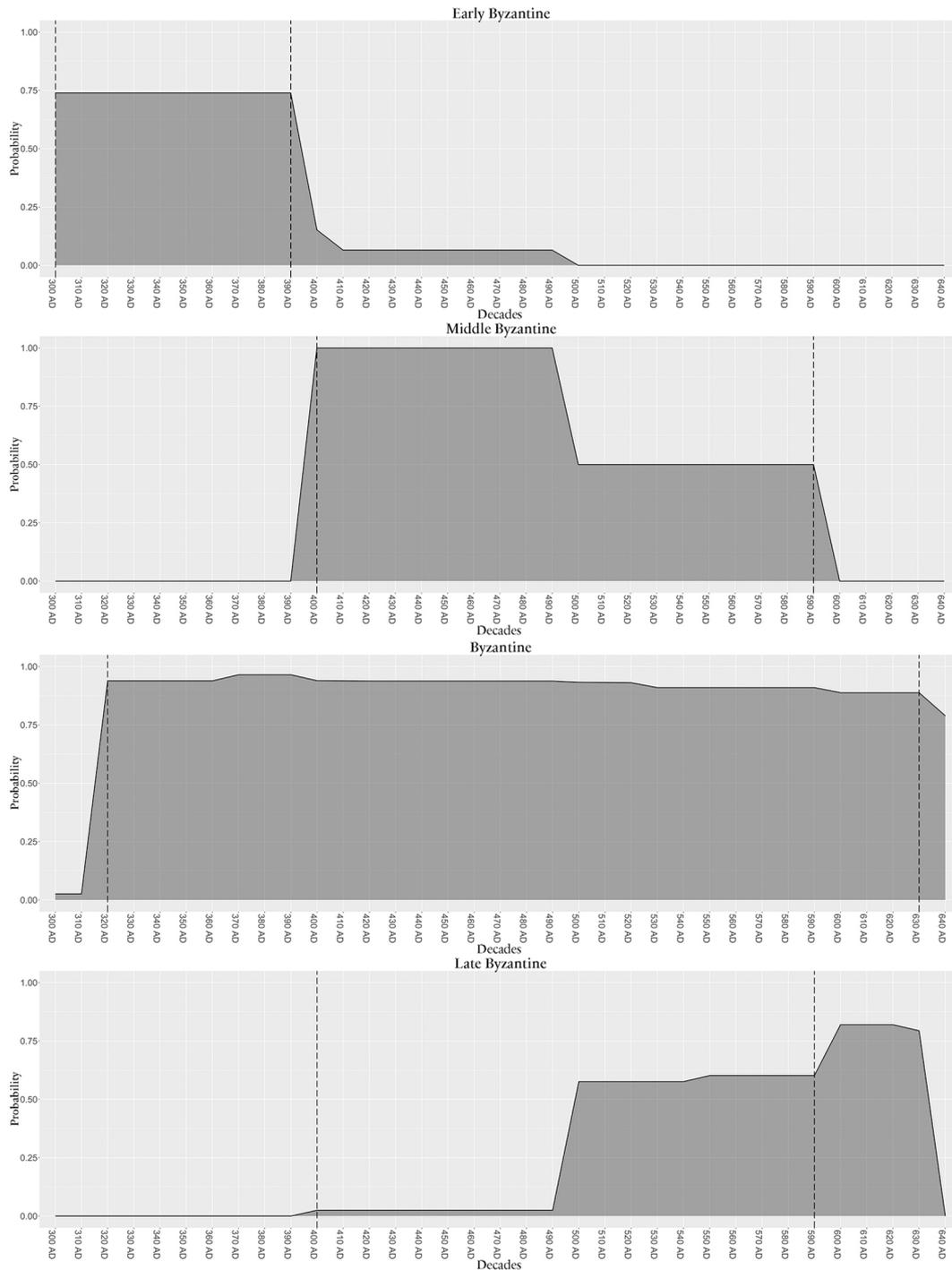


Fig. 8 | Dating probability graphs of the Nabataean Periods evidenced by Class A and B survey data.

and “Late Byzantine” (525–625 AD).⁹¹ Both ARNAS and ShamAyl do not further divide the Byzantine Period and date the entire phase between 324 and 640 AD.⁹²

91 Silvonén 2013, 130. Similar to the FJHP’s definition of “Nabataean A.D” where the latest date is simply defined as the “early 2nd century”, the Byzantine Period is defined as the “late 4th to early 6th century” (see Silvonén 2013, 130, table 9). Since the definition of “early 2nd century” was interpreted here as the first quarter of the second century (125 AD), “the late 4th century” was understood as the last quarter of the fourth century (375 AD) and the “early 6th century” as the first quarter of the sixth century (525 AD). Also, according to the FJHP, the Late Byzantine Period is defined as “in the course of the 6th century to the early 7th century” (see also Silvonén 2013, 130, table 9). This was interpreted as following the end

In total, 23 sites, including Class B survey sites giving cultural periods only, are dated to the Early Byzantine Period. The maximal temporal range is set between 300 and the last decade of the fifth century AD, although the dating probability graph (Fig. 8) shows a very small probability for Byzantine sites dating to the fifth century AD and a very high probability (85%) for sites dating between 300 and 390 AD.

Abudanh dates only one site to the Middle Byzantine Period. Since he does not give a more precise definition, the Boolean values for this period were artificially assigned during this study as mentioned above. This also explains the course of the dating probability graph (Fig. 8). With only one evidenced site, this period is negligible.

Being the second most evidenced cultural phase after the Nabataean Period, 574 sites can be dated to the Byzantine Period. The maximal temporal range is set between 300 and the 640's AD, although the dating probability graph (Fig. 8) shows a very small probability for Byzantine sites dating to the first two decades of the fourth century AD and a very high probability (85%) for sites dating between 320 and 630 AD.

In total, only 39 sites, including Class B survey sites giving cultural periods only, are dated to the Late Byzantine Period. The maximal temporal range is set between 400 AD and the 630's AD. The sudden rise in the dating probability with the end of the sixth century (Fig. 8) is due to the high amount of Late Byzantine sites recorded by Abudanh (87%). As stated above, since Abudanh does not give a definition for this period, the Boolean values were assigned subsequently and artificially in this study. The rise of the dating probability in the seventh century AD therefore must be seen critically.

6 Discussion

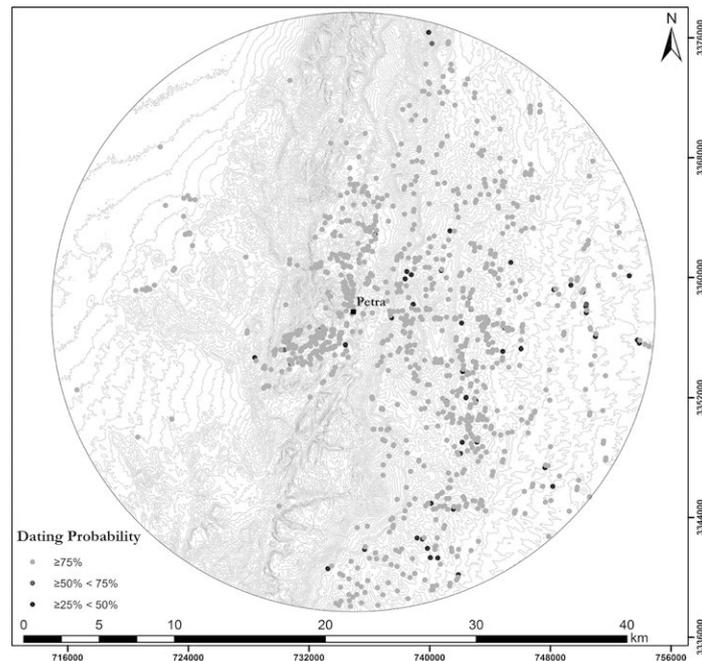
Based on the process of calculating the chronological uncertainties per cultural period, this study offers a rigidly structured dataset of archaeological sites within the Petra area, which can form the basis for further studies. The original survey data was comprehensively re-evaluated, the numerous site classifications standardized and, more importantly for this study, the differing chronological periodizations of the various surveys were worked into a uniform format. The definitions of each cultural period are now based on the dating probability values for each decade within the maximal temporal time span of the respective cultural periods. The probability graphs of the different cultural periods may seem historically imprecise or even false (e.g. the Nabataean Period continuing into the 3rd and early 4th centuries AD). However, such outliers are inherent to the original data and are thus represented in the probability graphs. As discussed in the passages above, it is therefore important to consider these graphs critically and acknowledge the chronological inconsistencies inherent to the original data. Also, the informative value of the graphs varies when considering the differing amount of sites that formed the basis of the analysis: The maximum amount of dated sites belong to the Nabataean Period (732), while the least evidenced cultural periods are the Early Nabataean and Middle Byzantine Periods with only one count. Expressed as percentages from all datable sites, 59,90% date to the Nabataean Period, while only 0,08% to the Early Nabataean and Middle Byzantine Periods.⁹³ This also has to be considered when evaluating the results presented here. While

of the FJHP's Byzantine period, thus at 525 AD. Again, the "early 7th century" was set here to the first quarter of the 7th century (625 AD).

92 MacDonald, Clark, et al. 2016, xvi; MacDonald, Herr, Quaintance, Clark, et al. 2012, xvi.

93 When expressing the amount of sites evidenced per cultural period as percentage values from all datable sites, it is possible to define a range of informative value or usefulness: cultural periods evidenced only between 0,08 and 1,47% can deemed informatively negligent. Cultural periods evidenced between 1,80 and 5,40% may have "little" informative value. All periods evidenced between 20 and 30% of all datable sites are "acceptable" and periods between 30 and 50% "good". Finally, periods evidenced by over 50%

Fig. 9 | Distribution map of the archaeological sites in the Petra area dating to the Nabataean Period based on the dating probability values. Sites classified according to percentage cut-offs for their dating probabilities represented in different shades of grey.



this would exceed the limits of this paper, farther-reaching research on the chronological inconsistencies of the survey data should experiment with different weighting of the percentage values of the various cultural periods in order to account for these variances.

Nevertheless, despite these remaining methodological issues, when considering e.g. the Nabataean Period in the Petra area, the graph in Fig. 5 simply defines the period as evidenced by the original survey data combined. Instead of giving an absolute definition of chronological periods, the probability graphs presented in this study visualize and make the existing chronological inconsistencies within the original survey data transparent for future research.

But what is the most appropriate method to visualize the temporal uncertainties on an archaeological site distribution map?

Several suggestions for visualizing temporal uncertainties of archaeological sites were already made, proposing to either use different coloring or symbols for the various dating probabilities.⁹⁴ Following Bevan et al., the most straightforward way for presenting site distributions according to the dating probabilities of a specific cultural period is to classify sites by certain dating percentages.⁹⁵ As an example, a site distribution map was created for the Nabataean Period showing the different dating probabilities of sites within that cultural phase (Fig. 9).

Based on the probability values shown in the dating probability graph of the Nabataean Period (Fig. 2 and 3), sites were classified according to percentage cut-offs for dating probabilities between $\geq 25\%$ and $< 50\%$ (represented in dark grey), $\geq 50\%$

of all datable sites are referred to as “excellent”. Hence, the periods Early Nabataean, Middle Byzantine, Iron Age 3, Iron Age 2a and b, Late Nabataean and Early Roman belong to the class “negligent”. The cultural periods Iron Age 1, Early Byzantine, Iron Age, Late Byzantine, Hellenistic, Iron Age 2c and Late Roman belong to class “little”. Iron Age 2 is “acceptable”. The Roman and Byzantine Periods are “good” and, finally, the Nabataean Period “excellent”. This signifies how differently the original surveys dealt with cultural periods, which is a major methodological issue. Therefore, this calls for transforming chronological information stated in terms of cultural periods into absolute time spans.

94 Bevan, Crema, et al. 2013, 45, figure 9; Bevan, Conolly, et al. 2013, 318, figure 2; Nakoinz 2012, 203–205, Abb. 8.

95 Bevan, Conolly, et al. 2013, 317.

and $<75\%$ (represented in grey) and $\geq 75\%$ (represented in light grey). While this map visualizes the dating uncertainties for the Nabataean Period well, for example, it also includes sites that are evidenced from the first century BC to the second century AD and therefore does not show chronological continuities of sites. It also shows Nabataean sites that, according to the probability graph, may date to the third century AD only, thus also failing to show sites that existed simultaneously. This is a general problem when studying the spatial distribution of sites based on cultural periods. For further analyses it is therefore more advantageous not to follow a chronological dating system based on culturally defined periods and break the chronological information of these cultural periods into absolute time blocks. By structuring site distribution maps by centuries for example, the contemporaneity of the displayed sites is much more likely and chronological continuities of sites are far easier to visualize. Also, the various site types can be shown as well, which is not possible with distribution maps showing the temporal uncertainties of cultural periods (see Fig. 9). As an example for such century-based site distribution maps, Fig. 10 shows the spatial distribution of archaeological sites within the Petra area from the 12th century BC to the 7th century AD laid over a simple density map in order to better show the spatial patterns of the archaeological sites.⁹⁶

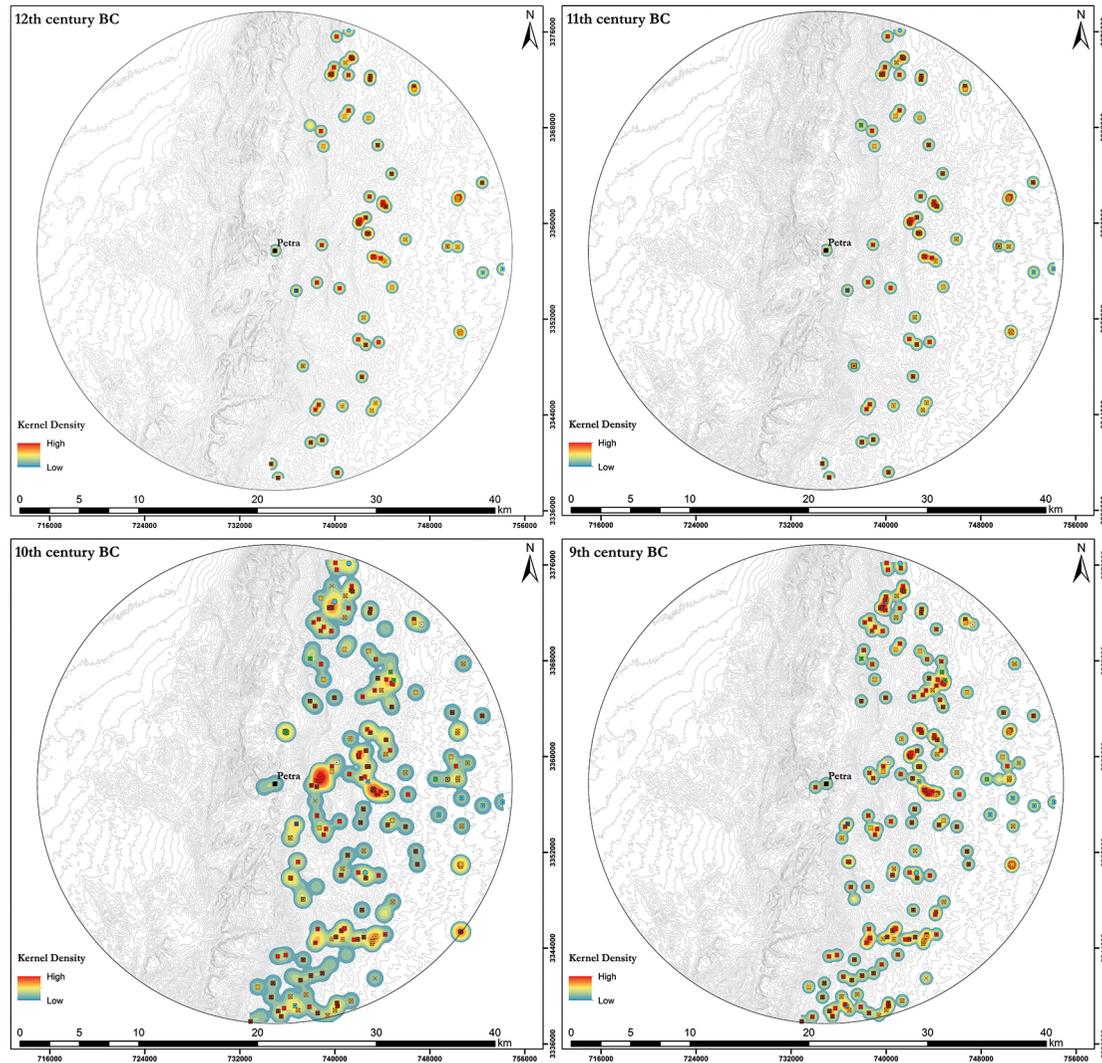
Although a more detailed study on the spatial pattern of archaeological sites within the Petra region has to follow, general trends can already be discussed here⁹⁷: The Iron Age Periods (12th to mid-6th centuries BC) show a relatively high density of occupation in the Jabal as-Shara region and high plateau east of Petra. However, there seems to be a higher density of sites in the 10th century BC. This trend continues until a dramatic decrease of archaeological sites in the 5th century BC where almost no sites are evidenced in the Petra region. While there is a slight increase of sites dating to the Hellenistic Period (4th to 2nd centuries BC), the most significant rise of documented sites can be observed for the 1st century BC. The highest density of sites is attested for the 1st century AD nucleating along a north-south axis in the Petra valley. During the 3rd century AD, however, the site density seems to gradually concentrate along the eastern Jabal as-Shara and high plateau region again until the Petra valley is basically void of archaeological sites by the 7th century AD and the large nucleus of sites lies in the eastern uplands.

As already mentioned, these observations remain general and superficial at this point. However, such a century-based visualization of the spatio-temporal dataset of the Petra hinterland, offers the opportunity to conduct further and more detailed analyses on the spatial patterns of archaeological sites through time. The possibility of considering such a vast archaeological dataset with reliable chronological information is based on the meticulous calculation of dating probabilities for cultural periods mentioned by the original survey data.

96 Please note, however, that the varying survey methods impact the results of the density analyses. For example, the FJHP has surveyed a far smaller area much more intensively than e.g. ARNAS, which covered a far larger area much more extensively.

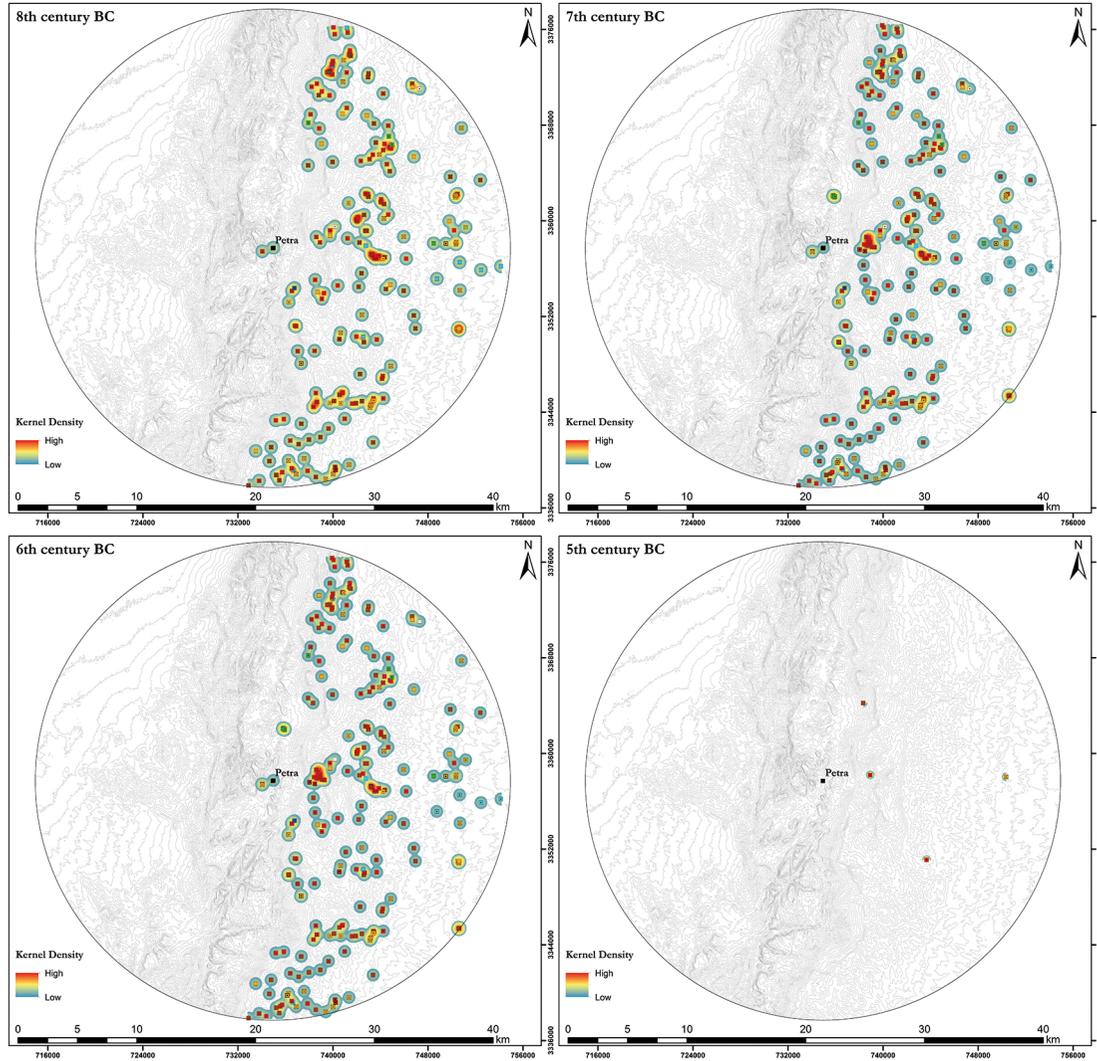
97 Further studies on the archaeological site distributions in the Petra hinterland will be discussed within Kennedy's doctoral research project.

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 - Agricultural Processing Installation
 - Agricultural Storing Installation
 - Agricultural Terrace/Field
- Communication Infrastructure**
 - Caravanserai
 - Road Station
 - Road Marker
 - × Road
 - + Route/Track (naqb)
- Exploitation/ Industrial Site**
 - Industrial/Exploitation Installation
- Funerary and Commemorative Structure**
 - Isolated Funerary Monument
 - Cemetery
- Military Structure**
 - Fortress
 - Fort
 - Fortlet
 - Watchtower
- Religious Structure**
 - Sanctuary
 - Significant Religious/Cultic Structure
 - Isolated Cultic Installation
- Settlement**
 - City
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 - Village
 - Farm
 - Cluster of Building Structures
 - Villa
- Unspecified Structure(s) and/ or Feature(s)**
 - Epigraphical Site or Location
 - × Find Cluster
 - Natural and/ or Rock-cut Structure(s) of Undetermined Function
 - Structure(s) of Undetermined Function
 - Wall(s) of Undetermined Function
- Water Structure**
 - Dam/Barrage
 - Spring
 - Water Conduit
 - Water Storage Installation
 - Well



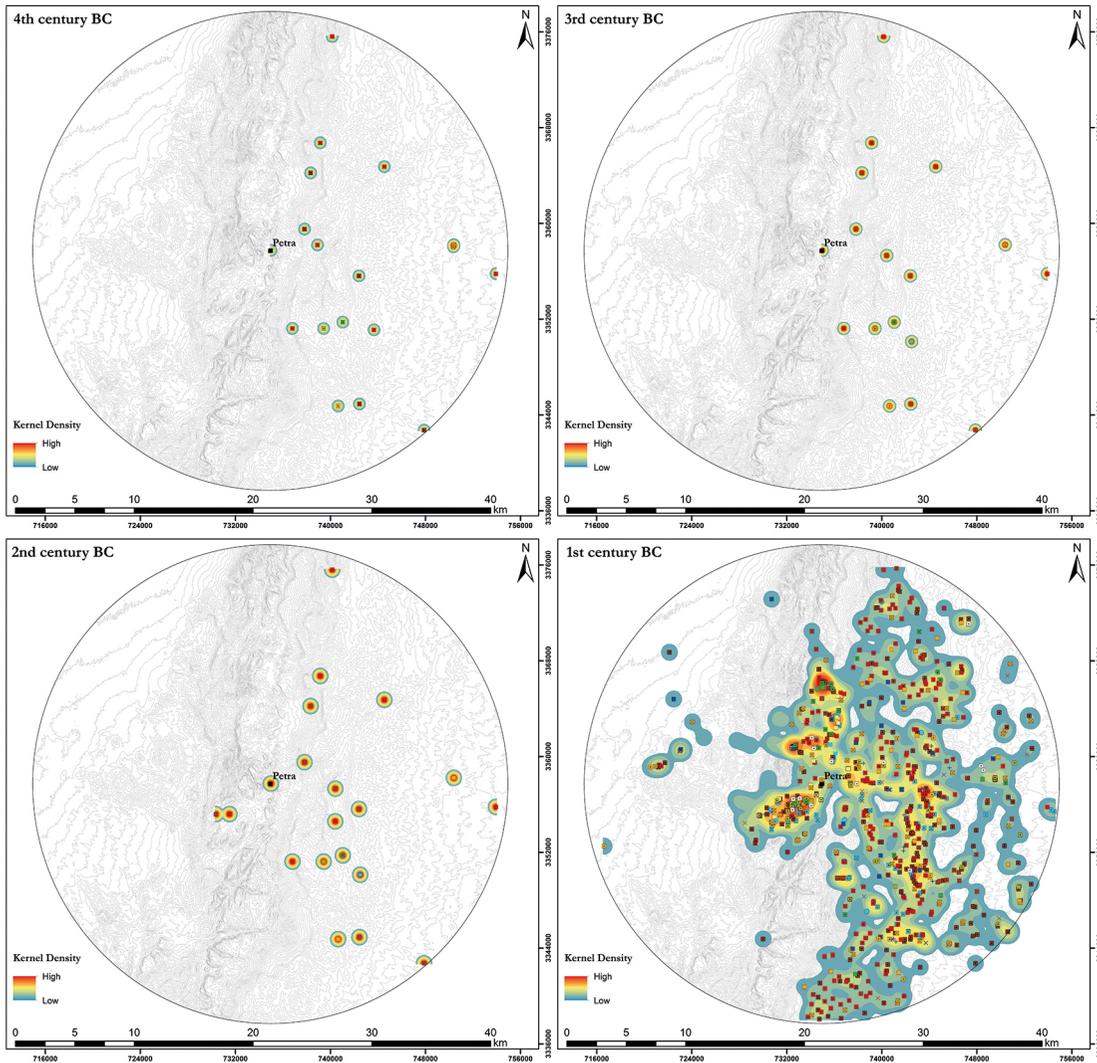
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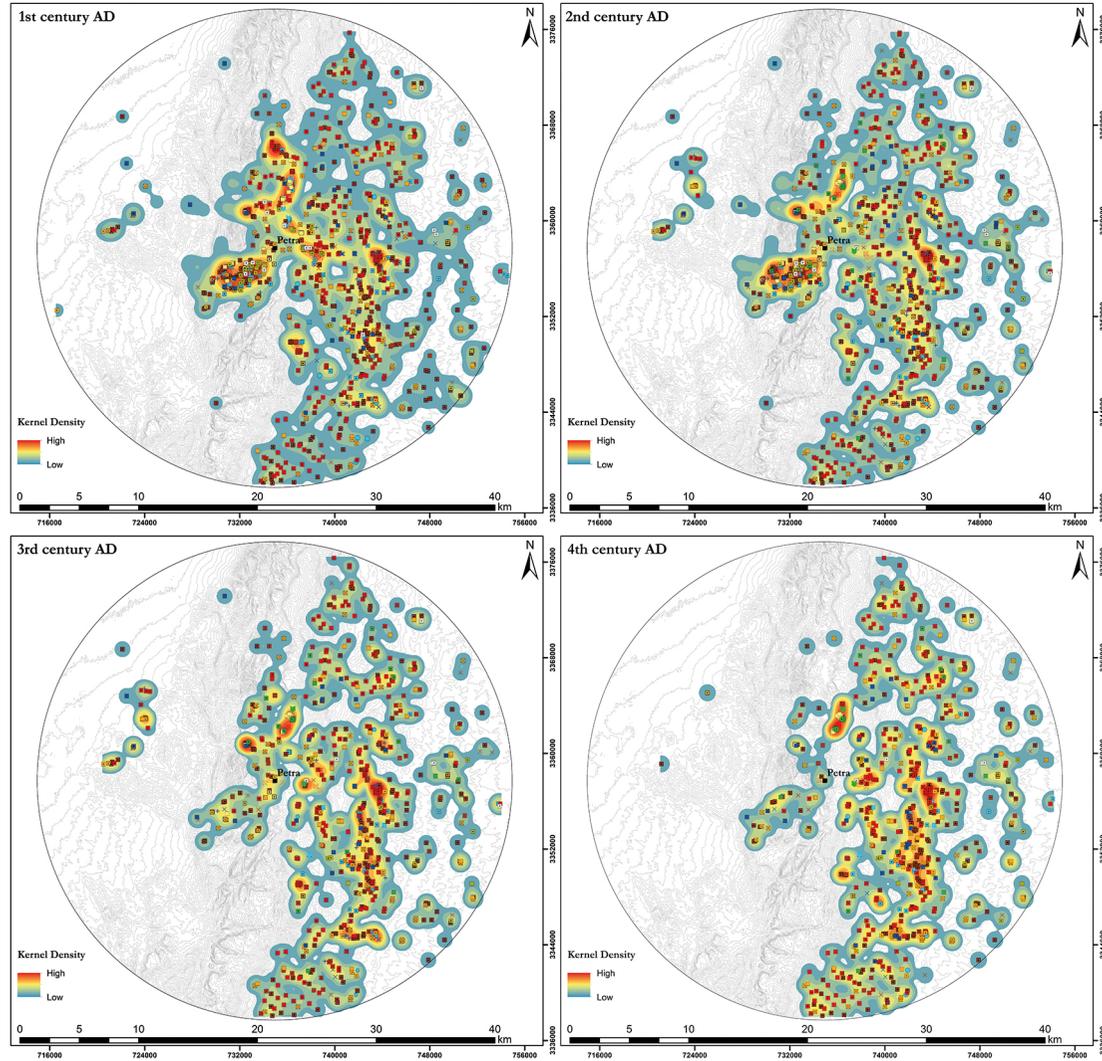
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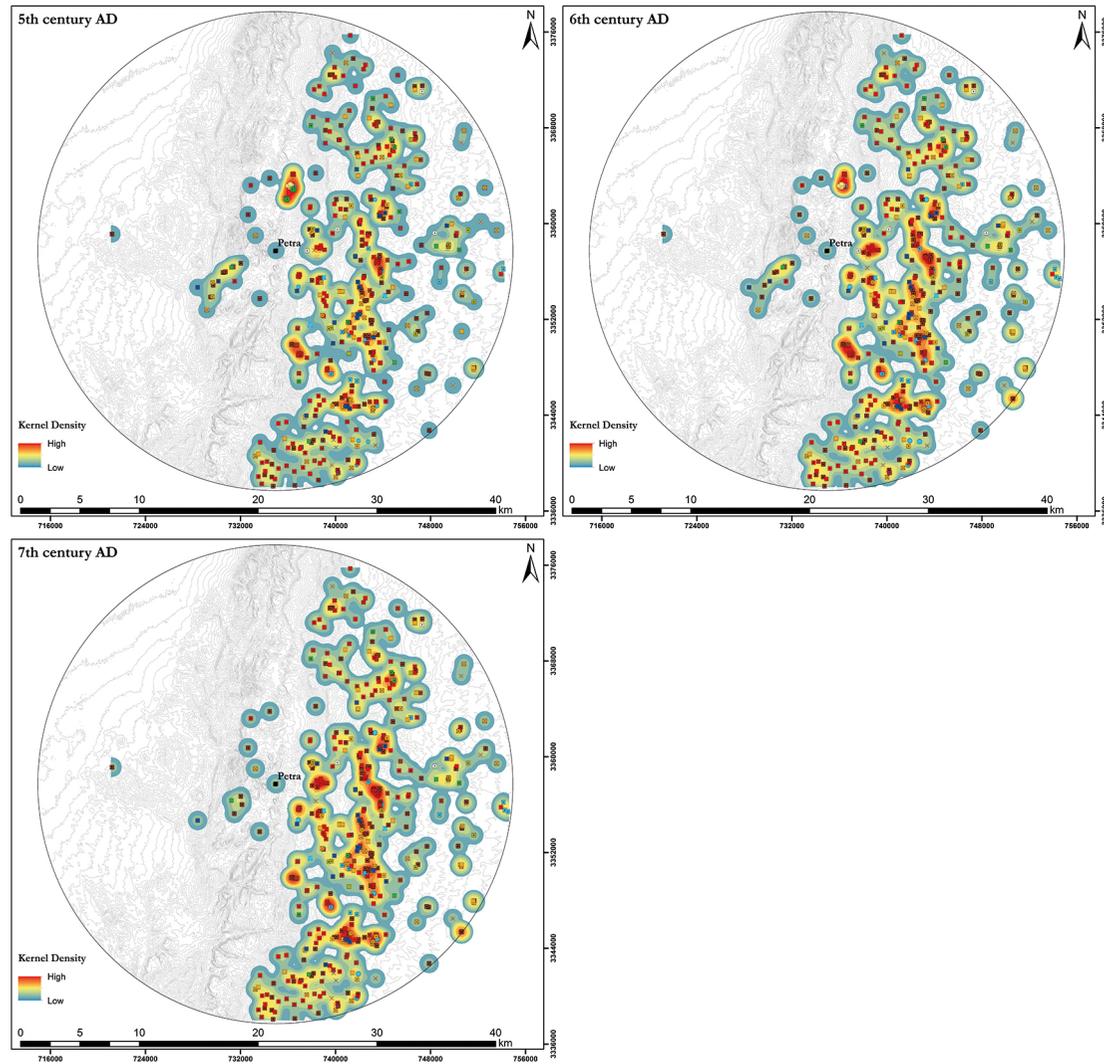


Fig. 10 | Century-based representation of the site distributions within the Petra hinterland laid over a density map based on the calculated dating probabilities.

6.1 Conclusion

This paper discussed the challenges and methodological issues concerning the quantification of chronological uncertainties inherent to the archaeological dataset of rural Petra. The aim of the study was to create a consistently defined database of archaeological sites surveyed within a 20km radius around the city and to establish a quantifiable chronological system respecting the various dating of sites stated in the original survey reports of the region.

The core of the study concerned itself with developing a methodology to allow for the critical incorporation of chronological information provided by the original survey reports. Following Nakoinz' temporal coding method, dating values were assigned to each site for each cultural phase and its respective maximal time span (measured in decades) evidenced by the original surveys. Based on the dating values of the individual sites, it was not only possible to establish the maximal time span of cultural periods evidenced by the original survey data, but also to calculate the dating probability values within their respective time spans. This allowed the creation of probability graphs for the 18 different cultural phases evidenced by the original surveys ranging from the Iron Age to the Byzantine Periods.

Admittedly, this approach involved sorting through and evaluating an extremely large amount of data which is immensely time consuming. This may raise questions about the efficiency of the methodology applied. However, for the first time, decades of original archaeological research were evaluated in terms of site classifications and chronological periodizations and subsequently brought into a secondary, reproducible dataset, which can now be further analyzed.

Based on the very detailed walk-through of the necessary steps to quantify chronological uncertainties, future research on the archaeological potential of the Petraean hinterland can now adopt the methodology and expand on the results presented here. Instead of offering yet another different chronological system which only adds to the problem of chronological uncertainty, this study was able to filter the various chronological inconsistencies within the original surveys and make them transparent for further research. However, this does not mean that the presented probability graphs should be seen uncritically. As exemplified here as well, it is crucial to discuss and evaluate the results and acknowledge their inherent challenges.

The presented probability graphs shall therefore not only be considered as graphic representations of statistical calculations, but more as a visualization of the inconsistent chronological periodization of archaeological sites within the Petra hinterland. The graphs shall not be taken as factually absolute definitions of chronological periods, but as transparent representations of dating (un) certainties.

Finally, based on the dating probabilities of the evidenced cultural periods, different modes of graphic representations of site distribution maps visualizing the dating probabilities of sites were proposed as well. However, it appeared more objective to break free from cultural periodizations and to sort the various survey data by centuries instead. While only very general trends of the spatial pattern of archaeological sites could be explored here, the century-based site density maps of the study area attempted to draw a methodologically more correct picture of the chronological development of rural Petra. Thus, based on this study's quantification of the chronological inconsistencies inherent to the core dataset, the way is now paved to reconstruct a more complex and methodologically coherent settlement model of the Petraean hinterland throughout time.

7 Appendix: R-Script

```
#####
#####
## Quantifying Chronological Inconsistencies of Archaeological Sites in the Petra Area
## - The Nabataean Period (Example) -
## =====
## Author: W.M.Kennedy
## Version: 01
## Date of last changes: Sat 26 Nov 18:41:44 CET 2016
## Data: XLSX-Table of archaeological sites in the Petra area from the Iron Age to
## Byzantine Periods (including fuzzy and Boolean dating values per cultural period
## and their corresponding time spans)
## Author of data: Various surveys in the Petra Hinterland including Abudanh 2006, ARNAS,
## FJHP (Extended and Core Area), JSS, ShamAyl, Smith 2010, WMWS 1996 and 1998 as well as
## PHSP 2016 (compare table 1 in text for bibliographical reference)
## Purpose: Quantification of differing chronological definitions of cultural periods
## by the various surveys

#####
## Packages
#####
##install.packages("xlsx")
##install.packages("sqldf")
##install.packages("tcltk")
##install.packages("ggplot2")
library(xlsx)
library(sqldf)
library(tcltk)
library(ggplot2)

#####
## References
#####
##citation(package="xlsx"):
##Adrian A. Dragulescu (2014). xlsx: Read, write, format Excel 2007 and Excel
##97/2000/XP/2003 files. R package version 0.5.7.
##http://CRAN.R-project.org/package=xlsx

## citation(package="sqldf"):
##G. Grothendieck (2014). sqldf: Perform SQL Selects on R Data Frames. R package
##version 0.4-10. http://CRAN.R-project.org/package=sqldf

##citation(package="tcltk"):
##R Core Team (2015). R: A language and environment for statistical computing. R
##Foundation for Statistical Computing, Vienna, Austria. URL
##https://www.R-project.org/.

##citation(package="ggplot2"):
##H. Wickham. ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York,
##2009.

#####
## Working Directory
#####
setwd("Y:/directory")

#####
## Read Base Data (XLSX-table as stated above)
#####
library(xlsx)
df<- read.xlsx("table of all archaeological sites.xlsx", 1)

#####
## Extracting Single Cultural Periods and Respective Max. Time Spans (Century-based)
#####
##Example: The Nabataean Period:

S_N<- data.frame(sqldf('select * from df where "100 BC" > 0 or "100 AD" > 0 or
"200 AD" > 0 or
"300 AD" > 0 or "400 AD" > 0')) ## NOTE:"100 BC" etc.
## refer to 1. century BC etc.

## write xlsx table for Nabataean Period only:
write.xlsx(S_N, "./directory/table of Nabataean period.xlsx", sheetName = "Sheet1")

#####
## Summing All Fuzzy and Boolean Dating Values Per Cultural Period
## And Their Max. Time Spans
#####
N_dating<- cbind(length(df$N[df$N>0]),
sum(N[,42]), sum(N[,43]), sum(N[,44]), sum(N[,45]),
sum(N[,46]), sum(N[,47]))
colnames(N_dating)<- c("N Sites", "200 BC", "100 BC", "100 AD", "200 AD",
"300 AD", "400 AD")

## write table with Summed Dating Values for the Nabataean Period:
```

```

write.xlsx(N_dating, "./directory/SumDv_N.xlsx", sheetName = "Sheet1")

##=====
## Express as percentage by multiplying SumDv values with "pdec":

p<- 0.1366120218579235 ## = 1 percent value of all Nabataean sites
pdec<- p/100 ##divided by 100 for expression in decimal numbers

## save as new table "N_prob.xlsx"

#####
## Plotting Dating Graphs
#####
N<-read.xlsx("N_prob.xlsx", 1)

Nplot<- ggplot(N, aes(x=Decade, y= Probability, group= 1))+
  geom_line(colour= "black", size=1)+
  geom_ribbon(aes(ymin=0, ymax=Probability), alpha=0.4)+
  scale_x_discrete(limits= c("200 BC","190 BC","180 BC","170 BC","160 BC","150 BC",
                             "140 BC","130 BC","120 BC","110 BC","100 BC","90 BC",
                             "80 BC","70 BC","60 BC","50 BC","40 BC","30 BC","20 BC",
                             "10 BC","0","10 AD","20 AD","30 AD","40 AD","50 AD", "60 AD",
                             "70 AD", "80 AD","90 AD","100 AD","110 AD","120 AD",
                             "130 AD", "140 AD","150 AD","160 AD","170 AD","180 AD",
                             "190 AD","200 AD","210 AD","220 AD","230 AD", "240 AD",
                             "250 AD","260 AD", "270 AD","280 AD","290 AD","300 AD",
                             "310 AD", "320 AD"))+

  geom_vline(xintercept = which(N$Decade == "100 BC"), linetype = "longdash", size = 1)+
  geom_vline(xintercept = which(N$Decade == "110 AD"), linetype = "longdash", size = 1)+

  scale_y_discrete(limits= c(0, 0.25,0.5,0.75,1))+ ylim(0,1)+
  labs(x= "Decades", y="Probability", title= "Nabataean", size= 14 )+
  theme(text= element_text(size=25))+
  theme(axis.text.x = element_text(size = 20, angle = -90, hjust = 1))

ggsave(filename="./directory/Dating Graph_Nabataean Period.tiff", width=30, height=10,
        dpi = 800)

```

Illustration and table credits

FIGURES: 1–10 Will Kennedy. **TABLES:** 1 Will Kennedy and Felix Hahn. 2–3 Will Kennedy.

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