David M. Goldstein, Stephanie W. Jamison, Anthony D. Yates (eds.)

Proceedings of the 33rd Annual UCLA Indo-European Conference

November 12th and 13th, 2022

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Wheeled vehicles depicted on Bronze Age vessels and petroglyphs,
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Contents

Preface

These *Proceedings* mark a sharp break from the volumes of more than a decade. With the retirement of Brent Vine, we editors miss the wisdom, good sense, and unflappable competence of our "first among equals," who guided so many volumes of the *Proceedings* to successful publication. But we welcome Tony Yates as the new member of the editorial triumvirate.

These *Proceedings* include papers presented at the Thirty-Third Annual UCLA Indo-European Conference, held on November 12–13 at UCLA—our much-celebrated return to an in-person conference.

Special gratitude is owed, first and foremost, to the graduate students comprising the Indo-European Conference Student Organizing Committee, whose dedicated participation and skilled tech-savvy support helped ensure the success of our return to Royce Hall: John Clayton, Joel Erickson, Valentina Lunardi, Laura McLean, Elisa Migliaretti, Thomas Motter, Alex Roy, Paolo Sabattini, Arjun Srirangarajan, and Chengzhi Zhang. We are also grateful for significant administrative help from members of the Dodd Humanities Group: Bret Nighman, Carolyn Attanucci, Paul Gass—and above all, for crucial help and support, Neli Petrosyan. We also gratefully acknowledge the financial support furnished by the A. Richard Diebold, Jr. Endowment in Indo-European Studies.

Naturally, we are especially indebted to the scholars whose papers appear below, not only for their stimulating conference presentations, but also for their cooperation and patience throughout the editing process. We owe special thanks, among those scholars, to our featured speakers David Anthony and Russell Gray. (As usual, not all papers presented at the conference appear here, for a variety of reasons, including publication or planned publication elsewhere.)

We are also happy to repeat our annual praise of Angelo Mercado for his consummate skill and professionalism in the preparation of the camera-ready copy. This is, finally, our third outing with Helmut Buske Verlag: as with the preceding volume in this series, we are deeply grateful to Managing Director Michael Hechinger for his support and guidance throughout the production process, as well as Tim Oliver Pohl for his counsel on technical matters.

David M. Goldstein, Stephanie W. Jamison, and Anthony D. Yates
October 2023

Ten Constraints that Limit the Late PIE Homeland to the Steppes

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Since 2015, migrations from the Pontic-Caspian steppes into Europe and Asia have been revealed by the study of ancient DNA, leading to the recent resurgence of the steppe theory of Proto-Indo-European (PIE) origins. But the linguistic and archaeological support for the steppe theory has not been updated or integrated with recent specialist studies that examined aDNA not only from humans but also from horses, dairy peptides preserved in dental calculus, human skeletal pathologies associated with horseback riding, or other archaeological evidence. Here I differentiate Early PIE, prior to the Anatolian split, from Late PIE, also called Core or Nuclear PIE, the ancestor of all other IE branches. Ten linguistic, chronological, cultural, and genetic constraints taken from the LPIE vocabulary, its radiocarbon-dated material attestations such as wheels, and migrations revealed by aDNA are reviewed, supporting the hypothesis that the LPIE dialects were spoken in the Pontic-Caspian steppes 3500–2500 BCE.

1 Introduction

In 2015 the study of Indo-European origins was revolutionized when two research teams simultaneously published whole genomes from the ancient DNA (aDNA) of 170 individuals distributed across Europe and Russia (Haak et al. 2015; Allentoft et al. 2015). The spread and diversification of the Indo-European (IE) languages through preliterate tribal societies seemed to require a demographic expansion that could have affected language distributions in both Europe and Asia, a constraint that supported the Neolithic Farmer theory of IE expansion (Renfrew 1987; Bellwood 2001; Bouckaert et al. 2012). But artifacts and house plans are ambiguous as indicators of migration, so even the highly visible and datable spread of farming left a cloud of demographic and linguistic questions in its wake: were the farmers immigrants who introduced an intrusive Anatolian Neolithic language, or indigenous hunter-gatherers who adopted farming but spoke languages rooted in Europe?

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Haak et al. (2015) and Allentoft et al. (2015) were revolutionary because their methods were the first that could clearly reveal, based on whole genomes from large samples of individuals, who was a migrant and who was indigenous, and the frequency, speed, and sex bias of admixture between populations. The Neolithic farmers of Europe were revealed as immigrants, genetically descended almost wholly from the populations of Neolithic Western Anatolia. Initially they replaced the indigenous hunter-gatherers in Greece, southeastern Europe, and most places they colonized outside of Iberia. Their languages and cultures began to separate from those of Neolithic Western Anatolia in the millennium 6500–5500 BCE.

Both teams also studied the expansion of the Yamnaya culture from the Pontic-Caspian steppes westward into Europe and eastward to the Altai Mountains around 3000 BCE.[1] Both agreed that males and females genetically like the Volga-Ural Yamnaya population migrated as far west as Slovakia and east to the Altai Mountains, where they introduced the Afanasievo culture. Their rapid expansion was dated 3100–2900 BCE and covered 5,000 km across the center of Eurasia. In both Europe and Asia the Yamnaya migrants initially admixed with the resident populations only slightly. Furthermore, the people of the Corded Ware and Bell Beaker cultures, two archaeological horizons that covered most of Europe between 2900–2200 BCE, carried more than 70% and more than 50% steppe ancestry respectively, testifying to the post-Yamnaya movement of the descendants of steppe people across most of central and northern Europe and parts of western and southern Europe. This series of migrations and demographic shifts was a persuasive alternative candidate for the vector that spread the Indo-European languages. The Haak et al. (2015) paper carried the provocative title “Massive migration from the steppe was a source for Indo-European languages in Europe.” Since then, the “steppe theory” of Proto-Indo-European (PIE) origins has been resurgent (see the edited volume Olsen et al. 2023).

However, while aDNA and archaeological evidence have accumulated and arguments over interpretation have increased, the “steppe homeland” theory of PIE origins has not been defended in detail. Instead, European geneticists and archaeologists have asked whether what appears to be Yamnaya ancestry in Corded Ware populations could have been produced by parallel processes in Europe and the steppes, bringing aspects of steppe-like ancestry into Corded Ware genes without a significant migration from the steppes (Furholt 2017; Papac et al. 2021; Haak et al. 2023). The genetic basis for this hypothesis is a small excess of Eastern Hunter-

1 Anthony et al. (2016) provided samples from nine Yamnaya-culture individuals in the Volga-Ural steppes to Haak et al. (2015) and participated in writing its text.

Gatherer (EHG) ancestry in a minority of Corded Ware individuals that is within the Yamnaya range of variation and could have been a result of Yamnaya admixture (Lazaridis et al. 2022:7). But the genetic support for the steppe theory is much broader than these arguments admit, and the linguistic and archaeological support for the steppe theory has not been updated or integrated with new evidence from aDNA.

In what follows I will differentiate Early PIE, prior to the Anatolian split, from Late PIE, also called Core or Nuclear PIE (Kloekhorst 2022; Goldstein 2022), the ancestor of all other IE branches. The exact borders of the LPIE dialects before 3000 BCE cannot be mapped. But a general region—the Pontic-Caspian steppes—and date range—3500–2500 BCE—can be defined by ten chronological and cultural constraints taken from the LPIE vocabulary, its radiocarbon-dated material attestations such as wheels, and migrations revealed by aDNA. Most of the constraints were evident before aDNA data became available (Mallory 1989; Anthony 2007), but aDNA has greatly strengthened them and added important new ones. The PIE "homeland" is not a nationalist construct, but consists of archaeological sites that have dates, locations, genetic ancestry, and artifacts (counting milk proteins in dental calculus as artifacts) consistent with these ten factors. Most of the relevant sites were assigned decades ago, long before we knew their genomes, to the Yamnaya culture (3300–2600 BCE) and its Eneolithic predecessors, importantly the Seredny Stig (also known as Sredni Stog) culture in the Dnieper-Don Pontic drainage and Khvalynsk culture in the Volga-Caucasus Caspian drainage (Agapov 2010; Rassamakin 2002; Anthony 2007; Anthony et al. 2022; Kotova 2018; Korenevskii 2011; Shishlina et al. 2018; Shishlina 2008).

The constraints that limit LPIE to a time and place do not necessarily apply to the Anatolian or Early PIE (EPIE) languages. How the EPIE languages arrived in Anatolia is unclear (Serangeli and Olander 2020; Kloekhorst 2022). An EPIE homeland in Anatolia or the Caucasus is one possibility (Lazaridis et al. 2022). Anthony (2007) argued that EPIE probably evolved in the Pontic-Caspian steppes, following Childe, Gimbutas, and Mallory—a position retained here. The Anatolian split could have been caused by a migration from the steppes into the Balkans associated with the Csongrad grave (Ecsedy 1979) and other Eneolithic steppe-derived graves in the lower Danube valley dated 4400–4200 BCE, such as Giurgiuleşti and Suvorovo (Anthony 2007:249–62; Dergachev 2007; Frînculeasa et al. 2015; Heyd 2016; Govedarica and Manzura 2016). A millennium later their descendants' steppe ancestry could have been lost through local admixture before they moved into Anatolia, accounting for the absence of steppe autosomal ancestry in Anatolia. Lazaridis et al. (2022) described an analogous case of a loss of steppe autosomal ancestry in a one-millennium time-series of individuals dated ca. 1500–500 BCE in Armenia (see no. 10 below).

2 Constraints that limit the LPIE homeland to the steppes

Ten constraints restrict the LPIE dialects to a time, place, and set of cultural and economic practices consistent with a steppe origin.

1 The vocabulary in LPIE for **wheeled vehicles** constrains the date when it was spoken to a time after wheels and axles were invented, or after about 3500 BCE (Bakker et al. 1999; Bondár 2018; Holm 2019; Burmeister et al. 2019). LPIE roots referring to wheels and wagons constitute a robust semantic field including at least *$k^{w}e$-$k^{w}l$-o- 'wheel'; **Hrot*-eh_2- 'wheel'; *h_3nob^h-eh_2- 'nave'; *$h_2e\hat{k}s$- 'axle'; and *$h_3(o)iH$-s- 'thill', distributed across IE languages with regular sound changes indicating descent from shared LPIE roots (Anthony and Ringe 2015). Anatolian IE preserves only the 'thill' word, which could be part of a plow or sledge, so does not clearly indicate a wheeled vehicle; the Anatolian split may have happened before wagons were invented. The oldest dated wheel currently known is from a wagon buried in a kurgan at Sharakhalsun 6, Russia, in the North Caucasus steppes, dated 3336–3105 calBCE (4500±40BP, GIN-12401) (Reinhold et al. 2017). More than 300 wooden wheels and/or vehicle parts have been found in Yamnaya "wagon" graves from the Ural steppes to the Danube delta dated by radiocarbon in the interval 3300–2600 BCE, supporting the symbolic centrality of wagons and carts in Yamnaya ritual beliefs, and demonstrating the initial spread of wheeled vehicles across the steppes (Fansa and Burmeister 2004; Morgunova and Khokhlova 2006; Reinhold et al. 2017). The wheel vocabulary constrains LPIE to a time after 3500 BCE, and Yamnaya is the most important steppe culture to pass that filter.

2 By 3500 BCE farmers populated most of Europe, the Caucasus, Anatolia, and the Middle East. Yet Kroonen et al. (2022), in a study of **IE agricultural vocabulary** following that of Mallory (2013), found only two EPIE roots with possible agricultural meanings in the IE Anatolian languages: **(H)ieu̯(H)*- and perhaps *$\hat{g}^h(e)rsd$-, both with variable meanings across their IE daughters that cannot support an EPIE meaning more specific than 'edible seed'. Ancient people consumed wild seeds such as *Chenopodium*, so these 'edible seed' words were not necessarily agricultural. The founder crops of European Neolithic agriculture also included peas, chickpeas, beans, lentils, and flax, all named in the IE languages by words that appear to have been borrowed from non-IE languages (Iverson and Kroonen 2017: table 1), suggesting that IE languages spread into regions where the substrate population had a well-developed farming vocabulary that was borrowed into IE. Kroonen et al. concluded (2022: 31) "… the scarcity of shared cereal (cultivation and processing) vocabulary at this stage [i.e., EPIE] strongly contradicts a deeply agricultural language community and thus disqualifies the Anatolia Hypothesis." Indeed, any hypothesis that requires an EPIE homeland in a place with well-developed agriculture is not supported by this analysis.

Five potential agricultural words were assigned by Kroonen et al. (2022) to LPIE. These include: *h_2erh_3- 'plow', *h_2erh_3u̯r̥/n- '(arable) field,' *peis- 'grind (grain)', *se-sh_1-i̯o- 'a cereal', and *$h_2$ed-o(s)- 'a (parched?) cereal'. Familiarity with plow-using farmers seems to have increased between EPIE and LPIE. But two of these are derivatives of the same root, 'plow' and 'plowed field', and could have referred to an instrument used by neighboring Trypillia or Maikop farmers; and three are non-specific edible seed words. In contrast, at least 30 shared agricultural roots including specific crop names can be assigned to Proto-Afro-Asiatic, a language family that evolved among developed farmers (Militarev 2003). If we limit the LPIE homeland to places where archaeological studies have shown little evidence for agriculture as late as 3500 BCE, then the Pontic-Caspian steppes, northern Europe, Scandinavia, and the Baltic are the principal regions in Europe, the Caucasus, and the Middle East where that criterion is met. In the Volga steppes, studies show that dental caries were virtually absent in populations including Yamnaya throughout the Bronze Age, implying that starchy cereals were never a significant part of the steppe Bronze Age diet (Murphy and Khokhlov 2016).

3 LPIE also contained vocabulary related to **dairy** production (*g^wou̯- 'cow'; *$h_2$melĝ- 'to milk'; *d^he-d^hh_1- 'sour milk'; *t(e)nk-lo- 'buttermilk'; *tuH-ri- 'cheese'). Milk is a very old food among Neolithic farmers, but in the Pontic-Caspian steppes dairying was largely absent in the Eneolithic and became ubiquitous only with Yamnaya. A study of milk peptides preserved in dental calculus found no milk in the diet of seven Eneolithic individuals from the Volga steppes dated 4500–4200 BCE (Wilkin et al. 2021). In the Eneolithic cemeteries at Khvalynsk and Khlopkov Bugor cattle, sheep-goat, and horses were sacrificed in human graves (Anthony et al. 2022) but their milk was not consumed. In contrast, among sixteen Bronze-Age Yamnaya individuals from the same region dated 3300–2600 BCE, fifteen consumed milk from cows, sheep, and goats, and two of those also drank horse milk (Wilkin et al. 2021). The absence of dairy peptides in Eneolithic dental calculus is interesting because Anatolian did not attest the LPIE root for milk *$h_2$melĝ- (Mallory and Adams 2006:262), and if the Anatolian split was caused by a migration of Khvalynsk-like people from the Volga to SE Europe

(Csongrad, Giurgiuleşti), the absence of a clear word for milk in EPIE would be consistent with the absence of Eneolithic milk consumption in their home region on the Volga.

A second study of dairy peptides in dental calculus examined three Eneolithic burials in the North Caucasus steppes dated 4200–3800 BCE and found that one of the three had consumed milk, from a sheep (Scott et al. 2022). This was the only Eneolithic steppe individual yet published with evidence of milk consumption, and it was from a grave quite near Caucasus farmers. In contrast, all four Yamnaya individuals examined in the Scott et al. study, from three kurgan cemeteries in the steppes 150–200 km north of the North Caucasus piedmont, had consumed milk. The rich semantic field for dairy in LPIE suggests that, if the homeland was in the Pontic-Caspian steppes, it was dated to the Yamnaya culture or later.

4 Early PIE had words with the meanings **sheep**, **wool**, and **lamb** (*h_2u̯l̥$h_1$néh$_2$-*, 'wool'; *$h_2$ou̯i-* 'sheep'; *$h_2$eg^w-no-* 'lamb'), retained in LPIE. Domesticated sheep accompanied the first farmers from western Anatolia into Greece about 6500 BCE and reached Britain and Scandinavia by about 4000 BCE. Bones of sheep-goats, not native to the steppes, appeared in sites in the Dnipro-Azov steppes by about 5500 BCE and in the Volga steppes by about 5000–4800 BCE, excluding dates on organic residues, which seem skewed older by reservoir effects (Vybornov et al. 2018, 2019). By 5500–5000 BCE Eneolithic steppe economies included domestic sheep but still depended to a large extent on fishing, hunting, and fowling. At the Eneolithic Khvalynsk cemetery on the Volga dated ca. 4200 BCE only domesticated mammals and horses (of uncertain domesticated status) were used as a ritual currency in funeral sacrifices, and sheep-goat were more frequently sacrificed than cattle or horses (Anthony et al. 2022). Sheep-goat continued to account for most of the animals sacrificed in Yamnaya graves (Anthony 2023).

Wool, however, was thought to indicate a relatively late date, since it was thought to depend on special breeds of wool-bearing sheep that might not have existed until the late fourth millennium BCE or later, even in Mesopotamia (Pollack 1999:144–7). Shishlina et al. (2020) found no wool imprints or threads in any reported Yamnaya context in the steppes. So how could Early PIE already have a word for 'wool'?

The oldest woolen threads are often said to be contained in preserved textiles in two stone tombs in the Caucasus dated 3300–2900 BCE: the "royal tomb" at Arslantepe on the Euphrates, and the "royal" Maikop-culture grave at Tsarskaya in the North Caucasus piedmont (Shishlina et al. 2020; Laurito et al. 2014). These two grave sites were contemporary with the Yamnaya culture in the steppes, but threads were rarely preserved there. More important, wool was harvested long before “wool sheep” were developed (Breniquet and Michel 2014). The evolution of wool sheep was a gradual process, beginning with wild sheep that had long hair (kemp) and very short under-wool that was molted in the spring. Probably soon after sheep and goats were domesticated, they began to be selected for longer under-wool fibers that could be plucked or combed out in the molting season and spun into thread. Carbonized textiles from pre-pottery Çatal Höyük in Anatolia were identified as either wool fibers or as a mixture of flax and wool dated as early as 7000 BCE (Breniquet 2014:56). In the late fourth millennium BCE hornless ewes appeared in the Middle East as a new breed, and perhaps (?) they had longer under-wool, but wool was harvested before that. Olsen (2023) has derived Early PIE *h_2u̯l̥$h_1$néh$_2$, ‘wool’, from an EPIE verb ‘to pluck’, which accords with the standard Sumerian verb for harvesting wool, also using the verb ‘pluck’, not ‘shear’ (Breniquet 2014:65). Sheep covered with continuously growing wool fleeces that could be sheared twice a year were a genetic innovation of the Late Bronze or Iron Ages in the Middle East, but wool was already an important medium of exchange in the fourth millennium BCE. Given this background, the existence of a word for plucked wool in the late 5th millennium BCE in the steppes gives an important insight into the development of wool textiles but is not problematic chronologically. Perhaps wool was an elite product at this time, as only limited quantities of wool could have been produced per animal, and only once annually.

5 **Horses** were known to the speakers of EPIE and LPIE (*$h_1$ek̂u̯o- ‘horse’; and perhaps *polH- ‘foal’; *demh_2- ‘to tame’), but whether they were domesticated is unclear from these roots. In IE myths and poetry domesticated horses played a central symbolic role, particularly in relation to kingly authority, but the time depth of these references is uncertain.

A definitive study of horse aDNA presented whole-genome data from 264 horses (Librado et al. 2021) and found that horses genetically like those of today (the lineage DOM2) first appeared about 2300 to 2100 BCE in the Don-Volga steppes. But this was not when horse domestication or riding began. Horse domestication was discussed in Librado et al. (2021) as an event, the appearance of DOM2 at 2200 BCE. But the genetic data better fit a gradual domestication process, as expected by zoologists (Zeder 2015). At least four chronological-genetic phases can be seen in the Librado et al. data in the Dnipro-Don-Volga steppes. **Phase 1** (designated NEO-NCAS for Neolithic North Caspian horses) dated about 5500 BCE, is represented by wild horses found among other wild animals acquired through hunting, preceding the local acquisition of domesticated animals, but with the horse genetics positioned in a PCA ancestrally in the DOM2 clade. **Phase 2** was not assigned an acronym by Librado et al. but is represented by an Eneolithic horse from Semenovka in the lower Dnipro steppes (4315–4054 BCE/ UCIAMS 224904 5340 ± 20/ Ukr11_Ukr_m4185) and another from Oroshaemovoe in the lower Volga steppes (4673–4498 BCE/ UCIAMS 5730 ± 15 BP/ RN96_Rus_m4586), dated a millennium after NEO-NCAS and found in levels associated with domesticated sheep-goat and cattle bones. These horses seem to show a significant shift away from NEO-NCAS toward DOM2 values. **Phase 3** (designated C-PONT for Caspian-Pontic), dated 3300–2600 BCE, witnessed both an increase in genetic variability partly derived from admixture with domesticated west Siberian (Botai) horses, and another significant shift toward modern DOM2 values, detected in some Yamnaya and Steppe Maikop horses identified as the direct ancestors of DOM2. **Phase 4** DOM2 horses, dated ca. 2200 BCE, witnessed the first genetically modern horses, but were preceded by 2300 years of genetic change in the DOM2 clade. More than 95% of the modern DOM2 genetic pattern was present in some Yamnaya horses. Even Eneolithic horses were shifted toward modern DOM2, which might help to explain why the steppe migrant buried at Csongrad, Hungary (Ecsedy 1979) had the lower trunk and pelvic musculature of a habitual rider dated 4442–4243 calBCE (5470 ± 40 BP/ Poz-41865) (Trautmann et al. 2023).

Four or more skeletal pathologies associated with horseback riding have been found in one pre-Yamnaya individual (buried under a kurgan but with local artifacts and ritual) from Romania dated 3331–2927 calBCE (4437 ± 34 BP/ DeA-8814), contemporary with Yamnaya in the steppes; in five Yamnaya individuals dated 3021–2623 BCE from Bulgaria, Romania, and Hungary, representing the Yamnaya expansion onto SE Europe from the steppes; and in the isolated Eneolithic steppe individual from Csongrad in Hungary dated 4300–4100 BCE mentioned above (Trautmann et al. 2023). All these individuals had musculature in their lower bodies, pelvises, and thighs, and pelvic articular surfaces like those of Medieval Hungarian riders (Pálfi and Dutour 1996; Berthon 2019), best explained by habitual riding.

Librado et al. (2021) concluded that horse riding was not an important element in the Yamnaya expansions because Corded Ware horses, unlike Corded Ware people, lacked Western Steppe (DOM2 clade) ancestry, exhibiting only local European horse ancestry. If Yamnaya people rode steppe horses into central Europe, they argued, then Corded Ware horses should show steppe ancestry. But all their Corded Ware horses were from Hohler Stein, a cave site in the Franconian Mountains of Germany, a poor environment for horses. More important, a reanalysis of the Librado et al. genetic data (Maier et al. 2023) contradicted the claim that the Hohler Stein horses lacked ancestry from the DOM2 clade. Maier et al. (2023) produced a range of horse ancestry models with significantly better fits to the Librado et al. data than Librado et al. achieved, many of which did include gene flows from Yamnaya-related horses. In the best-fitting model (Maier et al. 2023: figure 3B) the Corded Ware horses from Hohler Stein received 21% of their ancestry from DOM2-related horses. Horses from other Corded Ware sites better suited ecologically to horses could have had higher DOM2-clade ancestry. This revision of Corded Ware horse genetic ancestry, combined with the new skeletal evidence for Yamnaya riders, suggests that horseback riding did play a role in the Yamnaya-to-Corded Ware expansion of people with steppe ancestry.

The combination of wheels, dairy, wool, and horses in the LPIE vocabulary, combined with the poverty of agricultural terms, fits the Yamnaya culture, which exhibited the initial expansion of a dairy-rich diet in the steppes, the initial expansion of wheeled vehicles, sheep-and-goat-dominated funeral sacrifices, and the earliest duplicated evidence for habitual, long-term horse riding, found in five Yamnaya individuals in three countries and in two pre-Yamnaya individuals.

6 By 1400–1300 BCE Mycenaean **Greek** (Cosmopoulos 2019:358) and Mitanni **Indo-Aryan** (Fournet 2010) were documented in inscriptions at Iklaina, Nuzi, in the Kikkuli text, and other places. The **phylogenetic placement** of Greek and Indo-Aryan is late in most non-computational phylogenies and in some computational phylogenies, in relation to the earlier separation of Tocharian, Italic, and Celtic (Ringe et al. 2002; Nakhleh et al. 2005; Olander 2019; Kassian et al. 2021). In contrast, the computational methods of Chang et al. 2015 made the separation of Greek and Indo-Aryan earlier than all other branches except Anatolian and Tocharian. These arguments cannot be resolved now. But LPIE, the grandparent from which the parents of Tocharian, Celtic, Italic, Greek, and Indo-Iranian evolved, cannot be placed any later than about 2500 BCE, and under the computational methods of Chang et al. 2015 can be no later than about 3000 BCE. Combined with no. 1, this constraint limits LPIE to a narrow chronological window, 3500–2500 BCE, probably at the early end of this range.

7 Within this chronological window **six large-scale cultural (archaeological) expansions** affected much of Eurasia (dates approximate): **Baden** in SE Europe (3500–2800 BCE); **Globular Amphorae** in north and central Europe (3300–2800 BCE); **Yamnaya** (also called Pit-Grave and Ochre Grave) first across the Pontic-Caspian steppes (3300–3000 BCE) and then into SE Europe (3000–2600 BCE), replacing Baden; **Corded Ware** in northern and central Europe (2900–2400 BCE); **Bell Beaker** in western Europe (2600–2100 BCE); and **Afanasievo** in the Altai

Mountains and western Mongolia (3100–2600 BCE). The latter four carried steppe ancestry. These entities were of different kinds. Baden refers principally to an expanding ceramic style, if that (Furholt 2008); while the Yamnaya expansion into SE Europe was thought by most archaeologists (Ecsedy 1979; Heyd 2012; Horváth et al. 2013; Frînculeasa et al. 2015; Alexandrov and Kaiser 2016; Dani 2020) to represent a migration from the steppes that introduced a suite of steppe cultural traits as far west as the Tisza River. The aDNA from Yamnaya graves in SE Europe confirmed that such a migration took place, shown by the introduction of "steppe ancestry," which largely replaced the ancestry of the indigenous Eneolithic population (Lazaridis et al. 2022; Allentoft et al. 2022; Mathieson et al. 2018). In the eastern direction, the Afanasievo population in the Altai Mountains was almost identical genetically with Yamnaya (Allentoft et al. 2015; Narasimhan et al. 2018).

The demographic spread of people from the steppes across Europe and Asia cannot have happened without also spreading the language(s) they spoke, at least initially. Near present-day Bohemia (Papac et al. 2021) relations between Yamnaya descendants and various others created the Corded Ware culture and population, blended from indigenous (polished stone battle-axes) and introduced customs (burial mounds), while retaining 70–80% steppe ancestry in most individuals outside Switzerland (Haak et al. 2023). Bell Beaker populations were more variable but exhibited 40–50% steppe ancestry outside of Italy and Iberia (Olalde et al. 2018; Scorrano et al. 2021:table S2). After 2000 BCE steppe ancestry remained a central element in Eurasian populations from Central Asia to western Europe, as did LPIE languages.

8 Within the chronological window 3500–2500 BCE, only the Yamnaya culture exhibited a new technological-economic adaptation, **nomadic pastoralism**, that imparted greatly increased mobility; and combined that economic innovation with the spread of its regional **genetic signature** and elements of its **funeral ritual**. The Yamnaya community arguably was the first to fully commit to mobile herding using ox-drawn wagons and horse-mounted herders (Anthony 2021, 2023; Wilkin et al. 2021; Reinhold et al. 2017; Trautmann et al. 2023; Shishlina 2008). The new nomadic economy combined extreme residential mobility with the production of a mobile economic surplus counted in animals, leading to a fundamental change in how animals functioned in human prestige and power systems (Sherratt 1997; Reinhold et al. 2017; Bogaard et al. 2019). This unique new economic adaptation evolved in the Pontic-Caspian steppes after 3500 BCE, when newly introduced wagons (for heavy residential needs) were for the first time combined with horseback riding (for more efficient herding of larger, more mobile herds) while the steppe diet was simplified to the milk and meat of four species: cattle, sheep, goats, and horses. Nomadic pastoralism created a political networking advantage (Mulder et al. 2010) in an increasingly mobile and interconnected world. A similar process occurred in Mesopotamia when long-distance political and commercial connections between nomadic polities elevated their leaders, famously Zimri-Lim of Mari and Hammurabi of Babylon, to rulership over competing regional city-states in the 2nd millennium BCE (Fleming 2009).

9 All ancient and modern **IE-speaking populations** that have been sampled for aDNA **had steppe ancestry**, except (yet) in Anatolia; while regions where non-IE languages were spoken had little or no steppe ancestry. Steppe ancestry was found in both rich and poor Mycenaean graves, in a political context ruled by Greek-speakers; but was much less in Minoan graves on Crete, mostly non-IE speakers, until after the Mycenaean "takeover" (Lazaridis et al. 2017; Lazaridis et al. 2022; Skourtanioti et al. 2023). Steppe ancestry averaging 22% was found in 31 ancient South Asians dated 1200–800 BCE from the Swat valley, but was not found in individuals dated before 2000 BC, probably associated with the Harappan civilization (Narasimhan et al. 2018). IE-speakers in modern South Asia have significantly more steppe ancestry than non-IE speakers. The Mediterranean region, where steppe ancestry was lowest in Europe, also had the highest diversity of non-IE languages when inscriptions began after 700 BCE (Ringe 2013:206–7; Mallory et al. 2019).

10 Finally, specific currents in the post-Yamnaya migrations of people with steppe ancestry seem to **solve small problems** in the **relations between IE languages**. For example, people with Corded Ware genetic ancestry turned eastward from the Baltic and introduced cattle pastoralism to the Russian forests about 2500 BCE under the guise of the Fatyanovo culture (Nordqvist and Heyd 2020); their Abashevo descendants re-entered the Don-Volga-Ural steppes and pushed eastward to become the Sintashta culture by about 2000 BCE, widely regarded as the material expression of the Indo-Iranian speech community (Parpola 2022:18–22; Kuz'mina 2007). That genetically defined return movement from the Baltic to the Central Asian steppes between 2500 and 2000 BCE explains the otherwise puzzling similarities between the Balto-Slavic and Indo-Iranian language communities: despite the distance between their modern speakers, they were at opposite ends of the same dialect chain at the turn of the third to the second millennium BCE.

One final puzzle is solved by the steppe theory: Armenian, a language traditionally placed by linguists in a subgroup with Greek and Phrygian, was an isolated LPIE language amid the non-IE languages of the Caucasus. How it got there has been a puzzle since Herodotus concluded that the Armenians were the descendants of the Phrygians. But Martirosyan (2013) and Clackson (2008) situated Proto-Armenian phylogenetically not only with Greek but between Greek and Indo-Iranian, raising the possibility of a steppe connection. A study of aDNA from the Caucasus (Lazaridis et al. 2022) found strong evidence for an intrusion of people from the steppes into Georgia and Armenia around 2500 BCE, during the Middle Bronze Age Bedeni-Trialeti period, when large "royal" kurgans appeared in Georgia containing horses and vehicles, an event that had a major cultural impact (Smith 2005), the causes of which were debated. Although the individuals analyzed by Lazaridis et al. (2022:8) came from a later period (Lchasen-Metsamor, 1500–1000 BCE) and from sites in modern Armenia, linkage disequilibrium dating found that the admixture date for their steppe ancestry was around 2500 BCE, just when the Bedeni-type kurgans first appeared in Georgia. Indeed, the typical Yamnaya R1b (R-Z2103) Y-chromosome haplogroup survives in appreciable frequencies in all studied Armenian groups even today (Lazaridis et al. 2022:11), the only place it remains significant in modern populations. After this steppe intrusion the population in Armenia was genetically stable into the Iron Age, so the cultural and genetic shift at 2500–2000 BCE is the best candidate for the arrival of a population speaking a LPIE language in Armenia.

The steppes north of the Caucasus witnessed between 2500 and 2000 BCE the transition from the archaic Yamnaya-Catacomb Middle Bronze Age genetics to the Corded-Ware-admixed Sintashta-Babino-Srubnaya Late Bronze Age genetics (Narasimhan et al. 2018). At 2000 BCE the Sintashta culture with its new chariot technology and DOM2 horses was developing in the steppes northeast of the Caucasus, with its presumed Indo-Iranian-speaking population. Armenian might have evolved from a steppe dialect of 2500–2000 BCE that arrived in the Caucasus in the Middle Bronze Age, phylogenetically linked to the emerging Indo-Iranian speech community to its northeast and Proto-Greek to its west. This interpretation fits a traditional phylogeny in which Greek and Indo-Iranian separated relatively late, rather than the Chang et al. 2015 computational phylogeny in which Greek separated before most other branches.

There is no better vector for the continent-spanning distribution of the IE languages than the Yamnaya and post-Yamnaya migrations. Dialects of LPIE probably were spoken by people who exhibited the material traits of the Yamnaya, Afanasievo, and early Corded Ware cultures; but not only by them, and not necessarily by all of them.

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