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Transforming Technical Know-how in Time and Space. Using the Digital Atlas of Innovations to Understand the Innovation Process of Animal Traction and the Wheel

Communicated by Jürgen Renn

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Transforming Technical Know-how in Time and Space. Using the Digital Atlas of Innovations to Understand the Innovation Process of Animal Traction and the Wheel

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The paper uses a new research tool, the *Digital Atlas of Innovations* to re-think the invention and diffusion of wheeled vehicles in Eurasia during the 4th and 3rd millennium BC. It is argued that the diffusion of wheeled vehicles is the result of the local transformation of several technical components which have been known since the Pottery Neolithic. The technical knowledge to combine these components was widely spread and resulted in experimentation with the use of animal traction already in the late 6th millennium. It were, however, the significantly better connected networks which were established during the early 4th millennium, which enabled the innovation-diffusion of the wheel from its presumed zone of origin in the Black Sea area to the Baltic. The same technology (minus the wheels) is also adopted in many other regions, where it is transformed according to local specifications (ploughs, sleds).

Technical innovation; diffusion of innovations; Neolithic; Bronze Age; wheel and wagon; ploughing; cattle traction.

Der Aufsatz untersucht die Verbreitung von Räderfahrzeugen während des 4. und 3. Jahrtausends mit einem neuen wissenschaftlichen Werkzeug, dem *Digital Atlas of Innovations*. Es wird argumentiert, dass die Diffusion von Rad und Wagen das Resultat der lokalen Transformation technischer Komponenten ist, die mindestens seit dem keramischen Neolithikum bekannt waren. Das technische Wissen, diese Komponenten zu kombinieren, war weit verbreitet und resultierte in Experimenten mit tierischer Zugkraft bereits im späten 6. Jahrtausend. Jedoch erlaubten erst die signifikant dichteren Netzwerke, die mit dem frühen 4. Jahrtausend beginnen, die schnelle Diffusion des Rades aus seiner angenommenen Ursprungszone im Schwarzmeerraum bis zur Ostsee. Dieselbe Technologie (ohne Räder) wird auch in anderen Regionen adaptiert und anhand lokaler Spezifikationen transformiert, zum Beispiel in den Pflug oder Schlitten.

Technische Innovation; Diffusion von Innovationen; Neolithikum; Bronzezeit; Rad und Wagen; Pflug; tierische Zugkraft.

1 Introduction

Maps have become a central part of modern information economies. While the illustrative appeal of traditional maps is widely acknowledged, new digital maps based on extensive and dynamic databases[1] also offer new prospects for science.

1 Cf., for instance, the database *The Counted: People Killed by Police in the US*, which allows users to visualize discrimination in law enforcement (https://www.theguardian.com/us-news/ng-interactive/2015/jun/01/the-counted-police-killings-us-database, visited on 17/02/2017).

Within the Excellence Cluster Topoi, area D6 is working on the Digital Atlas of Innovations (Fig. 1).[2] The Digital Atlas of Innovations is a new research tool that can map repartitions of artifact types, styles, and techniques. The Atlas also includes a research program where the results of scientific discussions are turned into interactive and interoperable maps, which in themselves are a tool to ask new questions.[3] The maps not only allow for an enhanced visualization of scientific problems, but also offer a novel heuristic approach that enables researchers to reconceptualize these problems and work on new solutions. This paper will demonstrate the use of the Digital Atlas of Innovations by studying the development of wheeled vehicles in the 4th and 3rd millennium BC.

2 Early wagons as an example of paradigmatic shifts in prehistory

Traditional narratives of prehistory were based on diffusionist paradigms heavily influenced by Gabriel Tarde,[4] who was himself influenced by the archaeological debate of his time. In the works of Oscar Montelius, Sophus Müller, V. Gordon Childe, and others, change was the result of the successive adaption of innovations that had originated in a core area, in the surrounding peripheries.[5]

The chain-dating of objects from these 'peripheries' via typological analogies with sites dated by written sources, however, was easily vulnerable to errors: historical chronologies in the Near East and Egypt began around 3000 BC, such that wrong dates for older cultures were an inherent consequence of the dating system. Most regions outside the Near East lacked sites with multiple layers deposited upon each other (so-called tell settlements) and thus a control of the proposed chronology by stratigraphical means was impossible. Therefore the result of the analysis (diffusion) was also its methodological means, and this could easily lead to circular logic.

With the advent of large-scale radiocarbon records, the traditional diffusionistic relationships between Central Europe and Western Asia have become significantly more difficult to uphold.[6] Chronology was liberated from typological chain-dating, and this resulted in earlier dates for key technologies in the periphery. Since then, narratives about the European Neolithic often stress the cultural autochthony[7] or the possibility[8] of an evolution independent from the Orient. The discussion of early wagons closely follows this rough outline: whereas older models were based on an *ex oriente* perspective,[9] the radiocarbon revolution has caused a dramatic reevaluation of the known evidence, which has resulted in a lively and controversial discussion on the date and place of the origin of wheeled vehicles.[10]

2 For more details concerning research group D-6, cf. https://www.topoi.org/group/d-6/ (visited on 17/02/2017). Data entry for this study was assisted by Luisa Gerlach, B.A., Kyra Gospodar, B.A. and Friederike Jürke, B.A.

3 E.g. http://www.topoi.org/event/26293; http://www.topoi.org/event/26387; http://www.topoi.org/event/31052; https://www.topoi.org/event/33098/ (all visited on 17/02/2017).

4 Tarde 2008. Cf. also: Kinnunen 1996.

5 S. Müller 1897, 47–48; S. Müller 1905, 17–20.

6 Renfrew 1969; Renfrew 1973.

7 E.g. Todorova 1981; Radivojević and Rehren 2016.

8 E.g. Burmeister 2004b.

9 E.g. Childe 1951; Childe 1954; Sherratt 1981; Sherratt 1983; Sherratt 1986.

10 Bakker et al. 1999; Bakker 2004; Benecke 2004; Burmeister 2004b; Burmeister 2012; Boroffka 2004; Burmeister and Raulwing 2012; Fansa and Burmeister 2004; Köninger 2002; Maran 2004; J. Müller 2004; Sherratt 1996; Sherratt 2004; Vosteen 1996a; Vosteen 1996b; Vosteen 1999b; Vosteen 1999a; Vosteen 2001; Vosteen 2002.

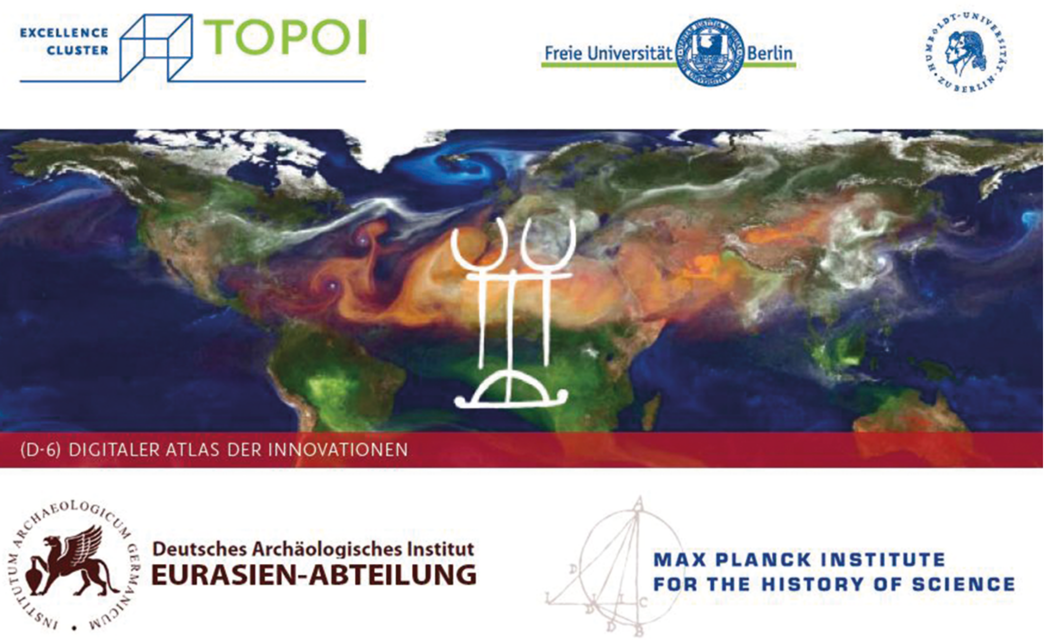

Fig. 1 | Logo of the Research Program *Digital Atlas of Innovations*, a Cooperation of the Eurasia Department of the German Archaeological Institute and the Max Planck Institute for the History of Science within the Excellence-Cluster Topoi, Area D6.

The wheel is considered one of the most important technical innovations in prehistory. The traditional model was invented in the Near East. From there, it was thought to have been transmitted to Europe during the 3rd millennium.[11] New discoveries and new radiocarbon dates of known finds have changed this picture dramatically. The current understanding of the distribution of wheeled vehicles between 3500 and 3000 BC spans the area from the North Sea to the Euphrates, and dating difficulties have made it impossible to determine the oldest evidence of wheeled vehicles.[12]

Some recent developments have changed the picture even more from the traditional model. High-precision dating of the megalithic grave of Flintbek LA3 in northern Germany corrected the age of the wagon traces under the grave slightly, to 3460–3385 BC,[13] while the earliest Near Eastern evidence has been considerably altered. Not only have the depictions on the tablets from Uruk been challenged as to whether they actually depict wagons,[14] but this view has also been strengthened by the new data from the ARCANE project, which makes clear that the earliest models of wheels did not appear until around 3100 BC.[15] That, in turn, would make the invention of wheeled vehicles in Mesopotamia less probable.

Nevertheless, it seems rash to conclude an autochthonous evolution of wheeled vehicles in northern Germany from this new evidence. Not only is the chronological dis-

11 Piggott 1992.
12 Burmeister 2004a; Burmeister 2011; Burmeister 2012.
13 Mischka 2011; cf. also Zich 1992.
14 Bernbeck 2004, footnote 8. Cf. also J. Crouwel 2004, 69.
15 Pruß 2011, 244, states that the "earliest undisputable wheels are attested at the EJZ 0/1 transition". Ristvet 2011 shows that EJZ 1 (Early Jezirah 1) would not start before 3350 calBC, while Lebeau in his summary of the evidence advocates a starting date of 3100 BC for EJZ 0 (Lebeau 2011).

cussion far from finished,[16] but it is also misleading and anachronistic to see 'Europe' and 'the Orient' as closed units inside which intercultural contacts are taken for granted, even as connections between both regions are usually doubted. Such a perspective needs to take into account the radically different state of research, for instance in Anatolia, Syria-Mesopotamia and Iran, as well as the cultural filters, region-specific adaptations, and local technical traditions. The results from prehistoric excavations in Upper Mesopotamia highlight that the time span in question is still largely unknown.[17] As a consequence, most scholars still agree that either a very quick diffusion or a stimulus diffusion remain better explanations.[18]

3 Defining the data set: Wheeled Vehicles vs. Animal Traction

The following text is based on the data set *Evidence for Animal Traction*, with the last update on 24 April 2015. The collection of this data set and the idea of mapping it came out of extensive discussion and classification.[19]

The available evidence of early wheeled vehicles cannot be summed up easily within the typological repertoire used to deal with archaeological finds, and consequently the archaeological discourse is often blurred by the mixing of several groups of finds, different categories of evidence, and debatable interpretations on the same level.

Evidence of early wagons might come from areas as diverse as wagon graves, pictographs on clay tablets, depictions on rock art, miniature discs interpreted as wheels, wagon-shaped drinking vessels, archaeological features thought to be track-marks of wagons, i.e. the preserved imprints created by the wheels of a wagon that was driving over soil, etc. This already very heterogeneous body of evidence is complemented by indirect proofs that modern interpreters think might be related to the wagon. The depiction of two cattle under a yoke,[20] double cattle-burials,[21] roads constructed to be wide enough to allow wagons to drive on them,[22] and even spindle whorls[23] have been brought forward in this respect.

With very few exceptions, there are no complete prehistoric wagons, with the archaeological record preserving only parts of the wagon or the draft animals in a variety of archaeological sources. The pieces of evidence themselves are often not very clear either. They may be shortened or stylistically abstracted, as well as damaged, incomplete, or badly preserved, and their interpretations may vary significantly as a consequence: in the Central European scientific discourse, depictions of two cattle under a yoke are often interpreted

16 Nevertheless, Pruß also acknowledges the value of the Uruk evidence as earlier (Pruß 2011, 244), and the recent reevaluation of the southern Levantine chronology suggests that the problem might be much more difficult, e.g., Lebeau's linking of EJZ 0 with the beginning of the Early Bronze Age II in Palestine (i.e., around 3100–2900 BC, cf. Regev, Miroschedji, Greenberg, et al. 2012); Regev, Miroschedji, and Boaretto 2012).

17 Oates et al. 2007.

18 Cf., inter alia, Burmeister 2004b; Bakker et al. 1999.

19 Two preliminary studies were presented at the yearly meeting of the *AG Neolithikum* in September 2013 in Lübeck (cf. Link, Pyzel, and Perschke (in press), 195) and the international conference *Contextualising Prehistoric Innovations* in November 2014 in Berlin. The respective papers are in preparation (Florian Klimscha: Äxte und Allianzen. Diffusionsprozesse und autochthone Entwicklungen im Europa des 4. Jahrtausends. *Fokus Jungsteinzeit* 6, ed. by R. Peerschke and J. Pyzel, forthcoming; Florian Klimscha: The diffusion of Know-how within spheres of interaction: Appropriating Innovations, ed. by J. Maran and P. Stockhammer, forthcoming).

20 Hansen 2014, 404–405.

21 Johannsen and Laursen 2010.

22 Burmeister 2002.

23 Schlichterle 2002; Schlichterle 2004.

as evidence of wagons,[24] whereas similar evidence is seen as a *pars pro toto* for plowing in Near Eastern archaeology.[25]

The ambiguity of the data, however, also stems from the technology itself. Wagons consist of a pair of cattle, a chassis, and wheels on an axle. It was not necessary to use all components of this package simultaneously all the time, but single components could be isolated for different tasks; for instance, the cattle pair was also able to pull a plow or heavy objects. Because of the blurry nature of the archaeological record, it is possible that evidence of such 'secondary' tasks might have been preserved without any evidence of the 'complete' wagon.

Previous analyses have also failed to cope with that complexity by only focusing on the wheeled vehicles themselves, ignoring their modular character: Wagons consist of several components developed and working independently from one another: wheels on an axle, a wooden chassis, and two animals trained to pull the vehicle. Components of this system can be extracted and reinvented (or 'developed') in different social and technical contexts. Yet these components may still be reintroduced into the technical system thereafter, or even a reinvented version thereof. This paper takes the most complicated module from the technical system 'wagon' to understand it, namely the pair of cattle trained to move at the same pace. The necessary woodworking skills and extensive knowledge of rotary motion[26] can be assumed to have been present since the Pottery Neolithic, but while domestic cattle were also widely known from the Neolithic onwards, their use for pulling vehicles or plows is not clear.[27]

I will argue, therefore, that it is the development of cattle traction that is decisive for the start of the innovation process. Toward this end, a data set comprising many types of evidence for the existence of cattle traction has been compiled (with the assumption that wheels in any case require animals to pull them).

The data set consists of 4,914 finds of more or less significant evidence for the use of traction that are described and classified in several categories. This includes wheeled vehicles or parts thereof, wagon figurines and miniature wheels, wheeled drinking cups, cattle burials, depictions of cattle pairs, depictions of wagons, drivable roads (i.e., with a width of more than 200 centimeters), unwheeled vehicles (like sleds and travois), plows, plow marks and tread marks, yokes, and evidence of pathological deformations on skeletons of cattle caused by heavy labor and surcharge of the bones. Only finds securely dated to the 3rd millennium or earlier are analyzed here, ignoring the large group of petroglyphs from Eurasia that have been very difficult to date.[28]

The finds were described in several categories, including general geographical and descriptive attributes (like length, width, material, registration number, etc.), as well as the dating method; the archaeological context (grave, hoard, settlement, single find, etc.); the type of evidence (real-life objects, pictures, models, imitations/skeuomorphs, archaeological features, skeletal evidence, and textual evidence); the number, diameter, thickness and type of the wheels; the gauge of the wheels; and the number and type of draft animals. Additionally, the finds were loosely grouped together according to their evidential and archaeological quality (bone deformation, cattle burial, drivable road, wagon figurine, miniature wheel, pictograph, plane surface art depicting a wagon, plastic pottery decoration, plow marks, pottery decoration, seal depiction, siege equipment, unwheeled vehicles, wagon or wagon part, wheeled animal figurine, wheeled ceramic vessel, wheel tread

24 E.g. Matuschik 2002; Bakker 2004, 284.

25 E.g. Dayagi-Mendels and Rozenberg 2010, 39.

26 For instance, the drilled perforations on axes (Brandt 1967, 14–19) and use of spindle-whorls (Grömer, Hofmann-de Keijzer, and Rösel-Mautendorfer 2016).

27 Benecke 2004; Boroffka 2004.

28 Novozhenov 2012.

marks, and yoke). The dating of the finds was discussed for every item individually, with radiocarbon dating taking priority over nonscientific dates. For the finds from western Asia, the ARCANE chronology[29] was used. It should be mentioned that this paper will not discuss every characteristic of this database in detail; instead, some features will be selected that are thought to be relevant for the scientific discourse.

4 Using an intellectual atlas to understand prehistoric wagons

The Digital Atlas of Innovations includes software that is able to plot queries from an attached archaeological database on a map and thereby calculate the rate of adoption and present it as a histogram. The time span, the geographical area, and the units of the histogram can all be freely defined and presented as pie charts with the user-defined criteria from the database. All elements are interconnected and thereby allow the diffusion processes to be analyzed in real time and the underlying data to be critically challenged.

While maps are frequently used to depict research results in archaeology, the Digital Atlas of Innovations allows archaeological maps to be deployed as heuristic tools to apprehend the diffusion of artifacts, knowledge, or social phenomena through time and space.

In this paper, I will demonstrate how a large set of nonuniform data can be tackled using the Digital Atlas of Innovations. My initial aim is to demonstrate the specifications of the data and make a meaningful selection for the question of the emergence of the wagon and its diffusion.

5 Evidence of early wagons in Eurasia

As a first step, all available data is selected and plotted. This makes a very broad perspective necessary involving Eurasia and North Africa. A first general overview of the mapped data, i.e., all finds relating to cattle traction until the end of the 3rd millennium, highlights several major concentrations: one huge cluster on the Indian subcontinent, another two large clusters in the Near East and Scandinavia, and smaller concentrations around the Black Sea region and in central Europe (Fig. 2).

It is striking that huge blank areas still appear on the map. Animal traction was not used in western Europe, Greece, northern Scandinavia, or North Africa – with the exception of Egypt and large parts of Eurasia – for as long as 1,500 years after the first appearance of the wagon.

The evidence is not divided evenly over all find groups, but the majority (ca. 71.3 percent) of finds are wagon figurines and miniature wheels, while only 14.5 percent belong to real-life wagons and cattle burials. The models and miniatures of wagons primarily derive from settlements; their main centers are Upper Mesopotamia and the northwestern part of the Indian subcontinent, with a number of scattered finds through central Europe. The majority of these finds date to relatively late within the sequence of early evidence for wagons (ca. 2600–1800 BC) (Fig. 3). Real-life evidence, on the other hand, is mostly found in graves and has its peak from 3300 to 2500 BC, with a strong concentration around the Black Sea (Fig. 4).

The interactivity of the Digital Atlas provides further decoding of the picture. The huge amount of figurines can be identified as mainly belonging to the Harappa culture, dating to ca. 2600–1800 BC. The social innovation of making small model carts is therefore responsible for the significant concentration in India and Pakistan, but not

29 http://www.arcane.uni-tuebingen.de/database/ (visited on 17/02/2017).

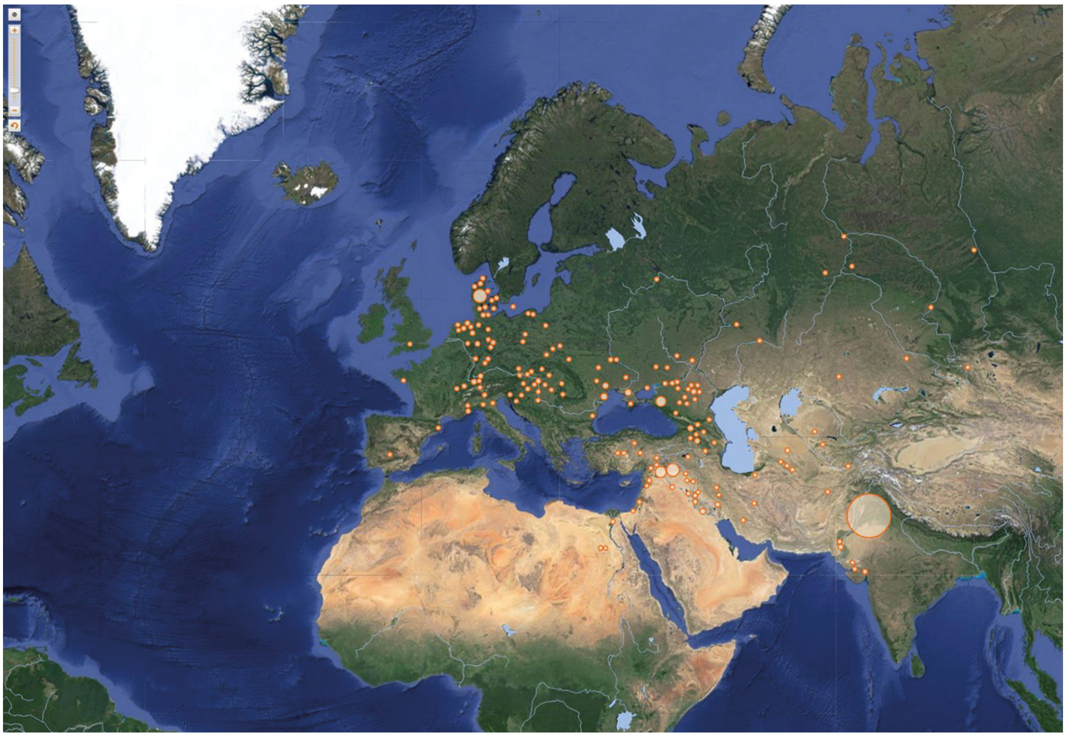

Fig. 2 | Repartition of evidence for the use of animal traction before 2000 BC.

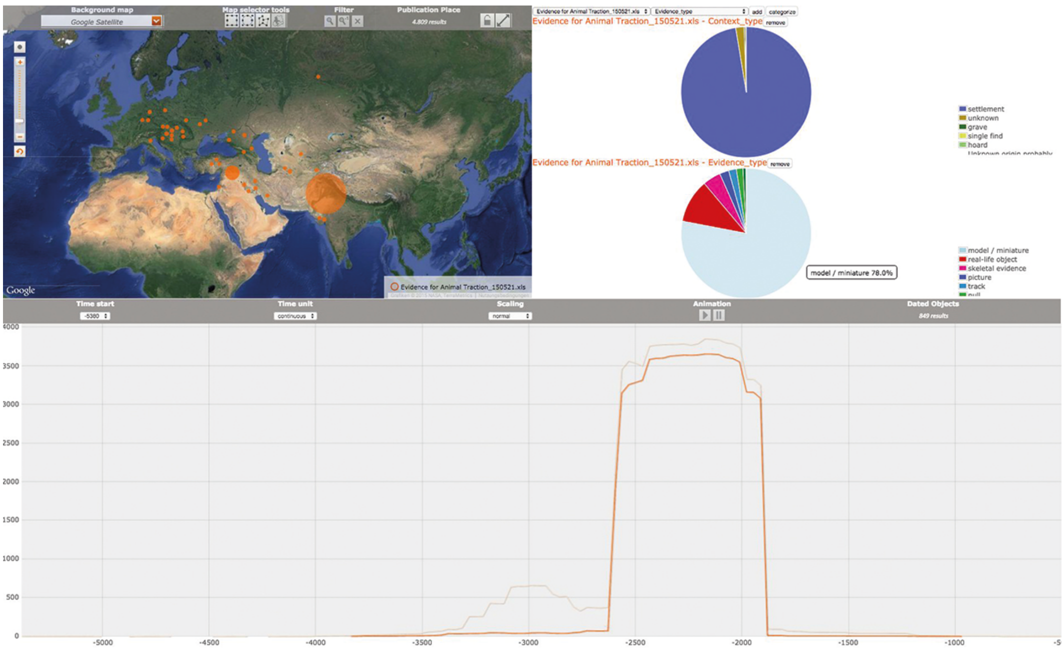

Fig. 3 | Repartition and adoption rate of 'models and miniatures' giving evidence for animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

necessarily for a similar more intensive use of real-life wagons (see Fig. 3). Selecting the finds from Harappa itself demonstrates that the over 3,000 finds from this site alone are also responsible for the peak in the dating frequency of the figurines in general (Fig. 5).

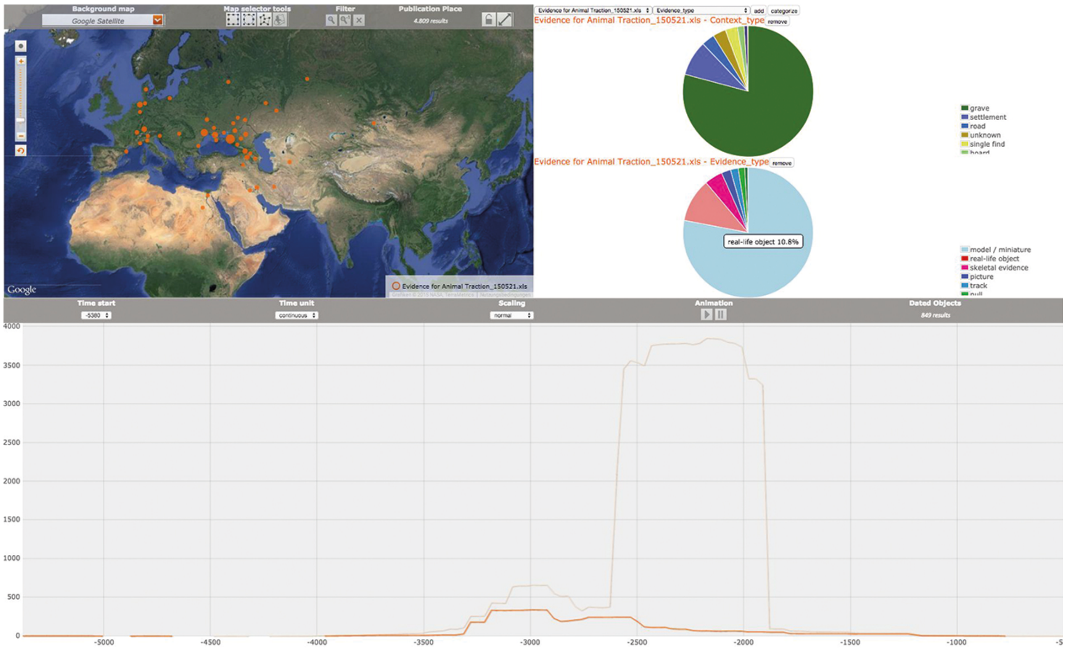

Fig. 4 | Repartition and absolute adoption rate of 'real-life evidence' for animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

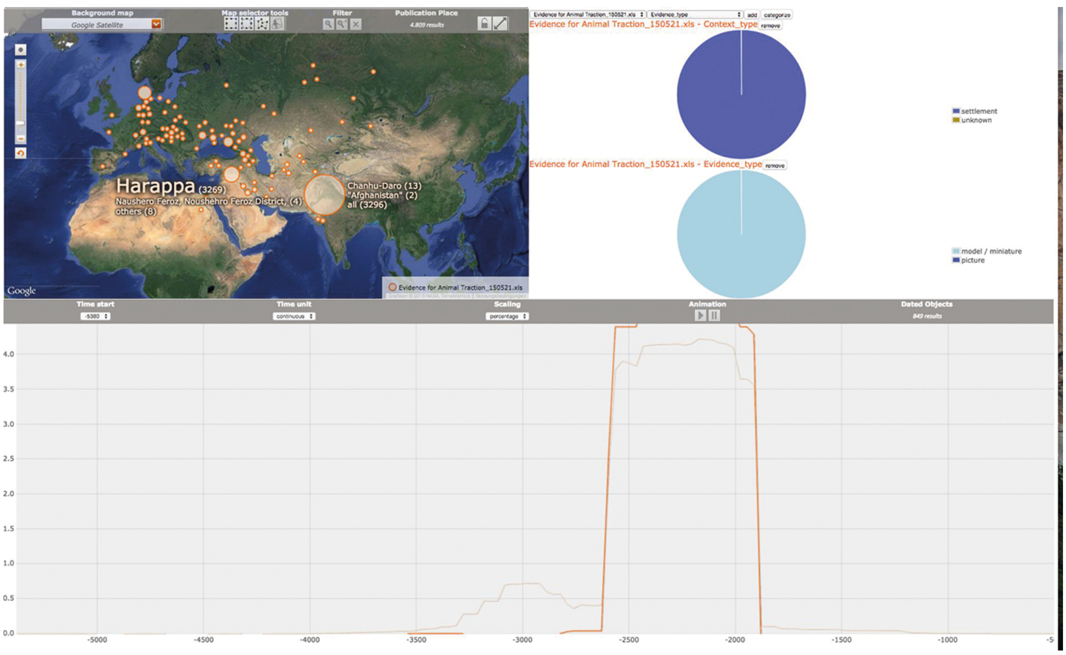

Fig. 5 | Evidence for animal traction from the 4th, 3rd and early 2nd millennium at Harappa (query from the Digital Atlas of Innovations).

In the same way, wagons or parts thereof form a heavy concentration in the area north of the Black Sea, and the main source of cattle burials can be identified as southern Scandinavia, where a large group of barrow graves (so-called stone-heap graves) are commonly interpreted as cattle burials (Fig. 6).

While there is some slight overlapping of these three find groups, there is not only a different chronological sequence, but also a surprisingly regional consistency visible, both

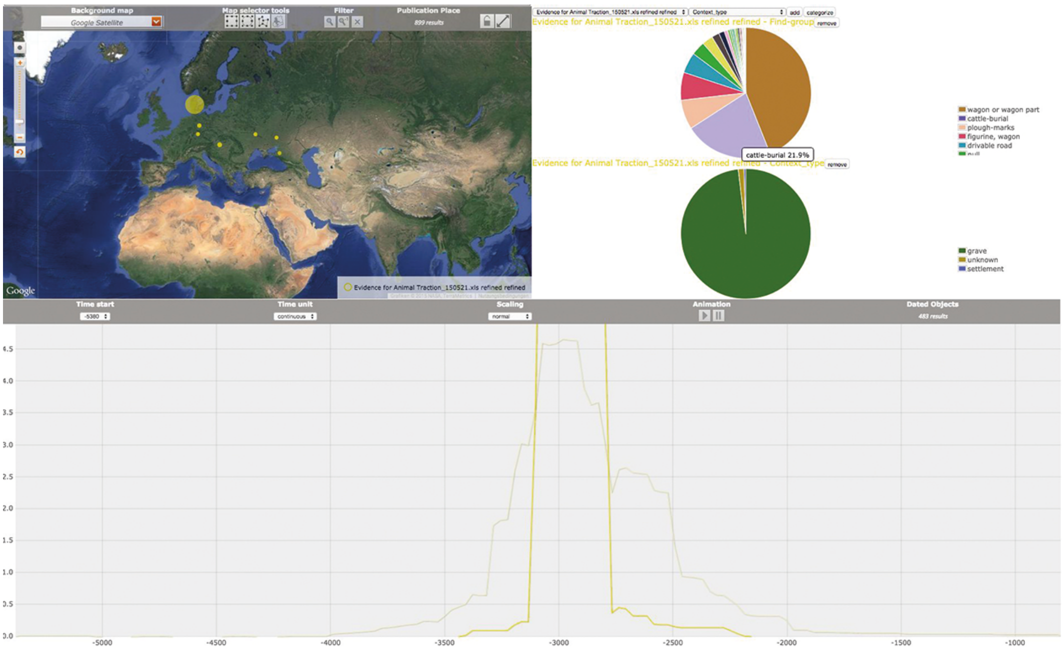

Fig. 6 | Repartition and dating of cattle burials during the 4th and 3rd millennium (query from the Digital Atlas of Innovations).

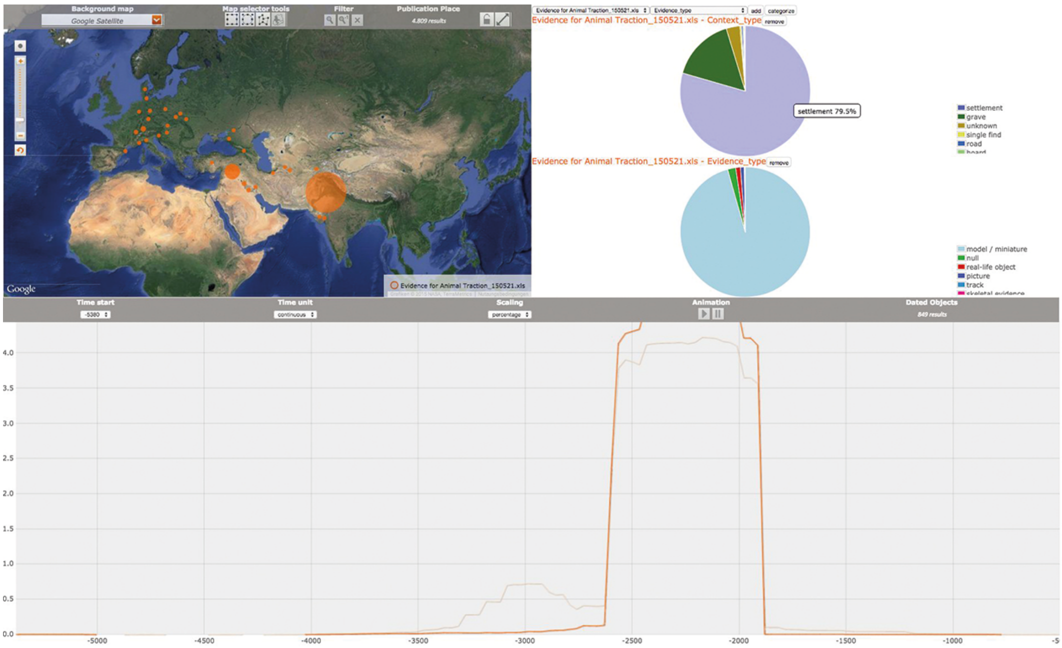

Fig. 7 | Repartition and relative adoption rate of evidence for animal traction found in settlements in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

of which call for further exploration. Therefore, the same data set will now be mapped according to the archaeological contexts and evidence types.

The vast majority of finds come from settlements (79.4 percent), mostly from the aforementioned three distinct centers of wagon figurines (Harappa, Upper Mesopotamia, and central Europe) (Fig. 7).

A smaller amount were placed in graves (15.8 percent), with concentrations in northern Germany, the Low Countries, and Jutland on the one hand, and the northern and

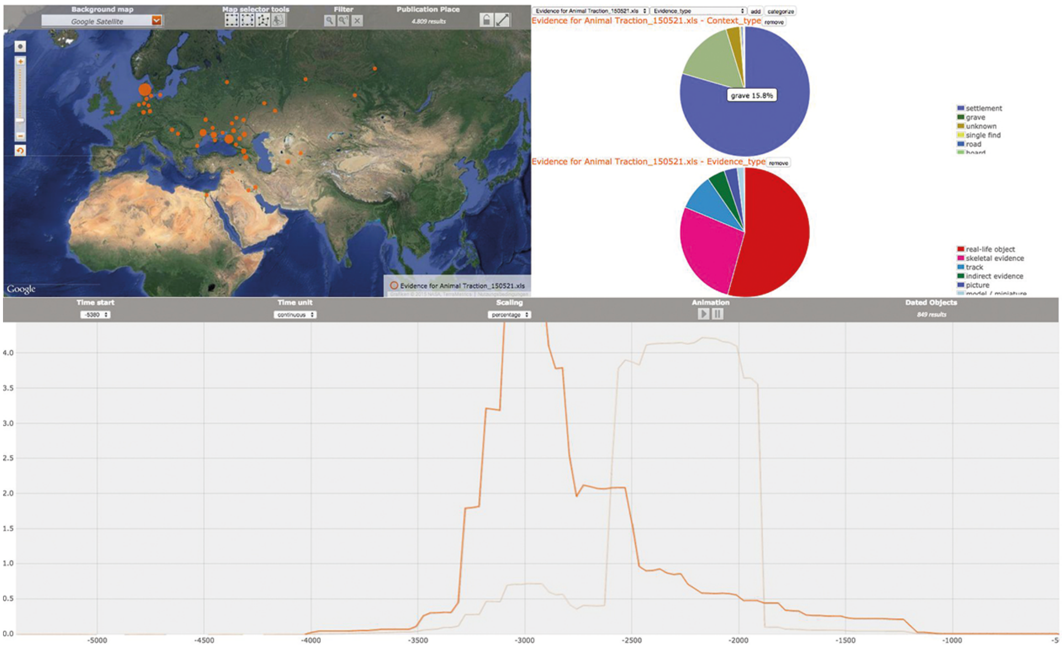

Fig. 8 | Repartition and relative adoption rate of evidence for animal traction found in graves in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

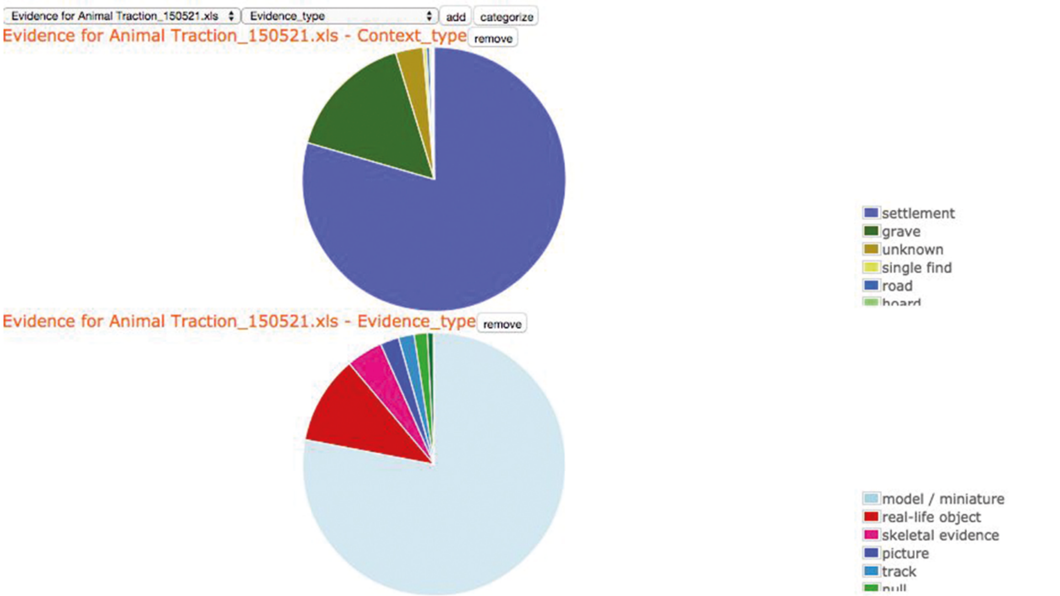

Fig. 9 | Contexts and Evidence types of evidence for animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

eastern Black Sea area on the other (Fig. 8). Unknown sources accounted for 3.4 percent, while the rest were either found as single finds, near prehistoric roads, or in a scant few hoards (Fig. 9). It is striking that the evidence from graves is significantly older than that from settlements, beginning as early as 3500 BC.

While the wagon-model group is almost completely responsible for all the settlement finds (97.4 percent) – again with a high concentration in the Harappa culture (see Fig. 3) – the real-life wagons are strangely absent in exactly that region. An explanation for this can be seen in the high correlation between graves and real-life objects: 79.2 percent of

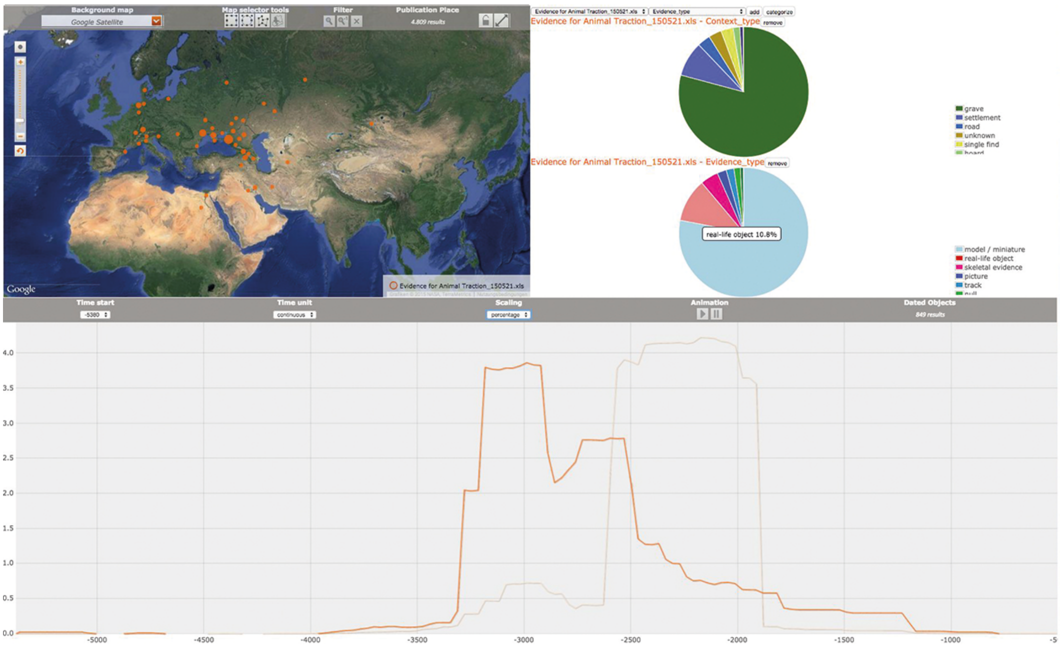

Fig. 10 | Repartition and relative adoption of real-life evidence for animal traction found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

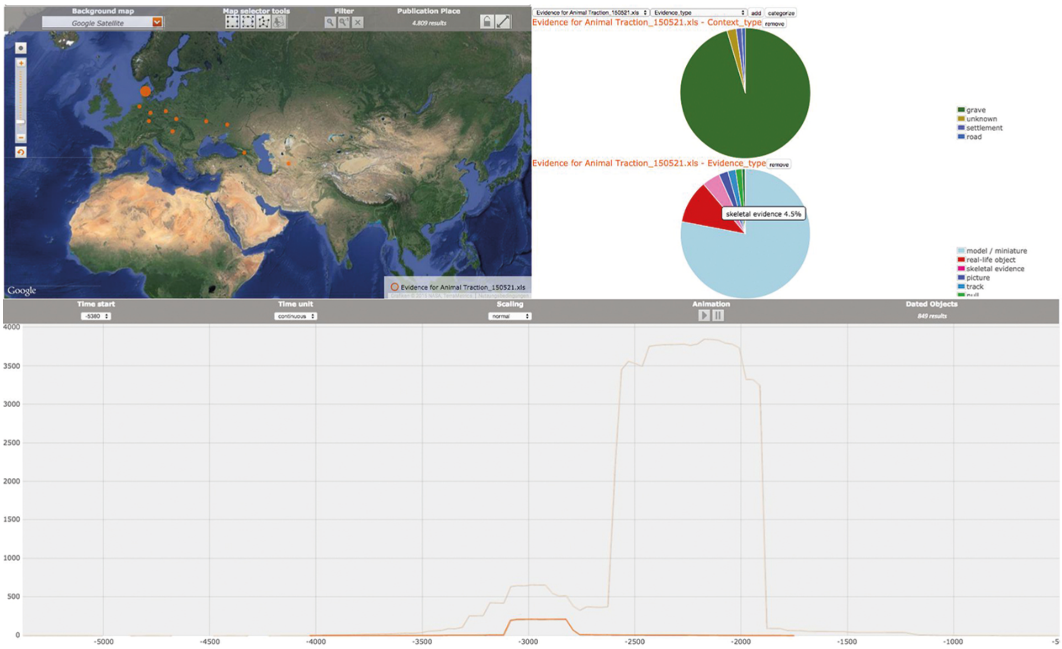

Fig. 11 | Repartition and absolute adoption of skeletal evidence for animal traction found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

real-life wagon evidence was found in funerary contexts, and this, in turn, corresponds with the aforementioned concentrations of finds in the Pontic area and on the Cimbrian Peninsula (Fig. 10).

The skeletal evidence (4.5 percent) is also mainly distributed in the latter region and derives from graves (Fig. 11), which correlates mostly with cattle burials, since it is difficult to identify single bones from settlement layers as being from cattle used for traction. The low number of skeletal evidence finds in comparison to the other groups, however,

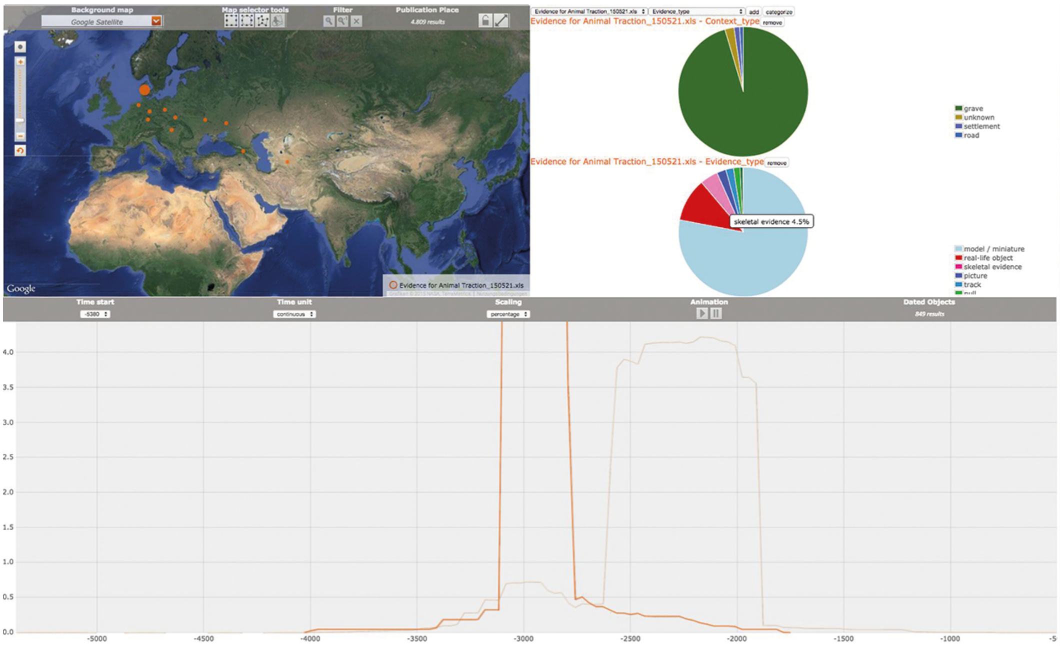

Fig. 12 | Repartition and relative adoption of skeletal evidence for animal traction found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

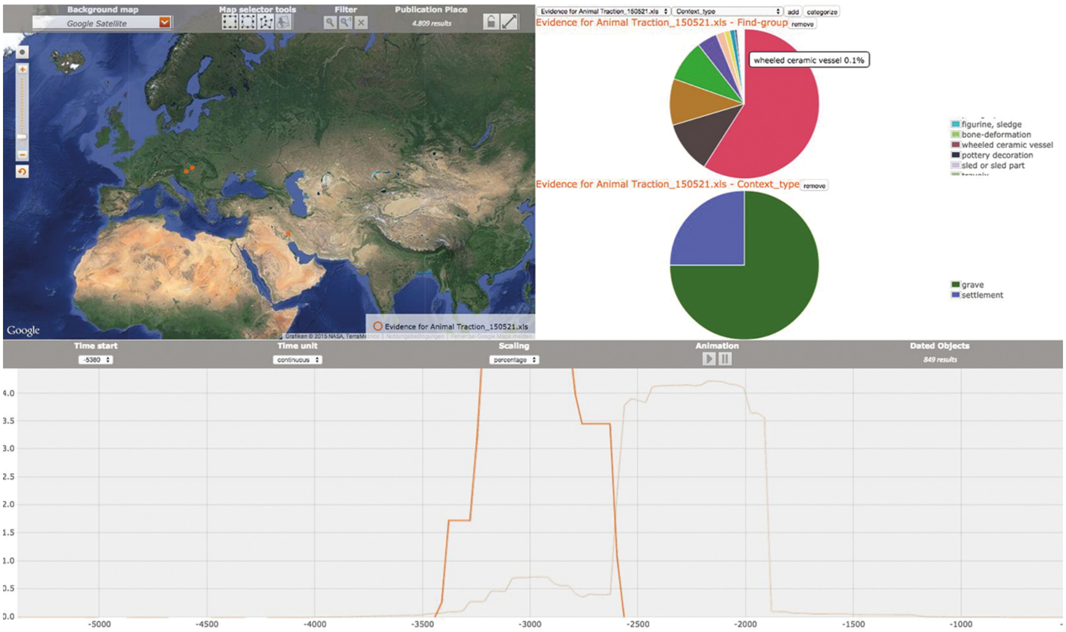

Fig. 13 | Repartition and relative adoption of wheeled ceramic vessel found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

makes it difficult to compare the frequency. The Digital Atlas of Innovation allows users to change the depiction of frequencies from absolute to relative or logarithmic scales. Changing the frequency to percentages highlights that skeletal evidence is rather short-lived (Fig. 12) and that its dating correlates with the date for cattle pairs in general (see Fig. 6).

The few wheeled drinking cups are limited to the Baden culture and usually found in graves (Fig. 13). The marks from plows, sleds, or wheels (1.9 percent), meanwhile, are

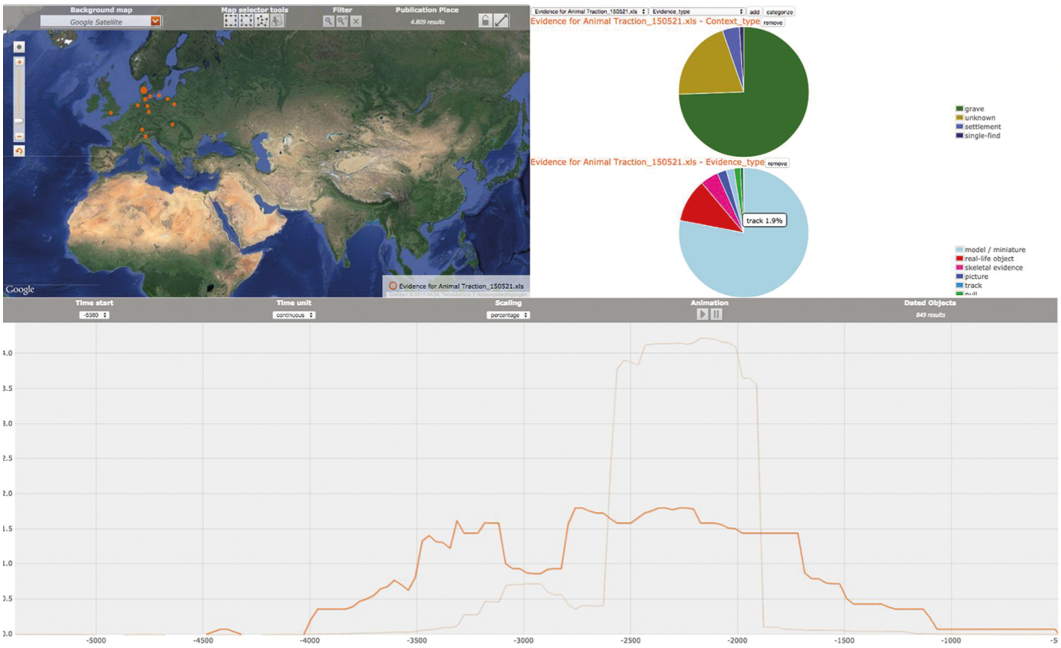

Fig. 14 | Repartition and relative adoption of trackmarks from ploughing, sleds and early wagons in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

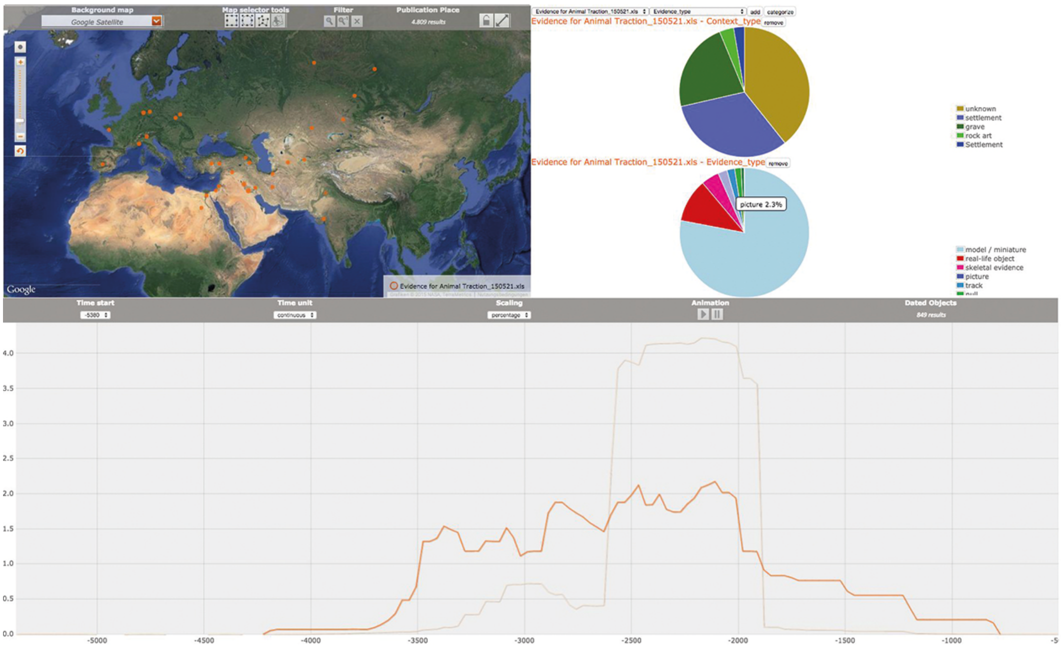

Fig. 15 | Repartition and relative adoption of depictions of animal traction found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

bound to the existence of barrows, which explains their limitation to England, Jutland, and northern Germany, or wet soils. This makes dating the marks rather difficult, and in most cases only a *terminus ante quem* can be given. Based on the available dating evidence, it is possible that plowing was used in the North European Plain as early as shortly after 4000 BC (Fig. 14).

Depictions (2.3 percent), on the other hand, have a fairly widespread repartition; they are known from Megalithic graves, for instance the Wartberg group of southern

Westphalia and Hesse,[30] and as rock art, for instance in the Alps[31] as well as Eastern Anatolia,[32] Mesopotamia, and Iran[33] (Fig. 15). There are also a significant number of finds in Central Asia.[34] Many of these finds, however, are difficult or even impossible to date, or date to later than the European finds, and also include pictographs, rock art, and wall paintings and carvings.

While the majority of finds considered evidence of early wagons come from the Harappa settlements, these finds consist only of model wagons, dating rather late (see Fig. 5). The knowledge of the use of animal traction in western Eurasia is heavily biased by the *cultural decision* to put parts of wagons or models thereof into graves or to decorate graves with wagon depictions, and even further by the choice of how to build graves: tread marks from plows and wagons had a significantly better chance of preservation in places where barrows were constructed over the deceased. Additionally, the soil conditions work as a natural filter for the archaeological record, and roads and real-life parts of wagons as well as skeletal evidence only survive outside graves that are located within regions with wet soils.

Early evidence of animal traction can thus be shown to be first and foremost the result of ritual actions by prehistoric communities. Region-specific deposition patterns are visible: the rich evidence in Jutland, northern Germany, and the Low Countries is not only due to the bogs, but also a result of the construction of graves in which cattle bones were preserved and the erection of barrows, under which marks from plowing and driving could survive the millennia. In central Europe, the evidence consists of a few depictions from Megalithic graves, double burials of cattle and wheeled pots found in a small number of graves, while in the northern Pontic region a vast number of wagons (this time, however, without cattle) were preserved in graves. Had prehistoric communities not chosen to build such graves, the amount of evidence would be significantly lower and more ambiguous.

The impact of prehistoric cultural choices for the preservation of finds is not only relevant in order to understand the representativity of the archaeological record, but also to grasp the rhythm of the innovation process: only 5.9 percent of all finds can be connected with a radiocarbon dating (Fig. 16). The repartition of these, however, is again strongly biased: while only 30 percent of all graves are scientifically dated (Fig. 17), 80.2 percent of all radiocarbon-dated finds derive from graves, and another 4.5 percent from roads (Fig. 16). This means that datings independent from typology are more or less congruent with the repartition of the evidence from graves and wet soil (where the wagon parts and parts of the skeleton can survive and appear in the archaeological record; cf. Fig. 18). An overwhelming amount of miniature wagons and miniature wheels can still only be dated by means of stratigraphy, however, often with a lack of connected scientific date (Fig. 19).

The aforementioned possible chronological priority of Europe should therefore be treated with great care. It is based on a record that is strongly filtered by cultural choices and natural conditions, and cannot simply be seen as giving objective evidence of diffusion gradients.

30 Günther 1990.
31 Vosteen 1996b, 44.
32 Есин, Ю. Н. 2012, 41, Abb. 21.
33 J. Crouwel 2004, 69, 77 Abb. 15.
34 Teufer 2012.

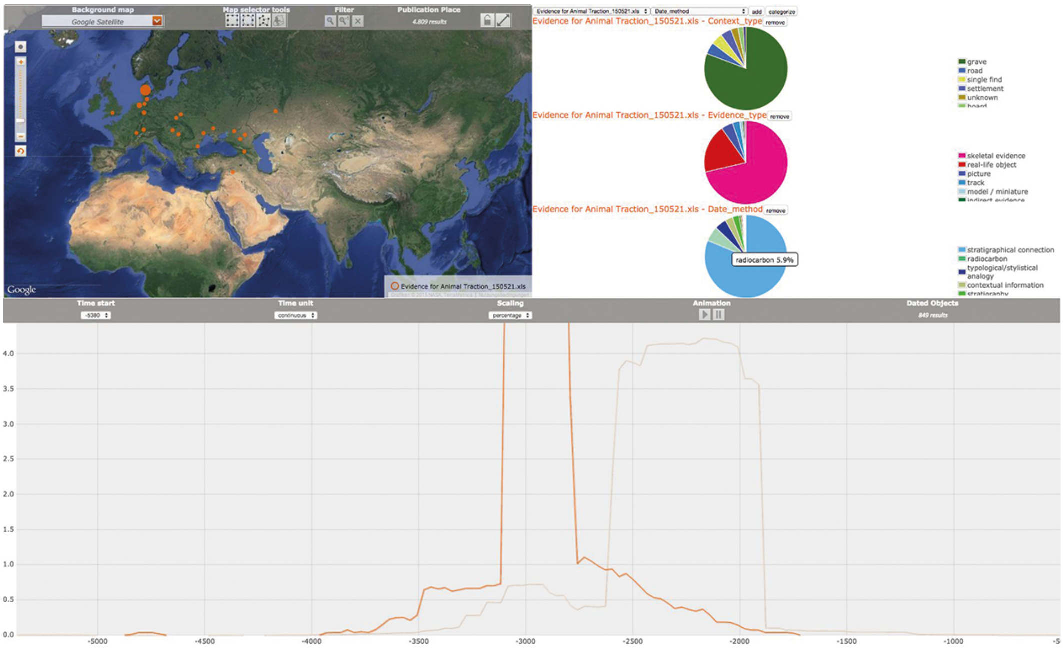

Fig. 16 | Repartition and contexts of C14-dated evidence for animal traction found in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

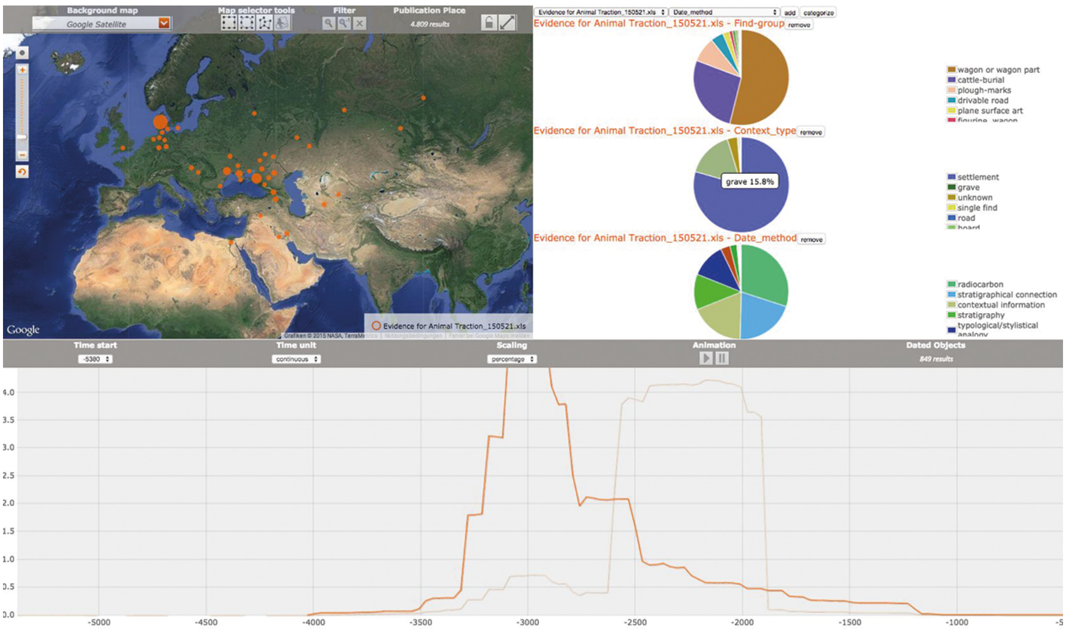

Fig. 17 | Repartition and dating methods of evidence for animal traction found graves in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

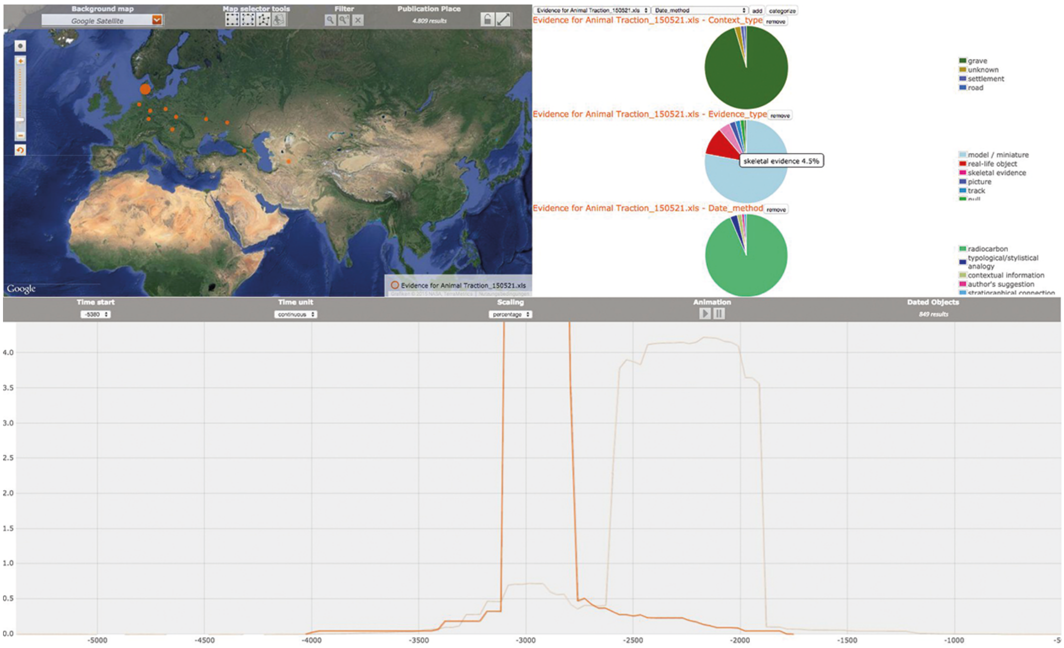

Fig. 18 | Repartition and dating methods of skeletal evidence for animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

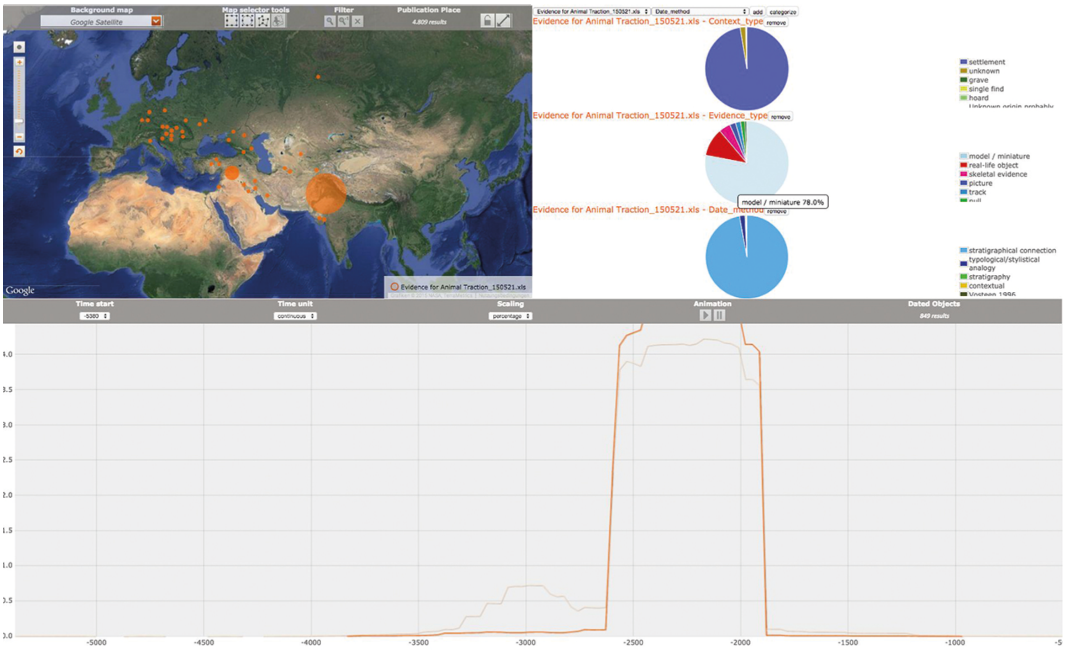

Fig. 19 | Repartition and dating methods of miniatures and models, interpreted as evidence for animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

6 The takeoff of the wagon reconsidered

Scholars have identified the 4th millennium as the time span in question for the emergence of the wagon, or more precisely the time from the middle of the 4th until the first quarter of the 3rd millennium. If only finds from this period are mapped, a histogram of the finds shows a rapid increase in the 34th century BC (see Fig. 7). This would allow the diffusion to be connected with the well-known S-curve from innovation theory, which is meant to describe a successful innovation process:[35] within a given time frame, the number of users slowly rises until a critical mass is reached, which causes further diffusion to commence much faster and resemble a cascade. Rogers calls this phase the 'take-off'.

But does the histogram in question indeed show the prehistoric reality, or are the cultural and natural filters discussed above blurring the picture to an extent that it is impossible to converge on the takeoff of the wagon using empirical data? I will try to discuss this further by disassembling the data into smaller units and comparing the preliminary result of an assumed takeoff with other data sets.

7 Rotary motion

As has been shown, the strong correlation between prehistoric religious actions and science-based dating hinders the understanding of the innovation process. A better understanding of the technical principles of traction and wheeled vehicles is needed.

One plausible idea would be to see the wagon as the result of a better understanding of rotary motion. And indeed, within the time frame of interest, the second half of the 4th millennium, several changes in the archaeological record have been connected with such a notion: in Swiss lake dwellings there is a dramatic rise in the number of spindle whorls that coincides with the beginning of the Horgen culture;[36] also appearing within this period are the fast-turning potter's wheel, the cylinder seal, and doors rotating around door-socket stones.[37] There seems to be a connection between spinning and the appearance of linen in the Circum-Alpine area, but a further correlation with a localized invention of wagons simplifies the underlying technical principles. Spinning and spindle whorls are already very prominent in the 5th millennium in the southern Levant[38] and on the Lower Danube.[39]

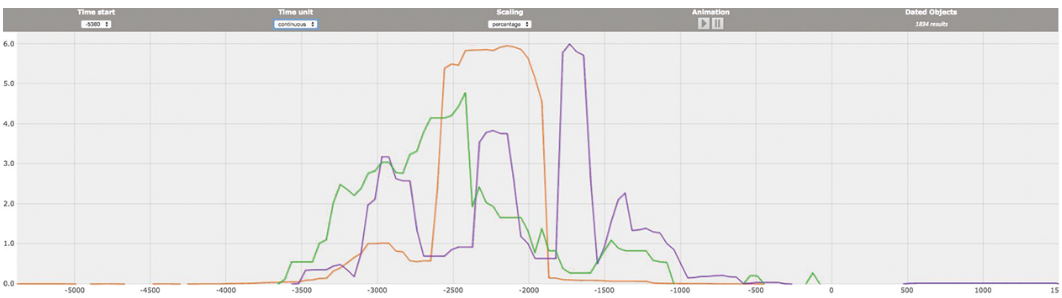

Fig. 20 | Frequency of finds of evidence for animal traction (orange), cylinder seals (purple) and potter's wheels (green) in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

35 Rogers 2003.
36 Schlichterle 2002, 31.
37 Rizkana and Seeher 1988.
38 Levy and Gilead 2012.
39 Cf.: Hansen, Dragoman, Reingruber, Gatsov, et al. 2005; Hansen, Dragoman, Reingruber, Becker, et al. 2006; Hansen, Toderaş, Reingruber, Gatsov, Georgescu, et al. 2007; Hansen, Toderaş, Reingruber, Gatsov, Klimscha, et al. 2008; Hansen, Toderaş, Reingruber, Becker, et al. 2009.

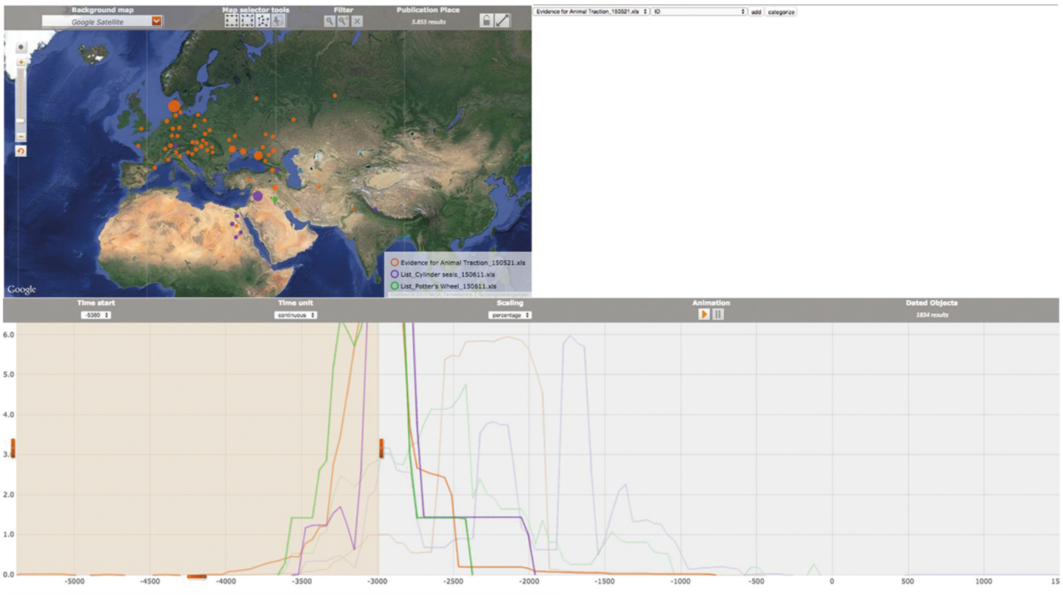

Fig. 21 | Repartition and frequency of finds of evidence for animal traction (orange), cylinder seals (purple) and potter's wheels (green) in the 4th millennium BC.

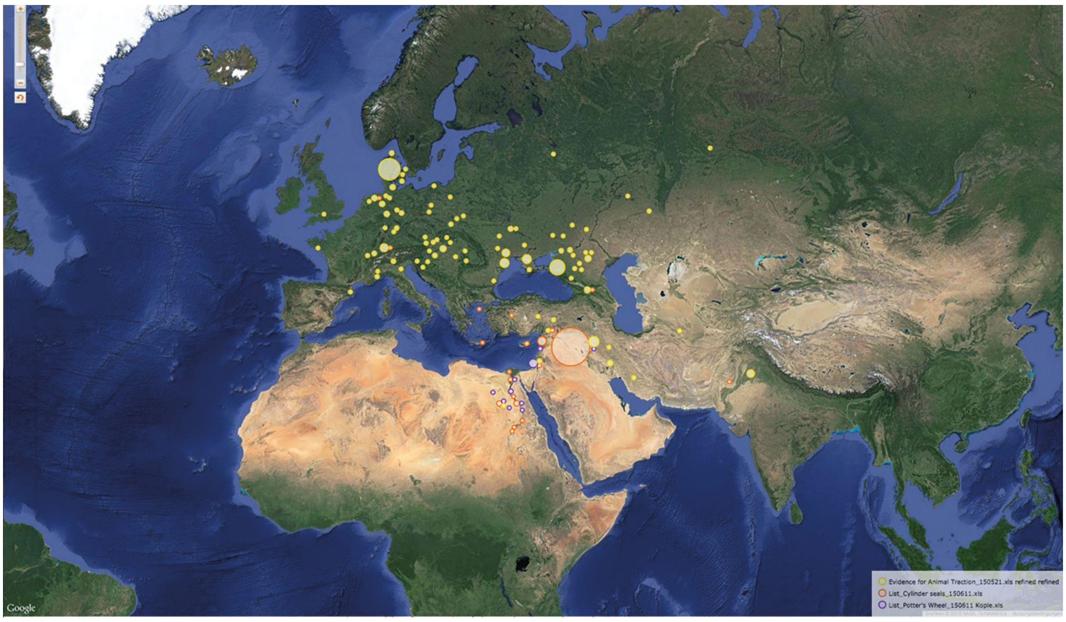

Fig. 22 | Repartition of finds of evidence for animal traction (orange), cylinder seals (purple) and potter's wheels (green) in the 4th millennium BC (query from the Digital Atlas of Innovations).

Nevertheless, while a comparison of the relative frequency of wheeled vehicles with the data sets 'potter's wheels' and 'cylinder seals' suggests that all three are independent innovation processes with different takeoffs within the 2nd half of the 4th millennium (Fig. 20), it also highlights that all three share a possible earliest beginning around 3600 BC. If the scope is narrowed to the 4th millennium only, it becomes clear that the specific takeoffs take place between 3300 and 3000 BC, with a clear priority of traction over cylinder seals and potter's wheels (Fig. 21). The corresponding mapping remains peculiar, however, because now the evidence for wheeled vehicles is concentrated only in Europe, and the evidence for the potter's wheels and cylinder seals is limited to the eastern Mediterranean (Fig. 22).

8 Regionally exclusive and time-specific find groups

It could also be argued that the ritual veneration of wagons, which resulted in the making of miniatures and the inclusion of these miniatures in burials, was the result of their great popularity after their emergence. To test this hypothesis, the dating and repartition of smaller classificatory units will be plotted.

The early evidence for animal traction does indeed appear in find groups specific to certain regions and time: in the Hessian-Westphalian region, it shows up as pecked depictions on the wall stone slabs of the gallery graves of the Wartberg Culture;[40] in Flintbek, as tracks under a burial mound of the late Funnelbeaker culture;[41] in Poland, as depictions on Funnelbeaker pots[42] and as cast copper sculptures;[43] in the area of the Baden and Coţofeni cultures, as models;[44] in the northern Pontic region, as grave goods;[45] in the lakeside settlements of the Circum-Alpine region and the bogs of northwestern Germany and the Netherlands, as *realia* finds;[46] and, finally, in the Cucuteni-Trypillian culture, as animal figurines on wheels.[47]

The repartition changes slightly if only the timespan until 2750 BC is selected, but its find frequency is different, as the thousands of models from Harappa are omitted (Fig. 23). This selection is used to create a new data set for the next mapping (Fig. 24):

The spatial exclusivity of the find groups mentioned has already been demonstrated, but it has remained unclear how these groups compared chronologically. Of course, with many of these categories, like the Funnelbeaker pots or the Wartberg megaliths, not only is the find number statistically irrelevant, but the absolute chronology is also heavily interdependent. This significantly limits the detailed chronological comparison of all find groups in a discussion that focuses only on single finds. With some of the larger, more generally distributed groups, however, there are some interesting tendencies visible, especially when using big data to argue the point: real-life wagons and wagon parts rapidly increase from around 3300 BC onwards (Fig. 25), while cattle burials are a bit later and do not have their takeoff until ca. 3100 BC; roads that could be used by wagons (see Fig. 6) are known from at least 4000 BC onwards, but have a significant increase around 3150 BC (Fig. 26). The ritual appreciations of cattle, as well as the construction of roads specifically designed for driving wagons, seem to have been the consequence of more widespread vehicle use.

40 Günther 1990.
41 Zich 1992.
42 Kruk and Milisauskas 1982; Kruk and Milisauskas 1991; Milisauskas, Kruk, and Poliszot-Makowicz 1993.
43 Bakker 2004, 284 Fig. 2.
44 Maran 2004, 271 Fig. 2–4, 272 Fig.5–6; Burmeister 2011, 225 Fig. 23.
45 Trifonov 2004.
46 Compiled in: Schlichterle 2004; Bakker 2004; Burmeister 2004a.
47 Gušev 1998.

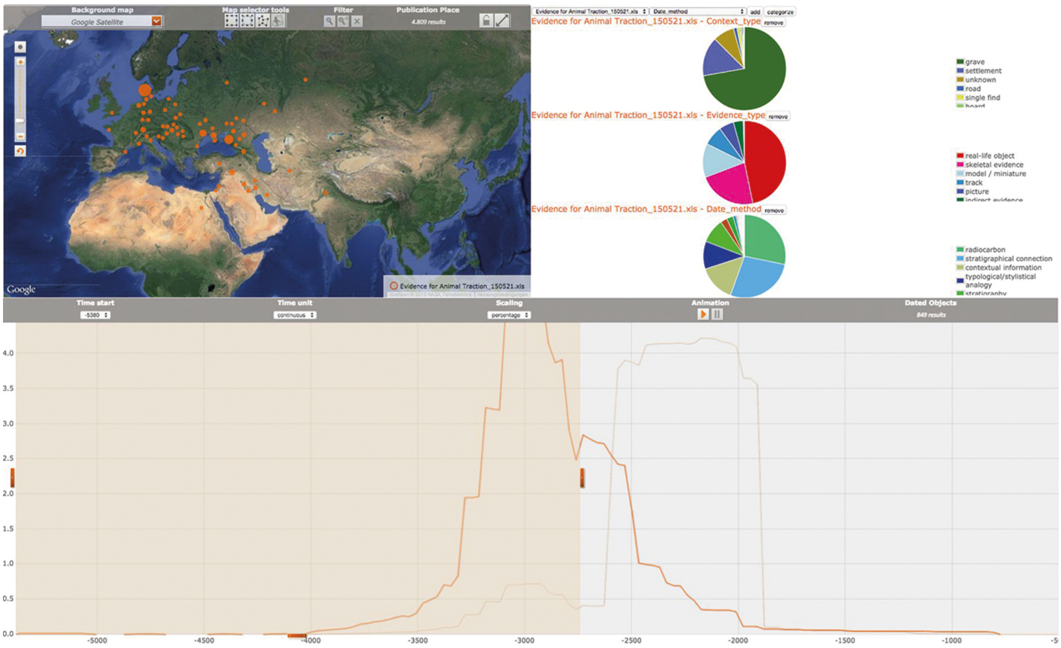

Fig. 23 | Selection process for evidence for animal traction in the 4th millennium BC (query from the Digital Atlas of Innovations).

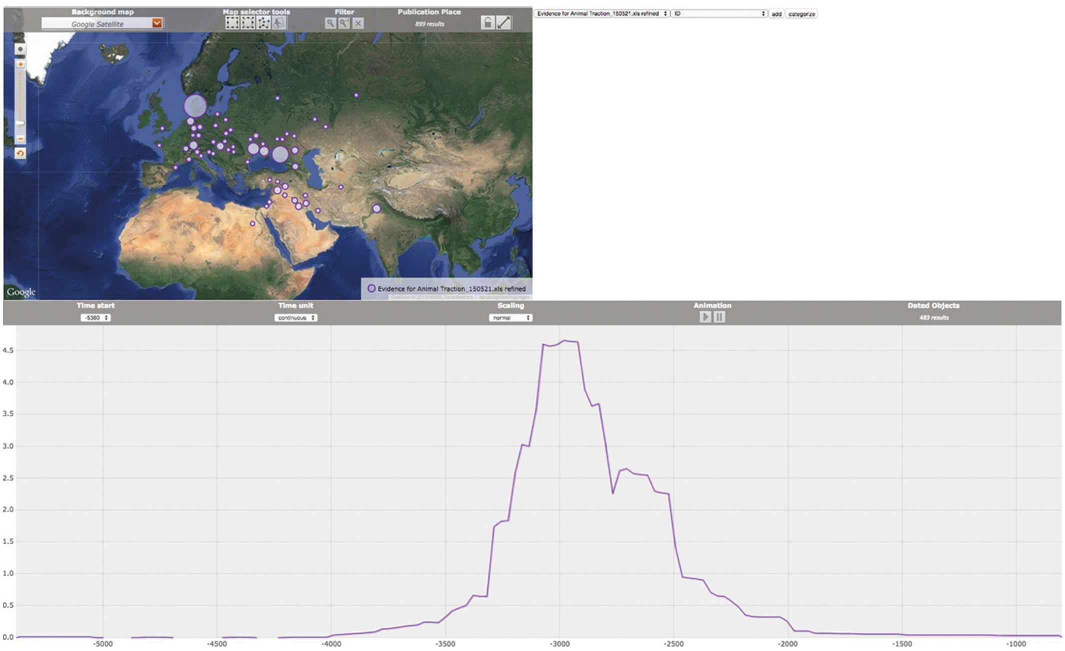

Fig. 24 | Repartition of evidence for animal traction in the 4th millennium BC (query from the Digital Atlas of Innovations).

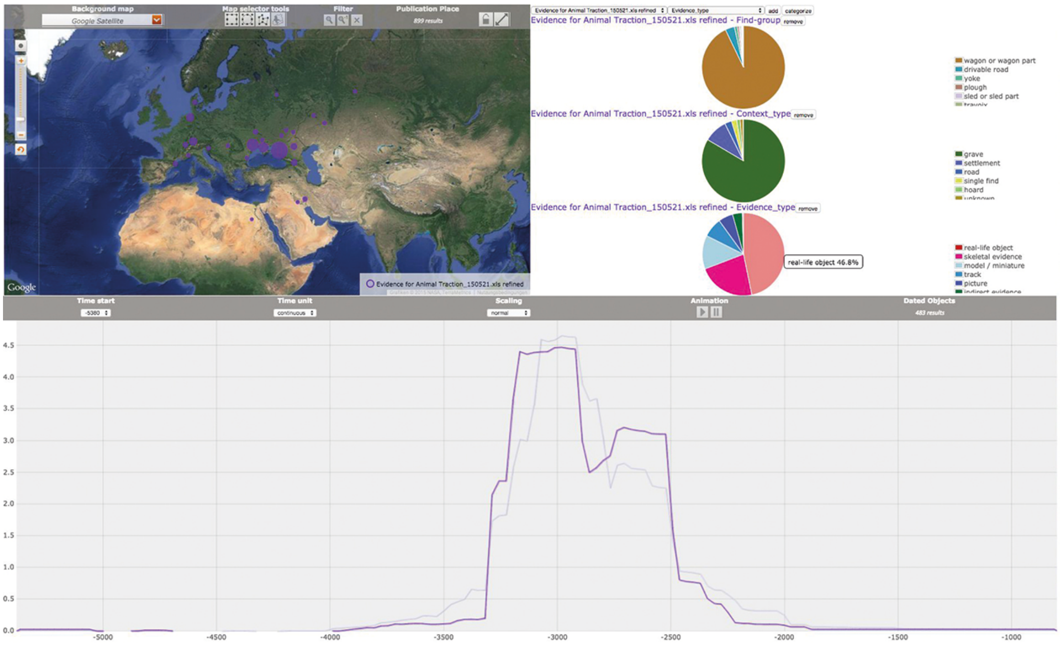

Fig. 25 | Repartition and frequency of real-life-sized evidence for animal traction in the 4th millennium BC (query from the Digital Atlas of Innovations).

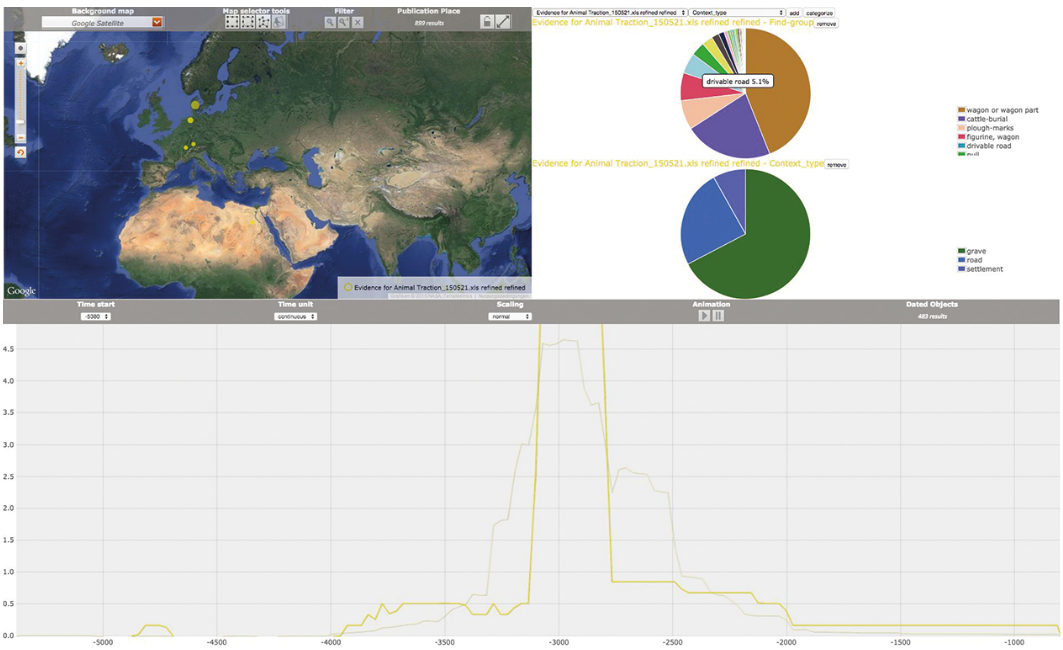

Fig. 26 | Repartition and frequency of drivable roads in the 4th millennium BC (query from the Digital Atlas of Innovations).

9 Local technical developments

The aforementioned exclusivity of the find groups greatly limits the comparison of the technical details of early wagons. The only objects that do appear in greater number are wheels.

Disc wheels made from one (Fig. 30), two (Fig. 31), or three parts (Fig. 32) are not limited to a specific area; rather, all basic principles of wheel construction seem to have been shared over the complete central and western area of the repartition of early evidence (in the case of the Harappa culture, this cannot be decided on the basis of miniatures alone).

Using additional construction details, it is possible to sketch different technical traditions. In the 4th millennium, four-wheeled wagons are restricted to Poland, the Carpathian Basin, the Caucasus, and Syria-Mesopotamia; their find numbers drastically increase from around 2750 BC onwards (Fig. 27). Light two-wheeled carts, on the other hand, are found only in the Wartberg Culture,[48] possibly central Germany,[49] and the western Alpine region, and these carts continue in great numbers in the Near East during the 3rd millennium (Fig. 28).[50] If it is accepted that these are transformations of the same basic principle, as discussed further above, then they must represent a rather *late* stage of the diffusion, in which the wheeled vehicle as a technological system has already been further developed into at least two constructional variants.

The elaborate design of early wagons also highlights the difficulty of seeing any experimentation phase. For instance, the wheels from Stare Gmajne in Ljubljana, Slovenia[51] belong to a small group of disc wheels with square-shaped center bores limited to southern central Europe (Fig. 29). The wheels are fixed on the axle and thus cause less abrasion, suggesting that they are already at a more developed stage of the innovation process.

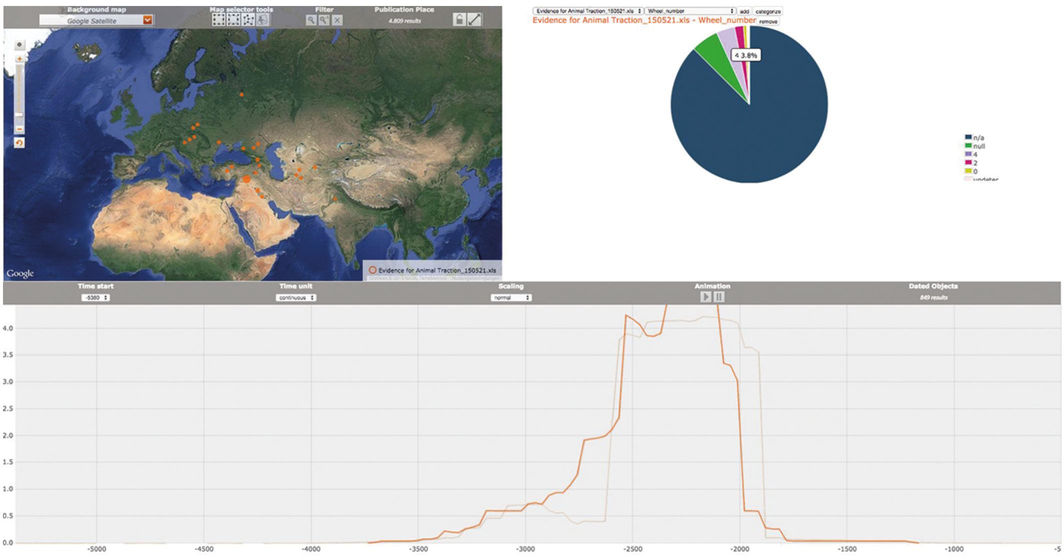

Fig. 27 | Repartition and relative frequency of evidence for four-wheeled vehicles in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

48 Günther 1990.
49 Friedrich and Hoffmann 2013.
50 Pétrequin et al. 2002, 62 Fig. 9.
51 Velušček 2002, 39 Fig. 2, 40 Fig. 3; Fansa 2004, 34 Fig. 41, however, the find is mistakingly placed into Czechia.

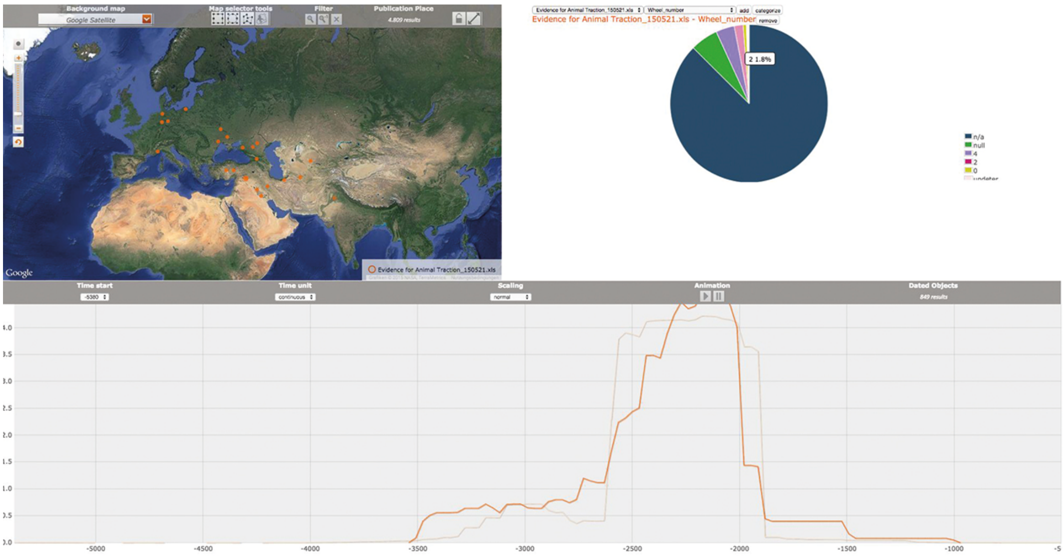

Fig. 28 | Repartition and relative frequency of evidence for two-wheeled vehicles in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

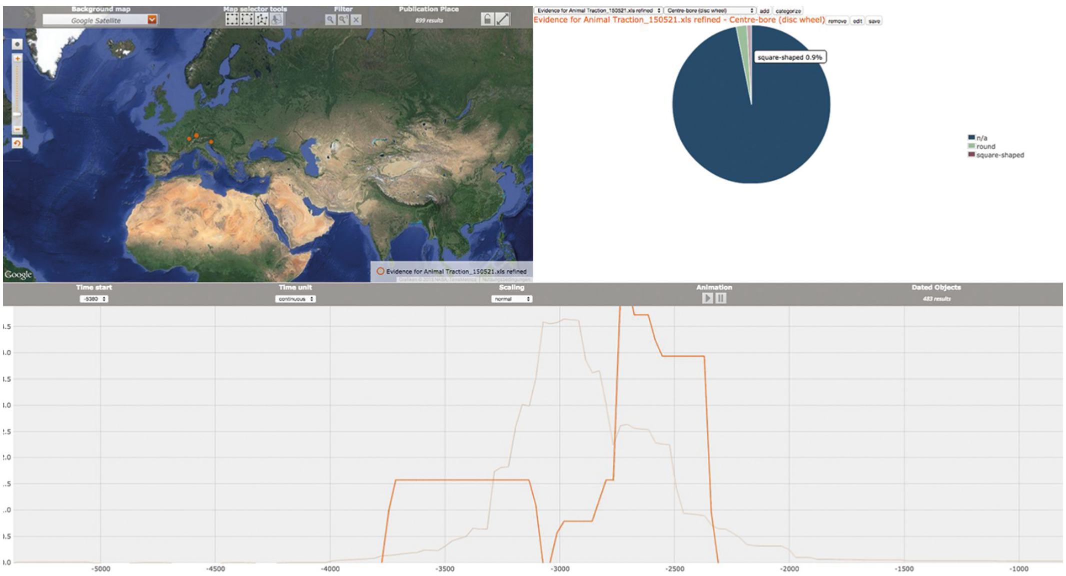

Fig. 29 | Repartition and relative frequency of evidence for wheels with a square-shaped centre-bore in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

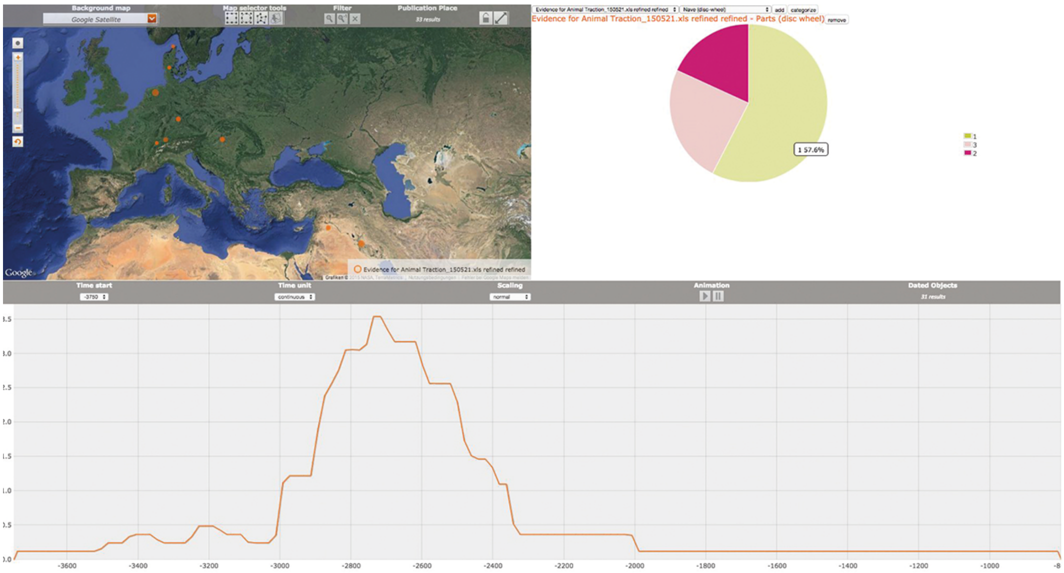

Fig. 30 | Repartition and relative frequency of single-piece disc-wheels in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

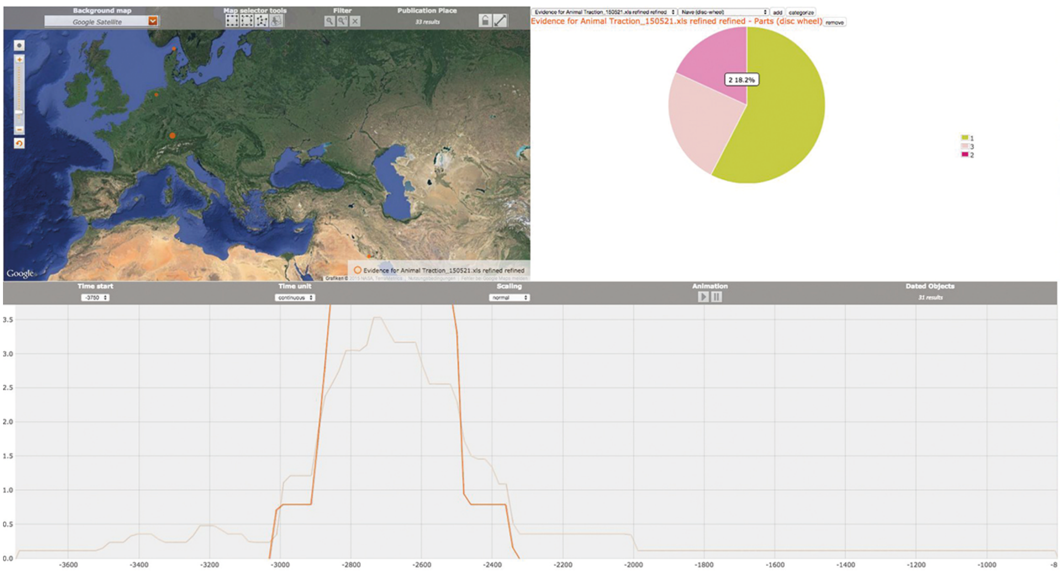

Fig. 31 | Repartition and relative frequency of bipartite disc-wheels in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

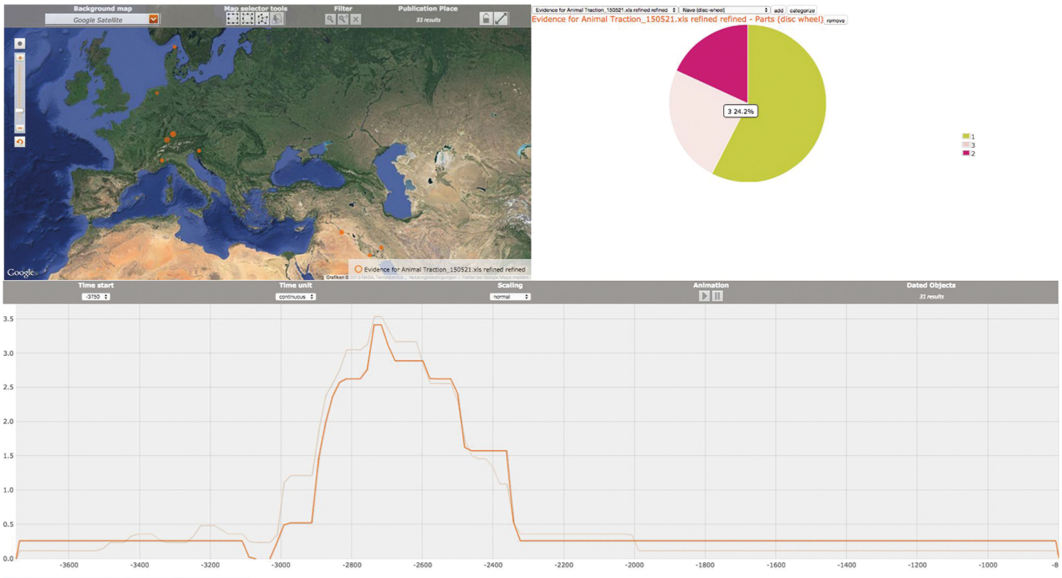

Fig. 32 | Repartition and relative frequency of tripartite disc-wheels in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

10 Cattle pairs and the wagon

The wagon is rarely shown (or preserved) completely in archaeological sources.[52] The scientific community has agreed to read various depictions as a *pars pro toto* sign for 'wheeled vehicle'. This is quite clear in the case of wagon drinking cups, but when dealing with pairs of cattle (sometimes under a yoke), other possibilities remain.

Nevertheless, even if the cipher of two cattle could also refer to cattle pulling a plow, or a sled or travois, any of these readings would require animal traction, and it is hardly by coincidence that the traction of a cattle pair is used as a signifier. Between 3300 and 2800 BC, the cattle pair can be found depicted in megalithic graves of the Wartberg group in Hesse-Westphalia,[53] as rock art in the Val Camonica[54] and the Black Sea region,[55] as cattle burials near stone heap graves on the Jutland Peninsula[56] and within the Bernburg[57] and Baden cultures[58], as copper figurines,[59] and as protomes or small figurines attached to pots in eastern central Europe[60] (Fig. 33).

With the exception of Jutland, contemporary evidence for wheeled vehicles exists in all these areas, so the reading of the cattle pair under a yoke as a wagon is possible. The same image is also found on a small bowl in Tell el-Farah (North) in the southern Levant dating to the older part of the Early Bronze Age,[61] as well as on a seal from Arslantepe[62] and a stone relief from southern Mesopotamia.[63] Thus, while the use of animal traction is

52 Cf. the excellent overviews in: Fansa and Burmeister 2004.
53 Günther 1990.
54 Inter alia: Schlichterle 2004, 311 Fig. 18; Piggott 1983, 52 Fig. 21; cf. also: Arcà 2011.
55 Günther 1990, 53 Fig. 9.
56 Johannsen and Laursen 2010.
57 Döhle and Stahlhofen 1985, 157–159 Fig. 1; Stahlhofen and Kurzhals 1983, 157–160; Vosteen 1996b, 48.
58 Korek 1951; Behrens 1963; Maran 2004.
59 Matuschik 2002; cf. also Bakker 2004, 284 Fig. 2; Matuschik 2006, Fig. 8.1.
60 Radošina and Boglárelle: Bondár 1990, Fig. 7.3a–c.; Bondár 2012, Fig. 7–8. – Krežnica: Dinu 1981.
61 Dayagi-Mendels and Rozenberg 2010, 39 Fig. 4.
62 Fansa 2004, 15 Fig. 9.
63 Fansa 2004, 17 Fig. 12.

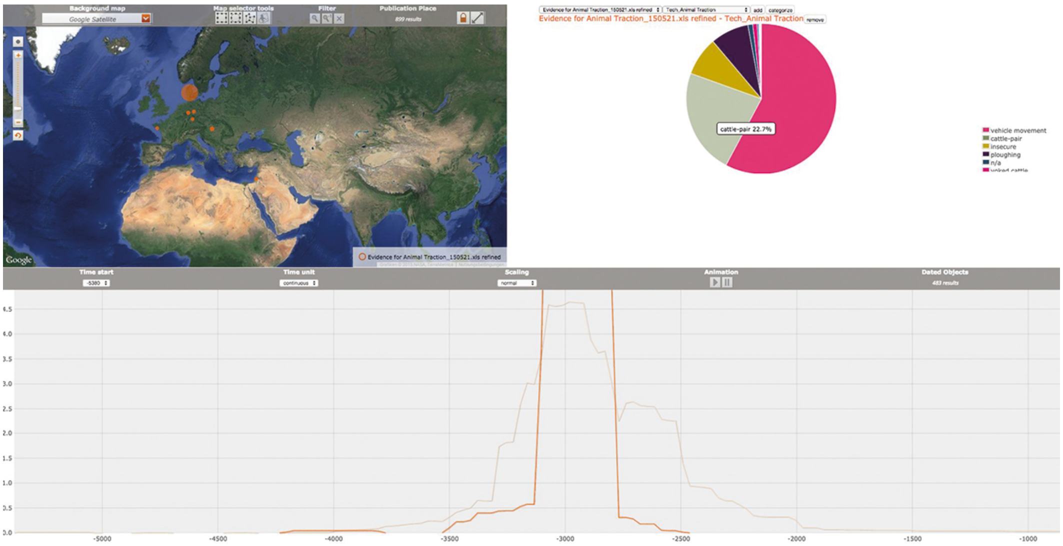

Fig. 33 | Repartition and relative frequency of cattle-pairs in the 4th and 3rd millennia (query from the Digital Atlas of Innovations).

well known, the evidence for constructing wheeled vehicles is rather sparse, and in Egypt even nonexistent.

10.1 Early indirect evidence

Interestingly, evidence that precedes the appearance of real-life objects can be found for the use of animal traction in both rock art (starting around 3850 BC, Fig. 34) and figurines. A possibly similar phenomenon can be seen for evidence of the wheel, where a group of wheeled figurines in the Tripylia culture[64] (Fig. 35) and some miniature wheels in the Carpathian Basin[65] (Fig. 36) date to as early as the first half of the 4th millennium.

The depictions thus predate the real-life evidence by up to 500 years.

How can this chronological discrepancy be explained? It could be taken as an argument to further strengthen the proposed interpretation of the general adoption curve as showing a cultural innovation rather than a technical one, or it might suggest flaws within the current interpretation of the archaeological record. The previously explained taphonomic factors are one option, but it is important at this stage of the argument to consider the different technical complexity of the components again. Human societies since at least the Neolithic have had knowledge of the necessary woodworking tools, the principle of rotary motion, the idea of vehicle movement, and the concept of animals pulling heavier objects.

64 Gušev 1998.
65 Burmeister 2011, 225 Fig. 23.

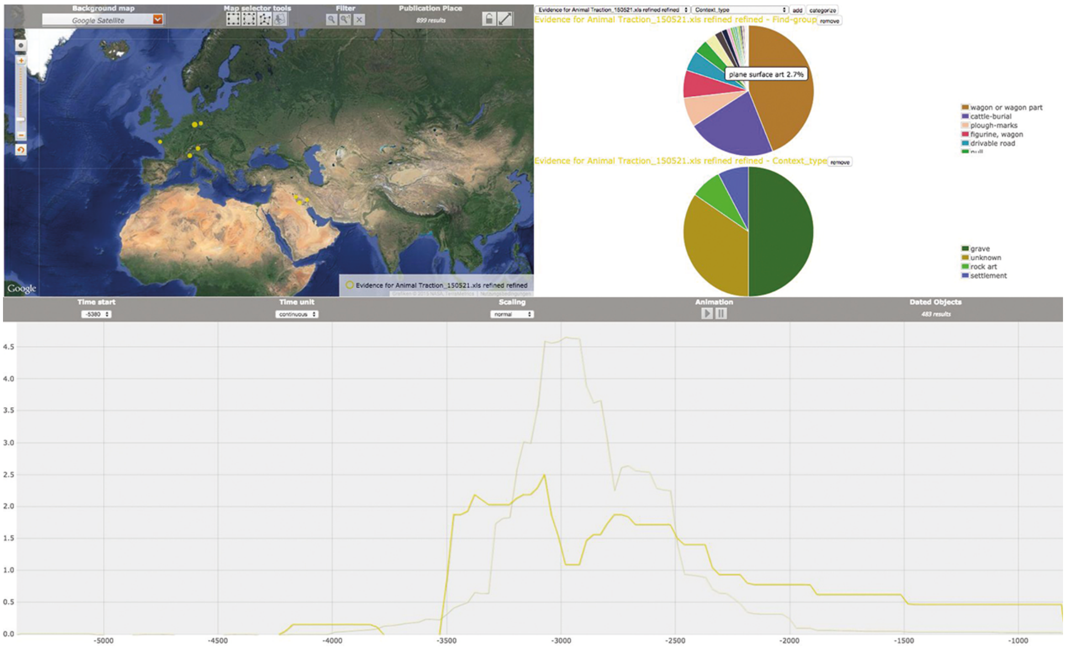

Fig. 34 | Repartition and frequency of plane surface art showing animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

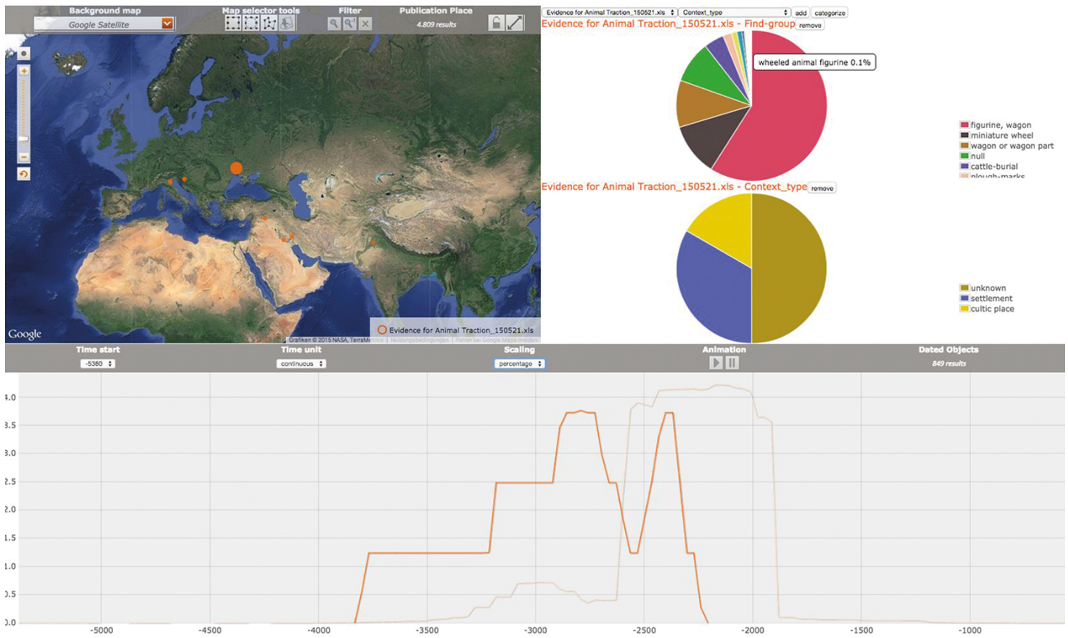

Fig. 35 | Repartition and frequency of wheeled animal figurines in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

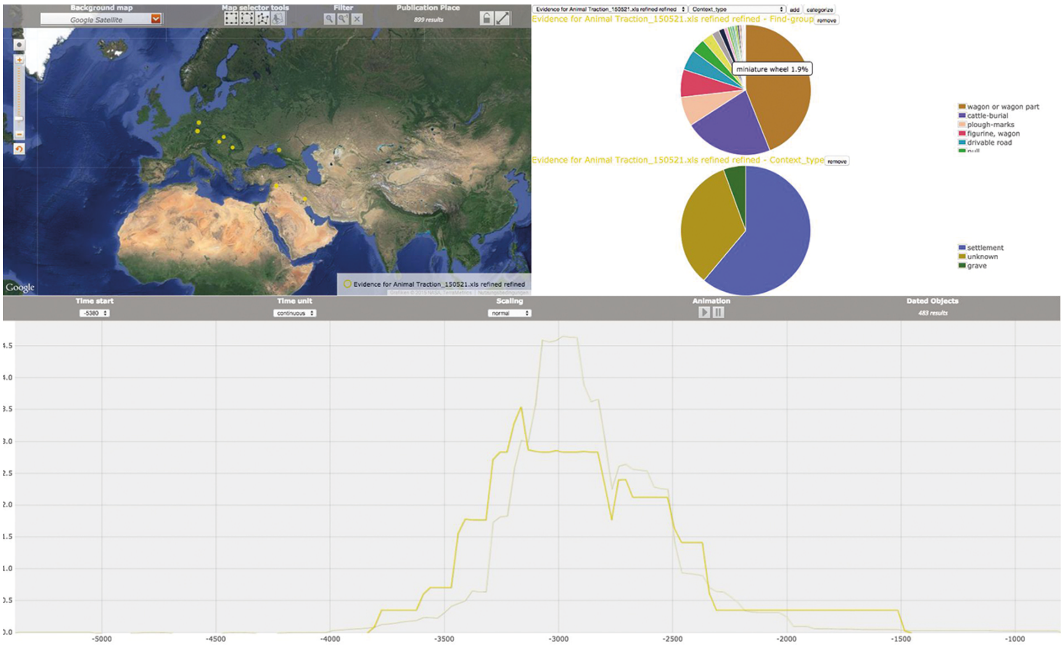

Fig. 36 | Repartition and frequency of miniature wheels in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

10.2 The use of cattle traction

Recall also that seemingly isolated early evidence was available inside the group of drivable roads as well (see Fig. 6). Furthermore, the recent find of a yoke dating to the Cardial culture[66] suggests some early experimentation with cattle traction, and cattle castration (which could be related to this) was indeed practiced beginning in the Early Pottery Neolithic.[67] The available data on cattle pathologies[68] shows that from the Pottery Neolithic onwards, there is evidence in the Near East of cattle regularly pulling heavy weights.

The repartition stretches from Scandinavia to the Levant (Fig. 38), and the evidence of skeletal pathologies is considerably older than the evidence of traction, beginning as early as the 7th millennium. If the selection is limited to the 4th millennium, there is a parallel increase around 3350 BC in both curves (Fig. 39), suggesting a connection between the two phenomena.

The area can also narrowed to central Europe by making a geographical selection with the Atlas of Innovation software (Fig. 40).

If this narrowing is performed, both adoption rates are nearly parallel (Fig. 41). This phenomenon is also reflected in the evidence of plowing in Europe. While plow treads are notoriously difficult to date, there is a plausible *terminus postquem* of 4000 BC (Fig. 42). The correlation of tread marks, cattle-pair depictions, and zooarchaeological evidence is striking and highlights that animal traction, plowing, and the wheel were very probably introduced into northern central Europe as a package.

Rogers defined defined five criteria for the successful takeoff of an innovation:[69] the *relative advantage* over other technologies, the *compatibility* with the social system, the *complexity* of the innovation, its individual *trialability*, and its *observability*. An innovation has to be perceived as being better or more prestigious than traditional techniques (*relative*

66 Bosch et al. 1999; Pétrequin et al. 2002, 63.
67 Bakker 2004, 283; Vosteen 1996b, 46 with further literature.
68 Compiled by Austin Hill for the research group.
69 Rogers 2003, 15–16; 112–118.

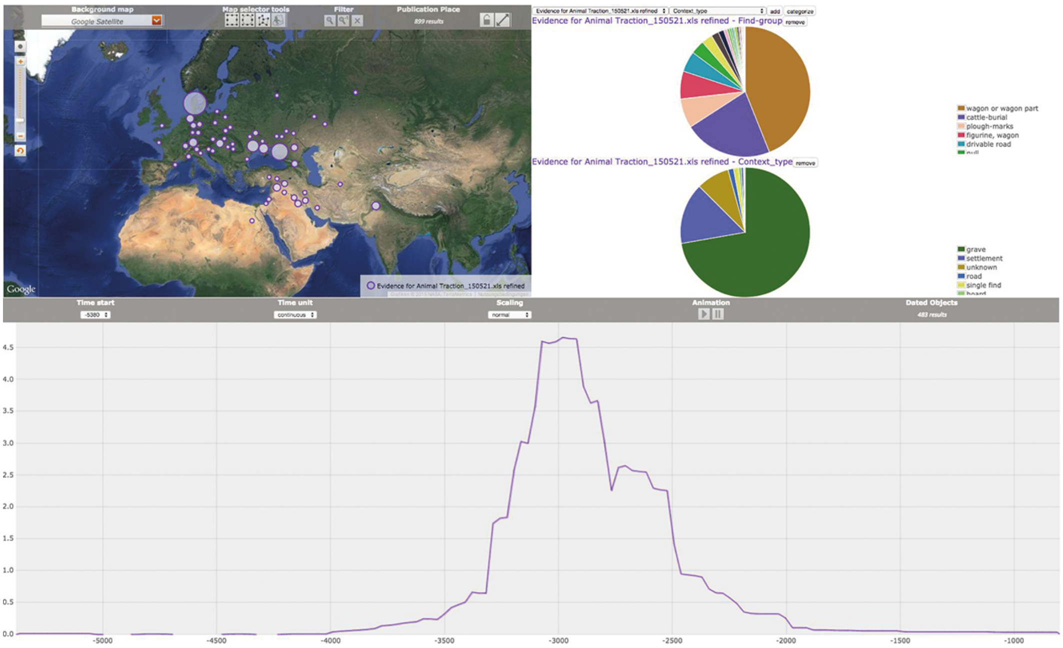

Fig. 37 | Repartition and relative frequency of evidence for animal traction in the 4th millennium BC (query from the Digital Atlas of Innovations).

Fig. 38 | Repartition of pathologies from traction on cattle skeleton in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

advantage); it has to be consistent with existing values and experiences of the society adopting it (*compatibility*); and it has to be understood, i.e., its *complexity* must not be too high.

Once prehistoric wagons had emerged, they could be *observed* by anyone living in the vicinity of a user. While these vehicles were significantly less mobile than the later chariots, their *advantages* in societies based on agriculture are obvious: they allowed the transport of heavier objects and the moving or shifting of objects with less effort. The main innovation aspects deserving more attention here are the criteria of compatibility and complexity.

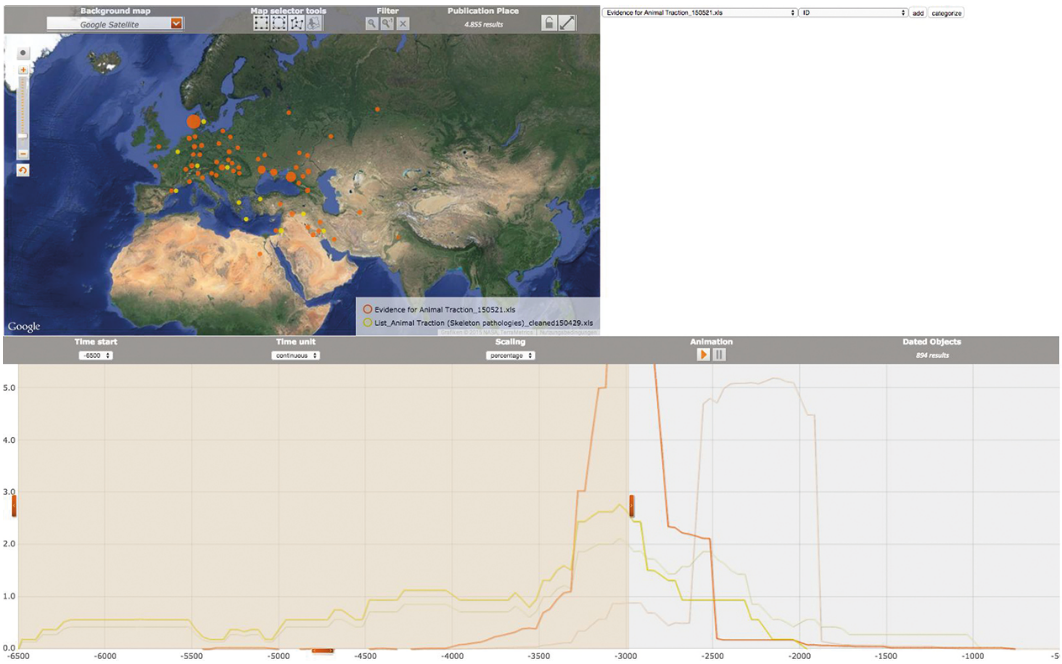

Fig. 39 | Repartition and frequency of pathologies from traction on cattle skeleton in the 4th millennium BC (query from the Digital Atlas of Innovations).

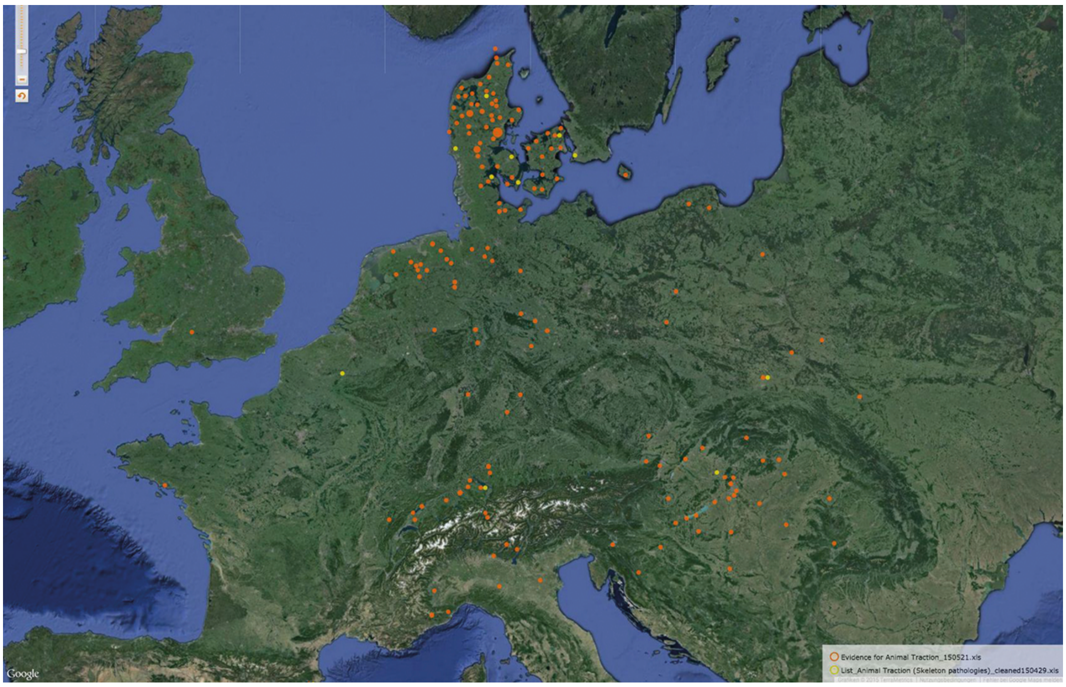

Fig. 40 | Repartition of pathologies from traction on cattle skeleton in Central Europe in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

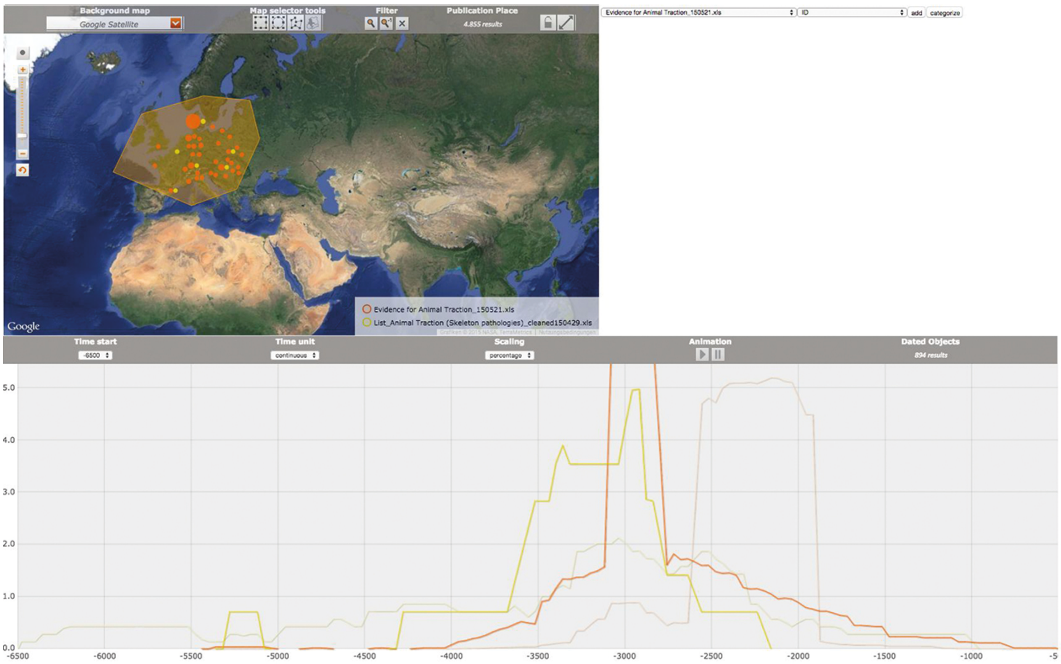

Fig. 41 | Geographical selection process and repartition and frequency of pathologies from traction on cattle skeleton in Central Europe in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

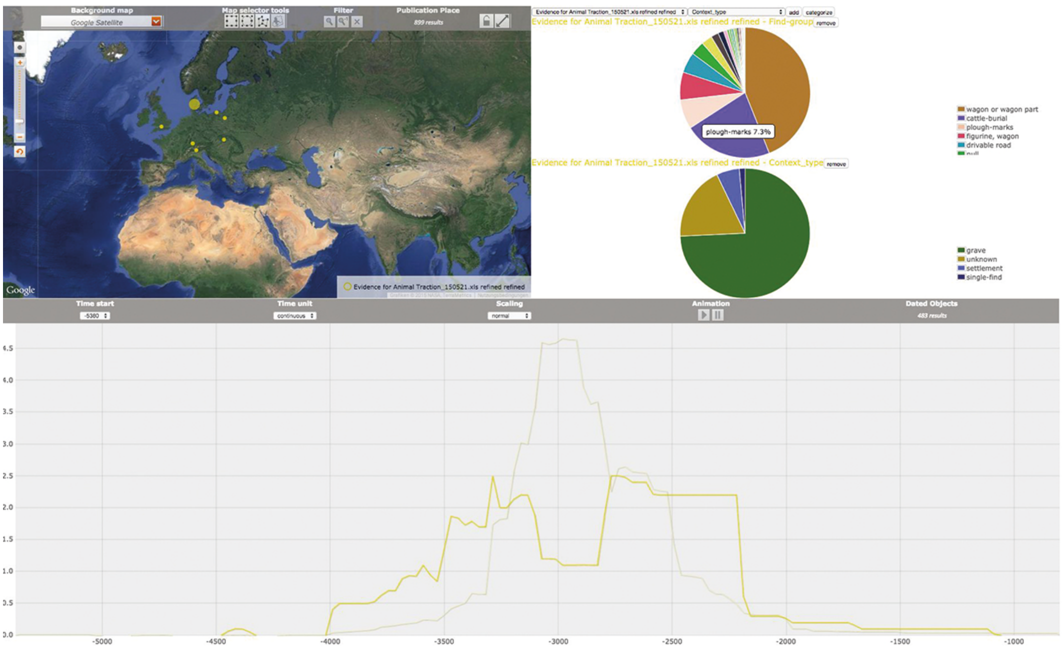

Fig. 42 | Repartition and frequency of ploughing marks in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

Wagons seem to have been incompatible with many societies, who either saw no use at all for them or decided that other ways to transport goods were better. The lengthy refusal to adopt the wheel in Greece[70] and Egypt[71] is striking; wheeled vehicles were obviously not the only choice for transportation. The record of wagon evidence is not continuous in the Near East, either, and there are several periods in which the evidence seems to disappear.[72]

The complexity of wagon technology was relatively low; it should have been easy for most Neolithic communities to build these simple machines. Rotary motion (see above) was well known and did not 'push' or enable wagon technology. Rather, the development went the opposite way, insofar as the knowledge of wagons inspired new applications for rolling objects and pivoting axes.

The technical know-how required to construct a chassis was certainly less complex than that necessary for constructing a wooden longhouse (which Neolithic societies began doing in the 6th millennium). One could, nevertheless, argue that the construction of wheels might have caused some difficulties. The introduction of hollow copper chisels has been brought forward as a direct prerequisite for the making of wheels,[73] mainly because of the association of two chisels in Ebla with a donkey and a wagon, dated around 2850 BC. In southeastern Europe, hollow chisels are known from finds in Brono-Lišeň,[74] Fajz in Transdanubia,[75] and Petralona,[76] as well as one at Tell Dipsis near Ezero, Bulgaria in a layer set into the late 3rd millennium because of analogies with Troy III-V.[77] Even if the chronological discrepancy makes clear that such chisels cannot be connected with the invention of the wheel, they might be partially responsible for its takeoff.[78] It is remarkable that neither the Early Neolithic cultures of Central Europe nor the early Funnelbeaker culture seems to have produced flint chisels, and that in these regions, chisels appear later towards the end of the 4th millennium BC.[79]

The necessary knowledge to construct vehicles, to use animals to pull these vehicles, and to understand a pivoting axle was available between Central Europe and Mesopotamia in the 4th millennium BC, but did *not* result in the diffusion of a uniformly designed cart. Instead, combinations of the single components were included in local technical systems.

Stefan Burmeister has remarked that the different technologies suggest that the idea and not the artifact was transferred,[80] but I think it is possible to specify this even more: the available know-how was used to produce objects that the socio-technical substructure of the given societies could support, and these were adapted to the local environment. For instance, in the Alpine region, wagons with an A-shaped chassis are thought to derive

70 The oldest evidence is still the model from Palaikastro, dating to the early 2nd millennium BC Couwel 1981 Taf. 49,T52.

71 The oldest find dates from the late 3rd millennium. Cf. Quibell and Hayter 1927 frontispiece; also shown: Burmeister 2004b, 23.

72 E.g., in the Middle Euphrates region wagon models do not appear before the Early Middle Euphrat 3 period, i.e., 2747/2625–2525/2492 calBC; cf. Pruß 2015; Deckers, Drechsler, and Sconzo 2015, 420 Fig. 14.

73 Piggott 1983, 25.

74 Hansen 2009a.

75 Kalicz 1968, 47 plates 16–17; 19–21; Hansen 2009a,34–36.

76 Hansen 2013, 162.

77 Klimscha 2010, 114 Fig. 7.

78 Hansen 2013, 162. Simpler, flat chisels nevertheless happen to be found in earlier contexts, for instance at Arslantepe, dating to c. 3800–3400 BC (Frangipane et al. 2001), and at Tall Hujayrat al-Ghuzlan, near Aqaba, Jordan, dating to 3650–3500 BC (Klimscha 2010).

79 Brandt 1967, 109–126.

80 Burmeister 2004a.

from the A-shaped travois[81] from Reute-Schorrenried[82] and Chalain,[83] or the rock art from the Val de Fontalbe in Mont Bego.[84]

With very few and ambiguous examples left outside, however, the evidence of the use of animal traction in cattle pairs correlates well with the overall innovation process of wheeled vehicles. Therefore, I would argue, the takeoff of wagons is the result of the wider availability of animal traction and, to a lesser degree, a better understanding of the economic usages of rotary motion, as well as the production of specialized woodworking tools. Vast areas of Eurasia were aware of the use of animal traction, but this knowledge led to very distinct solutions visible in the archaeological record because it still had to be translated into local technical and ritual traditions. The *châine opératoire* was simple enough to be moved between societies with grossly varying social complexity, and it could build upon technical knowledge that was widely known. Once established in a number of communities, the innovation could be scrutinized and easily transformed according to the requirements of different environments and social rules. The takeoff was remarkably quick, and within some 300 years cattle-drawn vehicles and plows were being brought into many areas between the North Sea and the Black Sea. The prerequisite for such a rapid takeoff should be a correspondingly high communication density within this area in the time preceding adoption.

11 Modeling the innovation process of the wheel and the wagon

The aim of this paper has been to highlight a *longue-durée* perspective on the innovation process of the wagon, using the interoperable maps of the Digital Atlas of Innovation. The technical principles necessary to build wheeled vehicles were known since the Neolithic Revolution, and the knowledge of even explicit technical modules like the pivoting axle and the use of cattle to pull heavy objects was present significantly earlier than the takeoff period of the wagon.

12 Conclusion: The secondary products revolution rethought

The foregoing has established a connection between the technical evolution of the wagon and the circulation of know-how within a larger sphere of interaction, with the knowledge of traction as the major factor. This sphere can be defined independently by the repartition of pottery styles, lithic technocomplexes, or copper artifacts. It is constructed from several smaller interaction zones that may also have included the exchange of human resources. The technical know-how circulating within these zones was then transformed according to local specifications.

A successive intensification of communication frequency and quality during the 4th millennium can be demonstrated, and its peak correlates with the takeoff of the wagon in western Eurasia, when evidence for animal traction and the wheel can be seen between the Persian Gulf, the Alps, the North Sea, and the Caucasus. Suddenly societies of grossly differing complexity (ranging from early states to egalitarian villages) seem to recombine their available know-how to produce wheeled vehicles. The analysis of the maps in this paper makes a monocentral diffusion very unlikely – even for stimulus diffusion. When the available knowledge is widely available and already being continuously transformed,

81 Schlichterle 2002, 26.
82 Mainberger 1997, Fig. 8.
83 Pétrequin et al. 2002 60 Fig. 6–7.
84 Pétrequin et al. 2002, 62 Fig. 9; Arcà 2011, 74 Fig. 2; cf. also the extensive catalogue of Lumeley 2003.

it is more plausible to assume a more active role for all the participants in the networks within the discussed sphere of interaction.

I do not want to propose multiple inventions, but instead to stress the *polynodal* infrastructure of the sphere of interaction. Such a network is not only continuously exchanging information, but also transforming it in the process. There is no single node emitting 'the' idea; rather, sets of ideas travel together with artifacts and people. This is how technical know-how is accumulated, and with techniques as simple as the wagon, the underlying idea can be used as a template to create region-specific technical solutions. The different ways that animal traction was used – the two-wheeled carts of the Alpine region, the cattle-drawn sleds in the Near East, or the four-wheeled wagons in the Pontic area – can be understood as interpretations of this template. All deploy the combination of traction and vehicle, and optionally (!) the wheel.

Stages of the innovation process of wheeled vehicles might therefore have taken place in different contexts and only for selected components of the technical system. Although some regions chose to construct different meanings for the innovation, this did not exclude them from adopting the original meaning at a later stage. The relative simple *chaîne opératoire* of wheeled vehicles allowed societies to quickly transform any development stage thereof to fit with locally reinvented components. A good example of this is the introduction of the battle cart as depicted on the Standard of Ur, which integrated a new form of traction that was originally developed in a completely different context. Other examples include the integration of the domestic donkey into the technical system[85] and the development in the Alps of wagons and travois with an A-shaped chassis.[86]

Indeed, the wheel is the least important part of this technical set. In Egypt, the Levant, and Syria-Mesopotamia, the set is used only rarely for vehicles. Nevertheless, the socio-technical relations within these societies make use of the principle in a multitude of ways: doors rotating on a door socket, cylinder seals, and the potter's wheel, for instance.

For a final look from a broader perspective, all data entries were classified according to whether they were evidence for vehicle movement, animal traction, or the wheel. Both the idea of vehicle movement by animal traction (Fig. 43) and the wide adoption of the wheel (Fig. 44) correlate fairly well and seem to be closely connected.

What was the impulse responsible for the wagon's takeoff? As I have shown, the technical components later used for the wagon were already in existence in earlier times, and as Burmeister has recently argued, it is very possible that the actual *invention* of the wagon could have happened as early as the 5th millennium.[87] The evidence for the use of animal labor clearly favors such a view.[88] Nevertheless, the widespread appearance of wheeled vehicles and the plow between the North Sea and the Euphrates is a striking novelty only in the late 4th millennium BC, and seem to confirm Andrew Sherratt's concept of a Secondary Products Revolution.[89]

This paper has shown that, for some parts of Europe, there is strong evidence that the visibility of the wagon is closely connected with its introduction, while for other parts of Eurasia, ideological changes are responsible for the evidence appearing in the archaeological record.

Thus, two lines of thought converge:

Either wagon technology could arrive as a package (traction + plow + wheel), or the necessary technical knowledge was already available. In both cases, the emergence of the

85 Littauer and J. H. Crouwel 2002, 26 Fig. 1

86 Pétrequin et al. 2002 60 Fig. 6–7.

87 Burmeister 2011; Burmeister 2012.

88 Hill 2011.

89 Sherratt 1981.

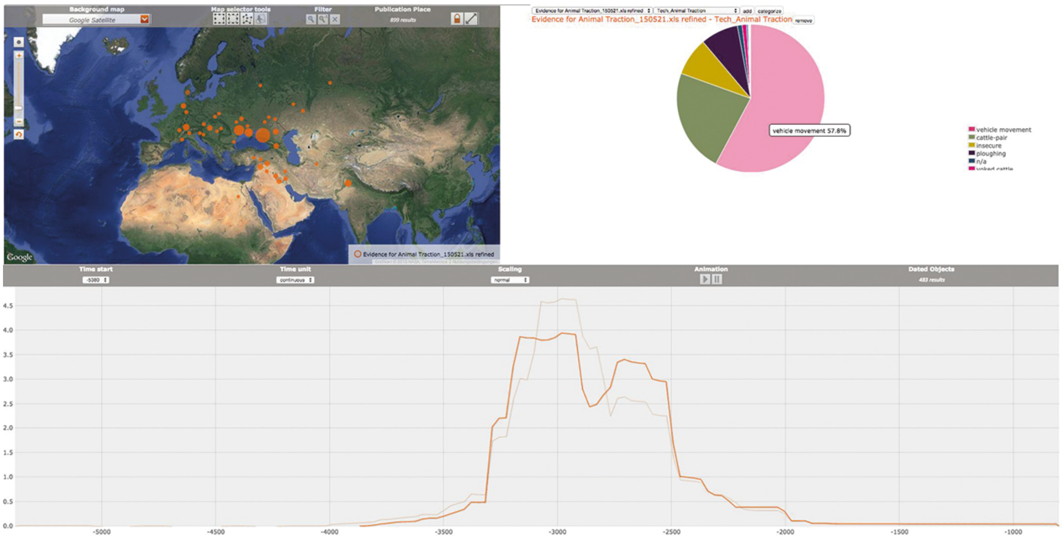

Fig. 43 | Repartition and frequency of evidence for vehicle movement by animal traction in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

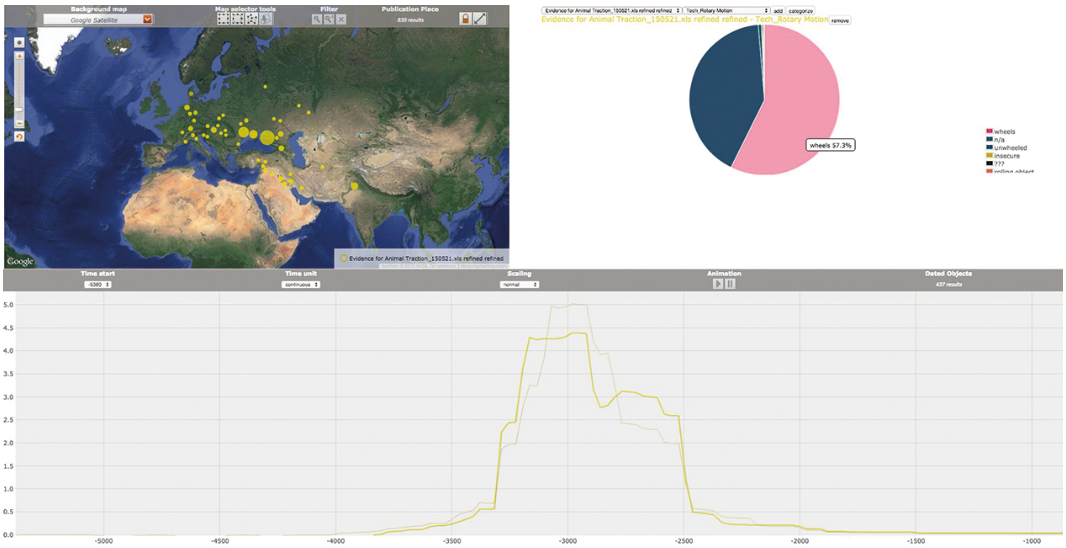

Fig. 44 | Repartition and frequency of finds of wheels in the 4th and 3rd millennia BC (query from the Digital Atlas of Innovations).

wagon resulted in experimentation with previously known technology and a variety of usages.

The archaeological evidence highlights many changes that might be connected with the intensified use of animal traction. Raising megalithic graves would definitely have been much easier using animal traction, and the context of the wagon tread marks at Flintbek clearly suggests the use of vehicles at some point during the construction. This intensification might have resulted in a dependency on such animal technology, and this, in turn, would explain the social innovations of using wagons in funeral rites. By this point, animal traction and the wheel would have become part of socioeconomic systems.

Yet this was not the end, but the start of new innovation processes connected with other innovations: in the Near East, for instance, the combination of wagon technology, the domestication of the donkey,[90] and specialized close-combat weapons[91] was integral to the construction of the first battle carts and the transformation of warfare.

These manifold changes were not caused by the wagon, of course, but the wagon was one part of a larger process that radically transformed Eurasia during the 4th millennium: the industry of heavy copper weapons and tools in the Balkans and the Carpathian Basin ceased to exist,[92] as did the production of clay figurines[93], while writing, sealing, balance systems[94] as well as the domestic donkey[95] appeared – but only in the eastern Mediterranean.

Contact and small-scale change did not stop at the end of the 4th millennium. On the contrary, within the time span from 3500 to 2200 BC, it is difficult to clearly see periods without innovations – it is only from a modern, etic perspective that innovations like animal traction, wheels, and plowing are valued higher than halberds,[96] flanged copper axes,[97] Baniabic-type axes,[98] or stone stelae.[99]

The implementation of key innovations like animal traction, the plow, and the wheel did have great long-term consequences, however, as Peter Bogucki has shown:[100] social units that were able to monopolize the control of such innovations were able to accumulate food, wealth, and possibly also political power. The subsequent transition from the Funnelbeaker ideology to the Corded Ware is connected with a shift from technical to social innovation, and it might therefore be another worthy adventure to closely analyze the long-term effects of technical change in the 3rd millennium in a similar manner.

Illustration credits

1 DAI/Eurasien-Abteilung und Max-Planck-Institut für Wissenschaftsgeschichte.
2–8 Svend Hansen, Florian Klimscha and Jürgen Renn: The Digital Atlas of Innovations. Figures: © Landsat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, U.S. Geological Survey; Map source: © Google, ORION-ME. **9** Svend Hansen, Florian Klimscha and Jürgen Renn: The Digital Atlas of Innovations. **10–19** Svend Hansen, Florian Klimscha and Jürgen Renn: The Digital Atlas of Innovations. Figures: © Landsat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, U.S. Geological Survey; Map source: © Google, ORION-ME. **20** Svend Hansen, Florian Klimscha and Jürgen Renn: The Digital Atlas of Innovations. **21–44** Svend Hansen, Florian Klimscha and Jürgen Renn: The Digital Atlas of Innovations. Figures: © Landsat, Data SIO, NOAA, U.S. Navy, NGA, GEBCO, U.S. Geological Survey; Map source: © Google, ORION-ME.

90 Milevski 2011, 178–197.
91 Klimscha 2014.
92 Schubert 1965.
93 Hansen 2009b.
94 E.g. Rahmstorf 2006; Rahmstorf 2011; Rahmstorf and Zimmermann 2012.
95 Cf. Milevski 2011, 185–186 Fig. 10.3 Fig 10.4; Klimscha 2013, 99–102.
96 Horn 2014, 172–173.
97 Klimscha 2010.
98 Hansen 2011.
99 Vierzig (unpublished).
100 Bogucki 1993.

References

Arcà 2011
Andrea Arcà. "Entre Bégo et Val Camonica Une clé pour mieux comprendre l'origine de l'art rupestre dans les Alpes". *Bulletin d'etudes prehistoriques et archeologiques alpines* XXII (2011), 71–91.

Bakker 2004
Jan Albert Bakker. "Die neolithischen Wagen im nördlichen Mitteleuropa". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 283–294.

Bakker et al. 1999
Jan Albert Bakker, Janusz Kruk, Albert E. Lanting, and Sarunas Milisauskas. "The Earliest Evidence of Wheeled Vehicles in Europe and the Near East". *Antiquity* 73 (1999), 778–790.

Behrens 1963
H. Behrens. "Die Rindskelettfunde der Péceler Kultur und ihre Bedeutung für die Erkenntnis historischer Zusammenhänge". *Acta Archaeologica Academiae Scientiarum Hungaricae* 15 (1963), 33–36.

Benecke 2004
Norbert Benecke. "Die Domestikation der Zugtiere". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 455–466.

Bernbeck 2004
Reinhard Bernbeck. "Gesellschaft und Technologie im frühgeschichtlichen Mesopotamien". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 49–68.

Bogucki 1993
Peter Bogucki. "Animal Traction and Household Economies in Neolithic Europe". *Antiquity* 67 (1993), 492–503.

Bondár 1990
Mária Bondár. "Das frühbronzezeitliche Wagenmodell von Börzönce". *Communicationes Archaeologicae Hungariae* 1990 (1990), 77–91.

Bondár 2012
Mária Bondár. *Prehistoric Wagon Models in the Carpathian Basin (3500–1500 BC)*. Vol. 32. Archaeolingua, Series Minor. Budapest: Archaeolingua Alapítvány, 2012.

Boroffka 2004
Nikolaus Boroffka. "Nutzung der tierischen Kraft und Entwicklung der Anschirrung". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 467–480.

Bosch et al. 1999
A. Bosch, R. Buxo, J. Chinchilla, M. Sana, and J. Tarrus. "La Draga (Banyoles) et le Néolithique ancien de la Catalogne". In *Le Néolithique du Nord-Ouest méditerranéen. Actes du XXIVe Congrès préhistorique de France, Carcassone, 1994*. Paris: Societé Préhistorique Française, 1999, 195–210.

Brandt 1967
Karl Heinz Brandt. *Studien über steinerne Äxte und Beile der jüngeren Steinzeit und Stein-Kupferzeit Nordwestdeutschlands*. Münstersche Beiträge zur Vorgeschichtsforschung 2. Hildesheim: Lax, 1967.

Burmeister 2002
Stefan Burmeister. "Straßen im Moor. Die befahrbaren stein- und bronzezeitlichen Moorwege in Nordwestdeutschland". In *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Hemmenhofener Skripte 3. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002, 123–132.

Burmeister 2004a
Stefan Burmeister. "Der Wagen im Neolithikum und in der Bronzezeit: Erfindung, Ausbreitung und Funktion der ersten Fahrzeuge". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 13–40.

Burmeister 2004b
Stefan Burmeister. "Neolithische und bronzezeitliche Moorfunde aus den Niederlanden, Nordwestdeutschland und Dänemark". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 321–340.

Burmeister 2011
Stefan Burmeister. "Innovationswege – Wege der Kommunikation. Erkenntnisprobleme am Beispiel des Wagens im 4. Jahrtausend v. Chr." In *Sozialarchäologische Perspektiven: Gesellschaftlicher Wandel 5000–1500 v. Chr. zwischen Atlantik und Kaukasus*. Archäologie in Eurasien 24. Mainz: von Zabern, 2011, 211–240.

Burmeister 2012
Stefan Burmeister. "Der Mensch lernt fahren – Zur Frühgeschichte des Wagens". *Mitteilungen der Anthropologischen Gesellschaft in Wien* 142 (2012), 81–100.

Burmeister and Raulwing 2012
Stefan Burmeister and Peter Raulwing. "Festgefahren. Die Kontroverse um den Ursprung des Streitwagens. Einige Anmerkungen zu Forschung, Quellen und Methodik". In *Archaeological, Cultural and Linguistic Heritage,Festschrift for Erzsébet Jerem in Honour of her 70th Birthday*. Ed. by P. Anreiter. Budapest: Archaeolingua Alapítvány, 2012, 93–113.

Childe 1951
Vere Gordon Childe. "The First Waggon and Carts- from the Tigris to the Severn". *Proceedings of the Prehistoric Society* XVII.17 (1951), 177–194.

Childe 1954
Vere Gordon Childe. “The Diffusion of the Wheeled Vehicles”. *Ethnologisch-Archäologische Forschungen*. Ethnographisch-Archäologische Forschungen 2 (1954), 1–17.

Couwel 1981
Joost Couwel. *Chariots and Other Means of Land Transport in Bronze Age Greece*. Allard Pierson Series Studies in Ancient Civilisation 3. Amsterdam: Allard Pierson Museum, 1981.

J. Crouwel 2004
Joost Crouwel. “Der Alte Orient und seine Rolle in der Entwicklung von Fahrzeugen”. In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Oldenburg: von Zabern, 2004, 69–86.

Dayagi-Mendels and Rozenberg 2010
Michal Dayagi-Mendels and Silvia Rozenberg, eds. *Chronicles of the Land. Archaeology in The Israel Museum Jerusalem*. Jerusalem: The Israel Museum, 2010.

Deckers, Drechsler, and Sconzo 2015
Kathleen Deckers, Philipp Drechsler, and Paola Sconzo. “Radiocarbon Chronology”. In *Middle Euphrates*. ARCANE 4. Turnhout: Brepols, 2015, 401–422.

Dinu 1981
Marin Dinu. “Clay Models of Wheels Discovered in Copper Age Cultures of Old Europe Mid-Fifth Millennium B.C.” *Journal of Indo-European Studies* 9.1–2 (1981), 1–14.

Döhle and Stahlhofen 1985
Hans-Jürgen Döhle and Heribert Stahlhofen. “Die neolithischen Rindergräber auf dem ‚Löwenberg‘ bei Derenburg, Kr. Wernigerode”. *Jahresschrift für Mitteldeutsche Vorgeschichte* 68 (1985), 157–177.

Fansa 2004
Mamoun Fansa, ed. *Führer durch die Sonderausstellung: Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa, vom 28.03. bis 11.07.2004*. Beiheft der Archäologischen Mitteilungen aus Nordwestdeutschland 41. Oldenburg: Isensee Verlag, 2004.

Fansa and Burmeister 2004
Mamoun Fansa and Stefan Burmeister, eds. *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004.

Frangipane et al. 2001
Marcella Frangipane, Gian M. Di Nocerra, Andreas Hauptmann, Paola Morbidelli, Alberto M. Palmieri, Laura Sadori, Michael Schultz, and Tyede Schmidt-Schultz. “New Symbols of a New Power in a ‘Royal’ Tomb from 3000 BC Arslantepe, Malatya (Turkey)”. *Paléorient* 27.2 (2001), 105–139.

Friedrich and Hoffmann 2013
Susanne Friedrich and Verena Hoffmann. “Die Rinderbestattungen von Profen – mit Rad und Wagen”. In *3300 BC. Mysteriöse Steinzeittote und ihre Welt*. Ed. by Harald Meller. Halle/Saale: Nünnerich-Asmus, 2013, 83–84.

Grömer, Hofmann-de Keijzer, and Rösel-Mautendorfer 2016
Karina Grömer, Regina Hofmann-de Keijzer, and Helga Rösel-Mautendorfer. *The Art of Prehistoric Textile Making. The Development of Craft Traditions and Clothing in Central Europe*. Veröffentlichungen der Prähistorischen Abteilung 5. Wien: Natural History Museum Vienna, 2016.

Günther 1990
Klaus Günther. "Neolithische Bildzeichen an einem ehemaligen Megalithgrab bei Warburg, Kreis Höxter (Westfalen)". *Germania* 68 (1990), 39–65.

Gušev 1998
S. A. Gušev. "Voprosu o transportnyh sredstvah tripolskoj kultury. [On the Issue of the Tripolye Culture Transportation Means]". *Rossijskaja archeologija* 1998 (1998), 15–28.

Hansen 2009a
Svend Hansen. "Kuperzeitliche Äxte zwischen dem 5. und 3. Jahrtausend in Südosteuropa". *Analele Banatului, S.N.* 17 (2009), 139–158.

Hansen 2009b
Svend Hansen. "Silber im Schwarzmeerraum während des 5. und 4. Jahrtausends v. Chr". In *Der Schwarzmeerraum vom Äneolithikum bis in die Früheisenzeit (5000–500 v. Chr.). Kommunikationsebenen zwischen Kaukasus und Karpaten. Internationale Fachtagung von Humboldtianern für Humboldtianer im Humboldt-Kolleg in Tiflis/Georgien (17.–20. Mai 2007)*. Ed. by J. Apakidze, B. Govedarica, and B. Hänsel. Rahden/Westf.: Leiden, 2009, 11–50.

Hansen 2011
Svend Hansen. "Innovation Metall. Kupfer, Gold und Silber in Südosteuropa während des fünften und vierten Jahrtausends v. Chr." *Das Altertum* 56 (2011), 275–314.

Hansen 2013
Svend Hansen. "Innovative Metals. Copper, Gold and Silver in the Black Sea Region and the Carpathian Basin during the 5th and 4th Millennium BC". In *Metal Matters. Innovative Technologies and Social Change in Prehistory and Antiquity*. Ed. by S. Burmeister, S. Hansen, M. Kunst, and N. Müller-Scheessel. Menschen – Kulturen – Traditionen 12: ForschungsCluster 2. Rahden/Westf.: Marie Leidorf, 2013, 137–167.

Hansen 2014
Svend Hansen. In *Metalle der Macht. Frühes Gold und Silber. 6. Mitteldeutscher Archäologentag vom 17. bis 19. Oktober 2013 in Halle (Saale). Metals of Power. Early Gold and Silver. 6th Archaeological Conference of Central Germany. October 17–19 2013 in Halle (Saale)*. Ed. by Harald Meller, Roberto Risch, and Ernst Ernst Pernicka. Halle/Saale: Landesamt für Denkmalpflege und Archäologie Sachsen Anhalt, Landesmuseum für Vorgeschichte, 2014, 390–410.

Hansen, Dragoman, Reingruber, Becker, et al. 2006
Svend Hansen, Alexandru Dragoman, Agathe Reingruber, Nico Becker, Ivan Gatsov, Tina Hoppe, Florian Klimscha, Petranka Nedalcheva, B. Song, and Joachim Wahl. "Pietrele. Eine kupferzeitliche Siedlung an der Unteren Donau. Bericht über die Ausgrabung im Sommer 2005". *Eurasia Antiqua* 12 (2006), 1–62.

Hansen, Dragoman, Reingruber, Gatsov, et al. 2005
Svend Hansen, Alexandru Dragoman, Agathe Reingruber, Ivan Gatsov, Jochen Görsdorf, Petranka Nedelcheva, Sorin Oanţă-Marghitu, and B. Song. "Der kupferzeitliche Siedlungshügel Pietrele an der Unteren Donau. Bericht über die Ausgrabungen im Sommer 2004". *Eurasia Antiqua* 11 (2005), 341–393.

Hansen, Toderaş, Reingruber, Becker, et al. 2009
Svend Hansen, Meda Toderaş, Agathe Reingruber, Nico Becker, Ivan Gatsov, Marvin Kay, Petranka Nedelcheva, Michael Prange, Astrid Röpke, and Jürgen Wunderlich. "Pietrele: Der kupferzeitliche Siedlungshügel ‚Măgura Gorgana' und sein Umfeld. Bericht über die Ausgrabungen und geomorphologischen Untersuchungen im Sommer 2008". *Eurasia Antiqua* 15 (2009), 15–66.

Hansen, Toderaş, Reingruber, Gatsov, Georgescu, et al. 2007
Svend Hansen, Meda Toderaş, Agathe Reingruber, Ivan Gatsov, Cristina Georgescu, Jochen Görsdorf, Tina Hoppe, Petranka Nedelcheva, Michael Prange, Joachim Wahl, and Petar Zidarov. "Pietrele, Măgura Gorgana. Ergebnisse der Ausgrabung im Sommer 2006". *Eurasia Antiqua* 13 (2007), 43–112.

Hansen, Toderaş, Reingruber, Gatsov, Klimscha, et al. 2008
Svend Hansen, Meda Toderaş, Agathe Reingruber, Ivan Gatsov, Florian Klimscha, Petranka Nedelcheva, Reinder Neef, Michael Prange, T. Douglas Price, Joachim Wahl, Bernhard Weninger, Heide Wrobel, Jürgen Wunderlich, and Petar Zidarov. "Der kupfer- zeitliche Siedlungshügel Magura Gorgana bei Pietrele in der Walachei. Ergebnisse der Ausgrabungen im Sommer 2007". *Eurasia Antiqua* 14 (2008), 17–98.

Hill 2011
Austin Hill. *Specialized Pastoralism and Social Stratification. Analysis of the Fauna from Chalcolithic Tel Tsaf, Israel*. PhD thesis. University of Connetticut AI3504774, 2011. http://digitalcommons.uconn.edu/dissertations/AAI3504774 (visited on 03/16/2017).

Horn 2014
Christian Horn. *Studien zu den europäischen Stabdolchen*. Universitätsforschungen zur Prähistorischen Archäologie 246. Bonn: Habelt, 2014.

Johannsen and Laursen 2010
Niels Johannsen and Steffen Laursen. "Routes and Wheeled Transport in Late 4th–Early 3rd Millenium Funerary Customs of the Jutland Peninsula: Regional Evidence and European Context". *Praehistorische Zeitschrift* 85 (2010), 15–58.

Kalicz 1968
Nándor Kalicz. *Die Frühbronzezeit in Nordost-Ungarn*. Archaeologia Hungarica 45. Budapest: Akadémiai Kiadó, 1968.

Kinnunen 1996
Jussi Kinnunen. "Gabriel Tarde as a Founding Father of Innovation Diffusion Research". *Acta Sociologica* 39.4 (1996), 431–442. http://www.jstor.org/stable/4194846 (visited on 01/26/2017).

Klimscha 2010
Florian Klimscha. "Kupferne Flachbeile und Meißel mit angedeuteten Randleisten: Ihre Bedeutung für die Entstehung und Verbreitung technischer Innovationen in Europa und Vorderasien im 4. und 3. Jahrtausend v. Chr." *Germania* 88 (2010), 101–144.

Klimscha 2013
Florian Klimscha. "Innovations in Chalcolithic Metallurgy in the Southern Levant During the 5th and 4th Millennium BC. Copper Production at Tall Hujayrat al-Ghuzlan and Tall al-Magass, Aqaba Area, Jordan". In *Metal Matters. Innovative Technologies and Social Change in Prehistory and Antiquity*. Ed. by S. Burmeister, S. Hansen, M. Kunst, and N. Müller-Scheessel. Menschen – Kulturen – Traditionen 12: ForschungsCluster 2. Rahden/Westf.: Marie Leidorf, 2013, 31–63.

Klimscha 2014
Florian Klimscha. "Technikarchäologische Perspektiven zum Aufkommen spezialisierter Angriffswaffen aus Stein und Kupfer in der südlichen Levante". In *Gewalt und Gesellschaft. Dimensionen der Gewalt in ur- und frühgeschichtlicher Zeit*. Ed. by Th. Link and H. Peter-Röcher. Universitätsforschungen zur prähistorischen Archäologie 259. Bonn: Habelt, 2014.

Köninger 2002
Joachim Köninger, ed. *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Hemmenhofener Skripte 3. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002.

Korek 1951
Joszef Korek. "Ein Gräberfeld der Badener Kultur bei Alsónémedi". *Acta Archaeologica Hungarica* 1 (1951), 35–54.

Kruk and Milisauskas 1982
Janusz Kruk and Sarunas Milisauskas. "Die Wagendarstellung auf einem Trinkbecher aus Bronocice in Polen". *Archäologisches Korrespondenzblatt* 12.2 (1982), 141–144.

Kruk and Milisauskas 1991
Janusz Kruk and Sarunas Milisauskas. "Utilization of Cattle for Traction During the Later Neolithic in Southeast Poland". *Antiquity* 65.248 (1991), 562–566.

Lebeau 2011
Marc Lebeau, ed. *Jezirah*. ARCANE 1. Turnhout: Brepols, 2011.

Levy and Gilead 2012
Janet Levy and Isaac Gilead. "Spinning in the 5th millennium in the Southern Levant: Aspects of the Textile Economyâ". *Paléorient Année* 38.1 (2012), 127–139.

Link, Pyzel, and Perschke (in press)
Thomas Link, Joanna Pyzel, and Reena Perschke, eds. *Das 4. Jahrtausend. Fokus Jungsteinzeit. Berichte der AG Neolithikum 6 (Tagung AG Neolithikum in Lübeck 20132)*. 2014. In press.

Littauer and J. H. Crouwel 2002
Mary A. Littauer and Joust H. Crouwel. *Selected Writngs on Chariots and other Early Vehicles, Riding and Harness*. Culture and History of the Ancient Near East 6. Leiden: Brill, 2002.

Lumeley 2003
Henry de Lumeley. *Région du mont Bego. Gravures protohistoriques et historiques. Tende, Alpes-Maritimes 14. Secteur des Merveilles. Zone du Grand Capelet. Zone XII. Groupes I á VI*. Aix-en-Provence: Edisud, 2003.

Mainberger 1997
Martin Mainberger. "'Rätselhafte Holzobjekte' des Pfahlbauneolithikums: Ein Transportgerätetyp vor der Erfindung von Rad und Wagen?" *Archäologisches Korrespondenzblatt* 27.3 (1997), 415–422.

Maran 2004
Joseph Maran. "Die Badener Kultur und ihre Räderfahrzeuge". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beiheift zu Archäologische Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 265–294.

Matuschik 2002
Irenäus Matuschik. "Kupferne Rindergespann-Darstellungen der mitteleuropäischen Kupferzeit". In *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Hemmenhofener Skripte 3. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002, 111–122.

Matuschik 2006
Irenäus Matuschik. "Invention et diffusion de la roue dans l'Ancien Monde: l'apport de l'iconographie". In *Premiers chariot, premiers araires. La diffusion de la traction animale en Europe pendant les Ive et IIIe millénaires avant notre ère*. Ed. by Pierre Pétrequin, Rose-Marie Arbogast, Anne-Marie Pétreuin, Samuel van Willingen, and Maxence Bailly. CRA monographies 29. Paris: CNRS Éditions, 2006, 275–278.

Milevski 2011
Ianir Milevski. *Early Bronze Age Goods Exchange in the Southern Levant. A Marxist Perspective*. London: Equinox, 2011.

Milisauskas, Kruk, and Poliszot-Makowicz 1993
Sarunas Milisauskas, Janusz Kruk, and Danuta Poliszot-Makowicz. "Observations on the Utilization of Domestic Animals by the Funnel Beaker and Baden Populations at Bronocice, Southeastern Poland". In *Actes du XIIe Congrès International des Sciences Préhistoriques et Protohistoriques*. Ed. by J. Pavúk. Vol. 2. Union internationale des sciences prehistoriques et protohistoriques. Bratislava: Institut Archéologique de l'Academie Slovaque des Sciences, 1993, 457–460.

Mischka 2011
Doris Mischka. "The Neolithic Burial Sequence at Flintbek LA 3, North Germany, and Its Cart Tracks: a Precise Chronology". *Antiquity* 85.329 (2011), 742–758.

J. Müller 2004
Johannes Müller. "Zur Innovationsbereitschaft mitteleuropäischer Gesellschaften im 4. vorchristlichen Jahrtausend". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 255–264.

S. Müller 1897
Sophus Müller. *Vor Oldtid*. Copenhagen: Det Nordiske Forlag, 1897.

S. Müller 1905
Sophus Müller. *Urgeschichte Europas. Grundzüge einer prähistorischen Archäologie*. Strassburg: Trübner, 1905.

Novozhenov 2012
Victor A. Novozhenov. *Communications and Earliest Wheeled Transport of Eurasia*. Moscow: TAUS, 2012.

Oates et al. 2007
Joan Oates, Augusta McMahon, Philip Karsgaard, Salam Al Quntar, and Jason Ur. "Early Mesopotamian Urbanism: a New View from the North". *Antiquity* 81.313 (2007), 585–600.

Pétrequin et al. 2002
Pierre Pétrequin, Rose-Marie Arbogast, Amandine Viellet, Anne-Marie Pétrequin, and Denis Maréchal. "Eine neolithische Stangenschleife vom Ende des 31. Jhs. v. Chr. in Chalain (Fontenu, Jura, Frankreich)". In *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002, 55–65.

Piggott 1983
Stuart Piggott. *The Earliest Wheeled Transport: From the Atlantic to the Caspian Sea*. London: Thames and Hudson, 1983.

Piggott 1992
Stuart Piggott. *Wagon, Chariot and Carriage. Symbol and Status in the History of Transport*. London: Thames and Hudson, 1992.

Pruß 2011
Alexander Pruß. "Figurines and Model Vehicles". In *Jezirah*. Ed. by M. Lebeau. ARCANE 1. Turnhout: Brepols, 2011, 239–254.

Pruß 2015
Alexander Pruß. "Animal Terracotta Figurines and Model Vehicles". In *Middle Euphrates*. Ed. by U. Finkbeiner, M. Novák, F. Sakal, and P. Sconzo. ARCANE 4. Turnhout: Brepols, 2015, 279–298.

Quibell and Hayter 1927
James Edward Quibell and Angelo George Kirby Hayter. *Teti Pyramid, North Side. Excavations at Saqqara*. Kairo: Imprimene de l'Institut Français d'Archéologie Orientale, 1927.

Radivojević and Rehren 2016
Miliana Radivojević and Thilo Rehren. "Paint It Black: The Rise of Metallurgy in the Balkans". *Journal of Archaeological Method and Theory* 23.1 (2016), 200–237. DOI: 10.1007/s101816-014-9238-3.

Rahmstorf 2006
Lorenz Rahmstorf. "In Search of the Earliest Balance Weights, Scales and Weighing Systems from the East Mediterranean, the Near and the Middle East". In *Weights in Context. Bronze Age Weighing Systems of Eastern Mediterranean. Chronology, Typology, Material and Archaeological Contexts. Proceedings of the International Colloquium, Roma 22nd–24th November 2004*. Ed. by M.E. Alberti, E. Ascalone, and L. Peyronel. Roma: Istituto Italiano di Numismatica, 2006, 9–46.

Rahmstorf 2011
Lorenz Rahmstorf. "Maß für Maß. Indikatoren für Kulturkontakte im 3. Jahrtausend". In *Kykladen. Lebenswelten einer frühgriechischen Kultur*. Ed. by Badisches Landesmuseum. Darmstadt: Primus Verlag, 2011, 144–153.

Rahmstorf and Zimmermann 2012
Lorenz Rahmstorf and Andreas Zimmermann. "Control Mechanisms in Mesopotamia, the Indus Valley, the Aegean and Central Europe, c. 2600–2000, and the Question of Social Power in Early Complex Societies". In *Beyond Elites. Alternatives to Hierarchical Systems in Modelling Social Formations*. Ed. by T. Kienlin. Universitätsforschungen zur Prähistorischen Archäologie 215. Bonn: Habelt, 2012, 311–326.

Regev, Miroschedji, and Boaretto 2012
Johanna Regev, Pierre de Miroschedji, and Elisabetta Boaretto. "Early Bronze Age Chronology: Radiocarbon Dates and Chronological Models from Tel Yarmuth (Israel)". *Radiocarbon* 54.1-3 (2012), 505–524.

Regev, Miroschedji, Greenberg, et al. 2012
Johanna Regev, Pierre de Miroschedji, Raphael Greenberg, Eliot Braun, Zvi Greenhut, and Elisabetta Boaretto. "Chronology of the Early Bronze Age in the Southern Levant: New Analysis for a High Chronology". *Radiocarbon* 54.3-4 (2012), 525–566.

Renfrew 1969
Colin Renfrew. "The Autonomy of the South East European Copper Age". *Proceedings of the Prehistoric Society* 35 (1969), 12–47.

Renfrew 1973
Colin Renfrew. *Before Civilization: The Radiocarbon Revolution and Prehistoric Europe*. London: Cape, 1973.

Ristvet 2011
Lauren Ristvet. "Radiocarbon". In *Jezirah*. Ed. by M. Lebeau. ARCANE 1. Turnhout: Brepols, 2011, 301–326.

Rizkana and Seeher 1988
Ibrahim Rizkana and Jürgen Seeher. *Maadi II. The Lithic Industries of the Predynastic Settlement*. Arch. Veröff. DAI Kairo 65. Mainz: von Zabern, 1988.

Rogers 2003
Everett M. Rogers. *Diffusion of Innovations*. 5. Auflage. New York: Free Press, 2003.

Schlichterle 2002
Helmut Schlichterle. "Die jungsteinzeitlichen Radfunde vom Federsee und ihre kulturgeschichtliche Bedeutung". In *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002, 9–34.

Schlichterle 2004
Helmut Schlichterle. "Wagenfunde aus den Seeufersiedlungen im zirkumalpinen Raum". In *Rad und Wagen – Der Ursprung einer Innovation.Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Archäologische Mitteilungen aus Nordwestdeutschland, Beiheft 40. Mainz: von Zabern, 2004, 295–314.

Schubert 1965
Franz Schubert. "Zu den südosteuropäischen Kupferäxten". *Germania* 43 (1965), 274–295.

Sherratt 1981
Andrew Sherratt. "Plough and Pastoralism: Aspects of the Secondary Products Revolution". In *Patterns of the Past, Studies in Honour of David Clarke*. Ed. by Ian Hodder, G. Isaac, and N. Hammond. Cambridge: Cambridge University Press, 1981, 261–305.

Sherratt 1983
Andrew Sherratt. "The Secondary Exploitation of Animals in the Old World". *World Archaeology* 15.1 (1983), 90–104.

Sherratt 1986
Andrew Sherratt. "Whool, Wheels and Ploughmarks: Local Developments or Outside Introductions in Neolithic Europe?" *Bulletin of the Institute of Archaeology (London)* 23 (1986), 1–5.

Sherratt 1996
Andrew Sherratt. "'Das sehen wir auch den Rädern ab' some thoughts on M. Vosteen's 'Unter die Räder gekommen'". *Archäologische Informationen* 19 (1996), 155–172.

Sherratt 2004
Andrew Sherratt. "Wagen, Pflug, Rind: ihre Ausbreitung und Nutzung – Probleme der Quelleninterpretation". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 409–428.

Stahlhofen and Kurzhals 1983
Heribert Stahlhofen and Andreas Kurzhals. "Neolithische Rinderbestattungen bei Derenburg, Kr. Wernigerode". *Ausgrabungen und Funde. Archäologische Berichte und Informationen* 28.4 (1983), 157–160.

Tarde 2008
Gabriel Tarde. *Die Gesetze der Nachahmung*. Frankfurt a. M.: Suhrkamp, 2008.

Teufer 2012
Mike Teufer. "Der Streitwagen: Eine 'indo-iranische' Erfindung? Zum Problem der Verbindung von Sprachwissenschaft und Archäologie". *Archäologische Mitteilungen aus Iran und Turan* 44 (2012), 271–312.

Todorova 1981
Henrietta Todorova. *Die kupferzeitlichen Äxte und Beile in Bulgarien*. Vol. 9. Prähistorische Bronzefunde 14. München: Beck, 1981.

Trifonov 2004
Viktor Trifonov. "Die Majkop-Kultur und die ersten Wagen in der Südrussischen Steppe". In *Rad und Wagen. Der Ursprung einer Innovation. Wagen im Vorderen Orient und Europa*. Ed. by M. Fansa and S. Burmeister. Beihefte der Archäologischen Mitteilungen aus Nordwestdeutschland 40. Mainz: Zabern, 2004, 167–176.

Veluščeк 2002

Anton Veluščeк. "Ein Rad mit Achse aus dem Laibacher Moor". In *Schleife, Schlitten, Rad Und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Hemmenhofener Skripte 3. Gaienhofen-Hemmenhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002.

Vierzig (unpublished)

Angelika Vierzig. *Steinstelen des 4. und 3. Jahrtausends v. Chr. zwischen Kaukasus und Atlantik*. PhD. Berlin: Freie Universität Berlin, 2014. Unpublished.

Vosteen 1996a

Markus U. Vosteen. "Taken the Wrong Way: Einige Bemerkungen zu A. Sherratts 'Das sehen wir auch den Rädern ab'". *Archäologische Informationen* 19 (1996), 173–186.

Vosteen 1996b

Markus U. Vosteen. *Unter die Räder gekommen. Untersuchungen zu Sherratts 'Secondary Products Revolution'*. Archäologische Berichte 7. Bonn: Holos, 1996.

Vosteen 1999a

Markus U. Vosteen. "Ein Vorschlag zur Funktion der ältesten Wagen in Mitteleuropa". *Archäologische Informationen* 22 (1999), 269–277.

Vosteen 1999b

Markus U. Vosteen. *Urgeschichtliche Wagen in Mitteleuropa. Eine archäologische und religionswissenschaftliche Untersuchung neolithischer bis hallstattzeitlicher Befunde*. Freiburger Archäologische Studien 3. Rahden/Westf.: Marie Leidorf, 1999.

Vosteen 2001

Markus U. Vosteen. "Die doppelte Erfindung". *Archäologie in Deutschland* 2001.4 (2001), 20–22.

Vosteen 2002

Markus U. Vosteen. "Die fünffache Erfindung von Rad und Wagen". In *Schleife, Schlitten, Rad und Wagen. Zur Frage früher Transportmittel nördlich der Alpen*. Ed. by J. Köninger. Gaienhofen-Hemmendhofen: Landesdenkmalamt Baden-Württemberg, Archäologische Denkmalpflege, Referat 27, 2002, 143–148.

Zich 1992

Bernd Zich. "Frühneolithische Karrenspuren in Flintbek". *Archäologie in Deutschland* 8.1 (1992), 58.

Есин, Ю. Н. 2012

Есин, Ю. Н. "Дргевяяя История И Традиционная Култура. Древнейшие Ревнейиие Изоборажения Повозок Минуинской Котловины". *Научное обозрение Саяно Алтая* 1.3 (2012), 14–47.

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