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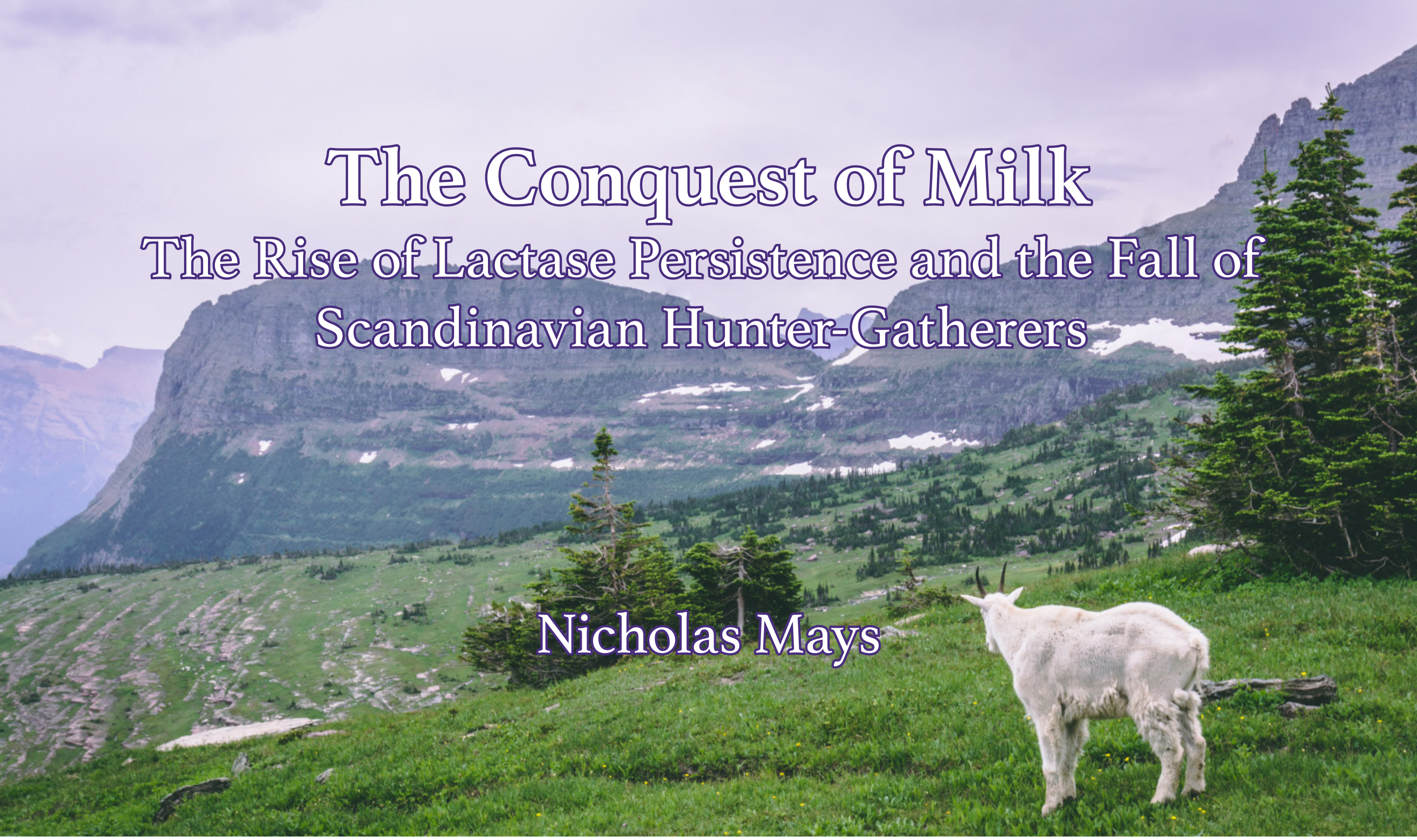

The Conquest of Milk

The Rise of Lactase Persistence and the Fall of Scandinavian Hunter-Gatherers

Nicholas Mays

Photo credit: "Glacier National Park" via Unsplash

Abstract

Over half of the global human population suffers from lactase nonpersistence, a condition marked by losing the ability to digest lactose after infancy. However, a minority of the global population, primarily located in Central and Northern Europe, has a genetic mutation that results in lactase persistence, which is the continued ability to process lactose after infancy. This interdisciplinary paper synthesizes research in archaeology, cultural anthropology, evolutionary biology, and archaeogenetics to explore the origin and rise of lactase persistence in Europe and its contribution to the end of hunter-gatherer societies in Scandinavia. Drawing on gene-culture coevolutionary theory, the paper argues that lactase persistence was introduced to Scandinavia by an outside culture and attempts to identify the geographical and cultural origin of the genetic mutation.

The majority of humanity is lactose intolerant. However, in Central and Northern Europe, lactose tolerance, brought on by a condition called lactase persistence is extremely common.[1] This has not always been the case; research shows that European lactase persistence was quite infrequent until the beginning of the Bronze Age (ca. 3000 BCE, which is fairly recent in evolutionary terms) when it spiked in frequency towards that observed in modern Europe. Around the time of lactase persistence's spread, the last hunter-gatherer cultures in Scandinavia disappeared from the archaeological and genetic record. Is there a connection between these two apparently unrelated phenomena? This paper synthesizes information from the fields of archaeology, molecular biology, evolutionary biology, and archaeogenetics to address the origin of lactase persistence in Europe and the prehistoric lifestyles that enabled its spread. It uses this information to argue that the consumption of dairy products helped bring about the end of hunter-gatherers in Scandinavia.

Physiological, Chemical, and Genetic Components of Lactase Persistence

Lactase persistence (LP) is a genetic condition defined as the continuous production of the enzyme lactase-phlorizin hydrolase after the end of weaning in infancy. The enzyme allows for the digestion of the milk sugar lactose by splitting its beta-glycosidic bond. This process reduces lactose to its simple sugar subunits: glucose and galactose. The enzyme is produced through the action of the gene lactase (LCT). The gene encodes a preproprotein that is processed into a matured lactase enzyme.[2] After infancy, LCT activity slows and eventually stops, which results in lactase nonpersistence (LNP) and the inability to digest milk sugars. LNP is an ancestral trait in humans, affecting approximately 65% of the global human population.[3]

In Northern Europeans, especially those of Swedish, Danish, and British ancestry, LP is strongly correlated with the presence of a single-nucleotide polymorphism (SNP). This SNP is known as rs4988235 and is located in the gene MCM6. Other SNP variants have been implicated in LP, but rs4988235 is the one most often observed among LP-affected Europeans.[4] More generally, it has been shown to have a stronger role in governing LP expression than any other related SNP. Experiments on rats transfected with human DNA containing rs4988235 demonstrated a 2.8-fold induction of lactase promoter activity when compared with nonpersistent rats. Meanwhile, rats transfected with other LP-associated SNPs demonstrated much lower induction of the promoter.[5] Finally, LP is an autosomal dominant trait, meaning individuals heterozygous at rs4988235's location have high enough levels of lactase activity to allow lactose digestion, though it is possible for them to experience bouts of LNP-like symptoms.[6]

LP and rs4988235 in Europe

Lactase persistence is strongly associated with rs4988235 in people of Northern European descent. LP is extremely widespread among those groups, with an estimated frequency between 73–95%.[7] It occurs so often that LP has nearly become a fixed component in the gene pool.[8]

1 A glossary offering working definitions of the terms and acronyms uesd in this paper is available on page 61.

2 NCBI, "LCT Lactase [Homo Sapiens (Human)]," updated January 25, 2022, https://www.ncbi.nlm.nih.gov/gene?cmd=retrieve&dopt=default&list_uids=3938&rn=1.

3 Eugenia Morales et al., "The European Lactase Persistence Genotype Determines the Lactase Persistence State and Correlates with Gastrointestinal Symptoms in the Hispanic and Amerindian Chilean Population: A Case-Control and Population-Based Study." *BMJ Open*, no.1 (September 2011): e000125, 2, https://doi.org/10.1136/bmjopen-2011-000125.

4 Sean Myles et al., "Genetic Evidence in Support of a Shared Eurasian-North African Dairying Origin." *Human Genetics* 117, no. 1 (April 2005): 40, https://doi.org/10.1007/s00439-005-1266-3.

5 Lynne C. Olds and Eric Sibley, "Lactase Persistence DNA Varient Enhances Lactase Promoter Activity In Vitro: Functional Role as a Cis Regulatory Element." *Human Molecular Genetics* 12, no. 18 (September 2003): 2334, https://doi.org/10.1093/hmb/ddg244.

6 Nana Yaa Baffour-Awuah et al., "Functional Significance of Single Nucleotide Polymorphisms in the Lactase Gene in Diverse US Patients and Evidence for a Novel Lactase Persistence Allele at -13909 in Those of European Ancestry." *Journal of Pediatric Gastroenterology and Nutrition* 60, no. 2 (February 2015): 183, https://doi.org/10.1097/MPG.0000000000000595.

7 Yuval Itan et al., "The Origins of Lactase Persistence in Europe." *PLOS Computational Biology* 5, no. 8 (August 2009): e1000491, https://doi.org/10.1371/journal.pcbi.1000491.

8 Anke Liebert et al., "World-Wide Distributions of Lactase Persistence Alleles and the Complex Effects of Recombination and Selection." *Human Genetics* 136, no. 11 (October 2017):

Occurrence of LP in other global populations, especially those in Africa and the Middle East, is more varied compared to Europe and cannot be accounted for by rs4988235 in those groups.[9] Though rs4988235 is seen in other global populations, it is most common in Northwestern Europe, with decreasing frequency as populations move further south and east. It is also common in the United States, where a large portion of the population is of European descent.[10]

Despite its current prevalence among Europeans, LP was a rare occurrence in prehistoric Europe. Imputation from genomic analysis of Europeans who lived during the Bronze Age (ca. 3000–1000 BCE) has shown that the frequency of LP was approximately 10%, while that of rs4988235 was about 5%, a significant difference from modern frequencies.[11] It is also apparent now that the SNP was strongly positively selected for, considering the evolutionarily short timespan within which it has spread and the wide geographical range it has covered. The period during which LP became commonplace in Europe mostly coincides with the disappearances of the final hunter-gatherer cultures in the region. The following sections explain the speed of LP's spread by analyzing prehistoric European lifestyles, migrations, and the concept of Neolithization, particularly in terms of gene-culture coevolutionary theory.

Hunter-Gatherers and European Neolithization

Anatomically modern humans have occupied Europe since at least 45 thousand years ago.[12] The dominant subsistence strategies for those people were fishing, hunting, and gathering. Agriculture and animal domestication originated around the eleventh or twelfth millennium BCE outside of Europe in the Fertile Crescent and over time spread westward (figure 1).[13] The development of agriculture was a major part of the period known as the Neolithic Revolution ca. 10000 BCE, which saw profound changes in food production techniques as well as a transition away from nomadic hunter-gatherer lifestyles towards sedentary and settled lifestyles.[14] These changes are collectively known as Neolithization.

Neolithization was adopted sporadically across Europe and in most regions did not occur until thousands of years after its inception in the Fertile Crescent. In Central Europe, the sedentary and agriculture-based way of life was introduced by the Linearbandkeramik (LBK) culture ca. 5500 BCE, which originated in the Carpathian (or Pannonian) Basin, modern Hungary. The LBK spread into Central Europe, including Germany, persisting until approximately 4900 BCE, after which multiple successive culture groups sprung up over time.[15] It was not until ca. 4700 BCE that agriculture, including the use of domestic cattle and sheep, made its way into Scandinavia, close to 80 years after its general introduction in Central Europe. The first established farming community in the southern part of Scandinavia, associated with a culture known as the Trichterbecherkultur (TRB), began around 4000 BCE.[16] However, hunter-gatherer cultures continued to live in Northern Europe (including Sweden, Poland, and Northern Germany) until about 2000

1445, https://doi.org/10.1007/s00439-017-1847-y.

9 Itan et al. "The Origins of Lactase Persistence in Europe," 1.

10 Dallas M. Swallow, "Genetics of Lactase Persistence and Lactose Intolerance." *Annual Review of Genetics* 37 (December 2003): 202, https://doi.org/10.1146/annurev.genet.37.110801.143820.

11 Morten E. Allentoft et al., "Population Genomics of Bronze Age Eurasia." *Nature* 522 (June 2015): 171, https://doi.org/10.1038/nature14507. The Bronze Age began at different times that varied between culture groups

12 Jean-Jacques Hublin et al.,"Initial Upper Palaeolithic Homo Sapiens from Bacho Kiro Cave, Bulgaria." *Nature* 581 (May 2020): 299, https://doi.org/10.1038/s41586-020-2259-z.

13 Lucy J. E. Cramp et al., "Neolithic Dairy Farming at the Extreme of Agriculture in Northern Europe." *Proceedings of the Royal Society: B Biological Sciences* 281, no. 1791 (September 2014): 20140819, 1, https://doi.org/10.1098/rspb.2014.0819.

14 Samuel Bowles and Jung-Kyoo Choi, "The Neolithic Agricultural Revolution and the Origins of Private Property." *Journal of Political Economy* 127, no. 5 (July 2019): 2192, https://doi.org/10.1086/701789.

15 Anna Szécsényi-Nagy et al., "Tracing the Genetic Origin of Europe's First Farmers Reveals Insights into Their Social Organization." *Proceedings of the Royal Society B: Biological Sciences* 282, no. 1805 (February 2015): 20150339, 2, https://doi.org/10.1098/rspb.2015.0339.

16 Helena Malmström et al.,"Ancient Mitochondrial DNA from the Northern Fringe of the Neolithic Farming Expansion in Europe Sheds Light on the Dispersion Process." *Philosophical Transactions of the Royal Society B: Biological Sciences* 370, no. 1660 (January 2015): 20130373, 1, https://doi.org/10.1098/rstb.2013.0373.

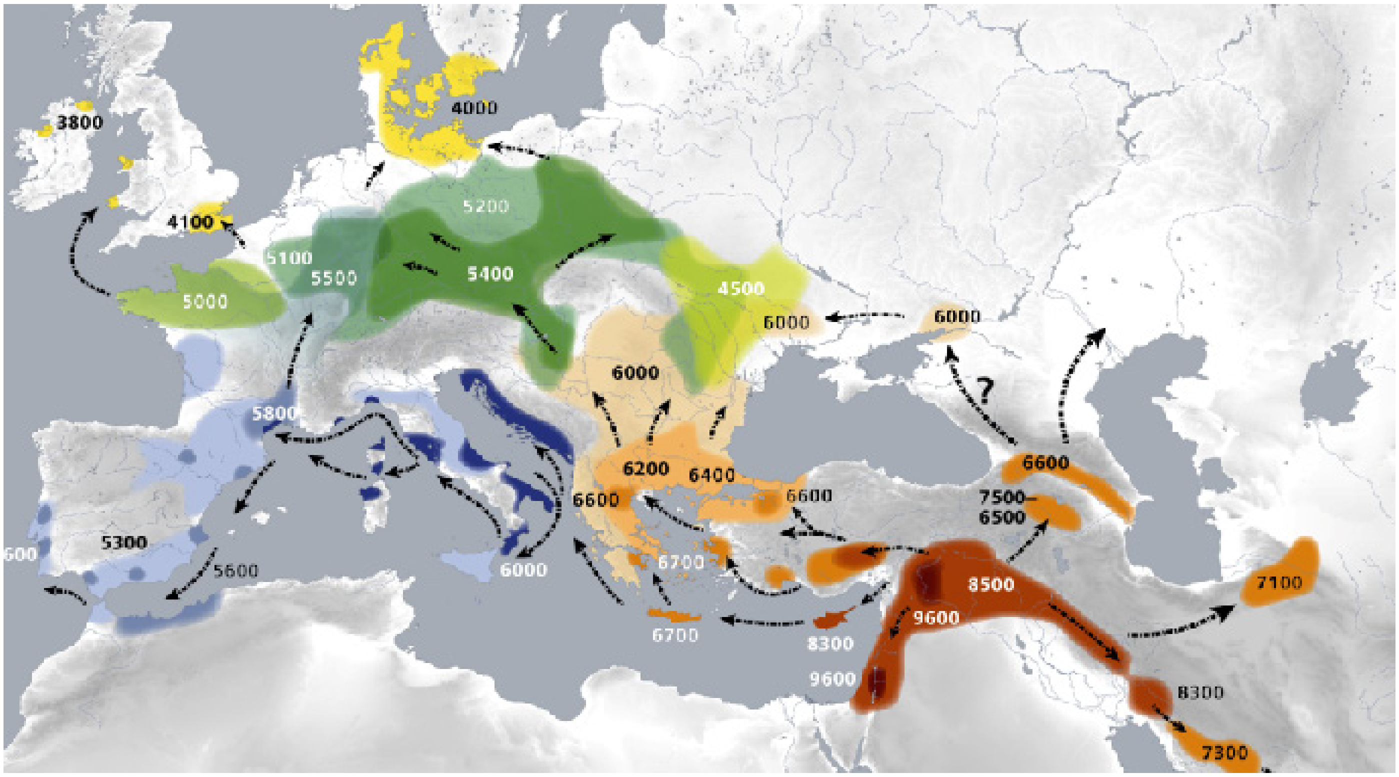

Figure 1: The expansion of agriculture into Europe. Each year given approximates the establishment of major agricultural communities. Agriculture originated in the Fertile Crescent (red/brown) and expanded westward over several millennia. Years are given as BC. From "Expansion of farming in western Eurasia, 9600 - 4000 cal BC (update vers. 2021.2)" by Gronenborn/Horejs/Börner/Ober licensed under CC BY-4.0.

BCE, when one of the last remaining groups, the Pitted Ware Culture (PWC), disappeared from the archaeological record.[17]

Lactase Persistence and Gene-Culture Coevolution

The Relationship between Behavior and Genetics

Gene-culture coevolutionary theory, also known as dual-inheritance theory, is a conceptual framework in which evolutionary mechanisms such as natural selection can be described in terms of their relation to cultural practices and behaviors.[18] Cultural practices encourage or discourage certain behaviors or value certain traits, indirectly encouraging evolutionary processes spreading or removing genes from the group. Simple examples of traits that specific cultural practices can select for include eye/hair color, skin tone, and musculature. Purposeful modification of the relationship between organisms and their environment is called niche construction. Human behaviors that interact with the environment, such as domestication of animals for pastoral use, are examples of cultural niche construction, modification of the environment in accord with cultural practices. In the context of prehistoric studies, gene-culture coevolution is best understood as humanity's manufacturing of its own evolutionary pressures through cultural niche construction.[19]

LP is considered a textbook example of gene-culture coevolution. Globally, all SNPs associated with LP, rs4988235 included, appear among cultures in which archaeological evidence demon-

17 Helena Malmström et al., "Ancient DNA Reveals Lack of Continuity between Neolithic Hunter-Gatherers and Contemporary Scandinavians." *Current Biology* 19, no. 20 (September 2009): 1758, https://doi.org/10.1016/j.cub.2009.09.017.

18 José M. Causadias and Kevin M. Korous, "How Are Genes Related to Culture? An Introduction to the Field of Cultural Genomics" in *The Handbook of Culture and Biology*, edited by José M. Causadias, Eva H. Telzer, and Nancy Gonzales (Hoboken: John Wiley & Sons, Inc., 2017): 156-157, https://doi.org/10.1002/9781119181361.

19 Kevin N. Laland, "Exploring Gene-Culture Interactions: Insights from Handedness, Sexual Selection and Niche-Construction Case Studies." *Philosophical Transactions of the Royal Society B: Biological Sciences* 363, no. 1509 (September 2008): 3578, https://doi.org/10.1098/rstb.2008.0132.

strates a connection with a pastoral lifestyle.[20] For the purposes of this discussion, "pastoralism" describes the use of animals by mostly nomadic people for food, especially dairy products. Initially, rs4988235 was rare in Bronze Age Europe but underwent a burst of positive selection over a large geographical area. There must have been a significant dietary change that accommodated the spread of LP and caused rs4988235 to become a positively selected trait. That dietary change may have been associated with adoption of pastoral cultural traits, implying a continent-wide cultural shift towards the care of dairying animals. Therefore, this change in culture should be associated with a change in genetic frequencies. It follows, too, that if rs4988235 was originally so infrequent, there was almost certainly no selective pressure being exerted on prehistoric Europeans for the SNP. Consumption of dairy products and the husbandry of dairying animals must have been nearly nonexistent, as the lack of LP-expressing individuals would preclude any need for raising animals expressly for dairying. Due to this lack of dairying practices in Europe, gene-culture coevolutionary theory suggests that the practice of pastoralism was introduced into Europe by an outside group and was not a novel development within Europe. What conditions allowed the SNP's rapid spread? How did this group influence the selection of rs4988235?

Introduction of rs4988235 in Europe

Computer simulations suggest that rs4988235 began to undergo selection around 5500 BCE in a region between the Central Balkans and Central Europe.[21] However, this does not necessarily imply that the SNP originated there. This timing would associate the selection with the arrival of the Linearbandkeramik (LBK) culture in Central Europe. It would be easy to attribute the spread of LP to the expansion of LBK peoples based solely on this fact, but the general frequency of rs4988235 in Europe was as low as 5% until well into the Bronze Age, many years after the LBK's end. Additionally, it has been shown that modern Berber peoples of North Africa across multiple ethnic groups, located primarily in Morocco and Algeria, possess the rs4988235 SNP in frequencies of approximately 15% across the groups. The SNP forms part of a haplotype shared between Berbers and Europeans, though in Berbers the SNP is not as strongly correlated with LP as in Europeans.[22] It is plausible, based on further genetic analysis, that the SNP originated in Southwestern/Central Asia.[23] These facts discount a potential LBK-based origin of LP in Europe.

Lactase Persistence and the End of Hunter-Gatherers

A Central Asian Origin for European Lactase Persistence

If the SNP did not come from the LBK, then from where? A Central Asian origin of European LP is strongly supported. Beginning with the onset of the Bronze Age, ca. 3000 BCE, European populations received genetic input from migrating Caucasian groups, particularly those of the nomadic, pastoralist Yamnaya culture group from the Pontic-Caspian steppe (figure 2).[24] The Pontic-Caspian steppe occupies much of modern Eastern Europe and Central Asia, from the Black Sea to the Caspian Sea. These migrations may have had a violent character to them, as the unexpectedly low distribution of Steppe-associated genes on X chromosomes present in modern Europe implies that the migrating waves were highly male-biased, potentially representing conquest.[25] Importantly, they carried rs4988235

20 Lin Fang et al., "The Human Lactase Persistence-Associated SNP—13910*T Enables In Vivo Functional Persistence of Lactase Promoter—Reporter Transgene Expression." *Human Genetics* 131, no. 7 (January 2012): 1153, https://doi.org10.1007/s00439-012-1140-z.

21 Itan et al. "The Origins of Lactase Persistence in Europe," 3.

22 Myles et al., "Genetic Evidence in Support," 35.

23 Wolfgang Haak et al., "Ancient DNA from European Early Neolithic Farmers Reveals Their Near Eastern Affinities." *PLoS Biology* 8, no. 11 (November 2010): e1000536, 9, https://doi.org10.1371/journal.pbio.10005366.

24 Allentoft et al., "Population Genomics," 168. *Caucasian* refers to groups originating from the Caucasus region, located between the Black Sea and Caspian Sea.

25 Amy Goldberg et al., "Ancient X Chromosomes Reveal Contrasting Sex Bias in Neolithic and Bronze Age Eurasian Migrations." *Proceedings of the National Academy of Sciences* 114, no. 10 (March 2017): 2660, https://doi.org/10.1073/pnas.1616392114.

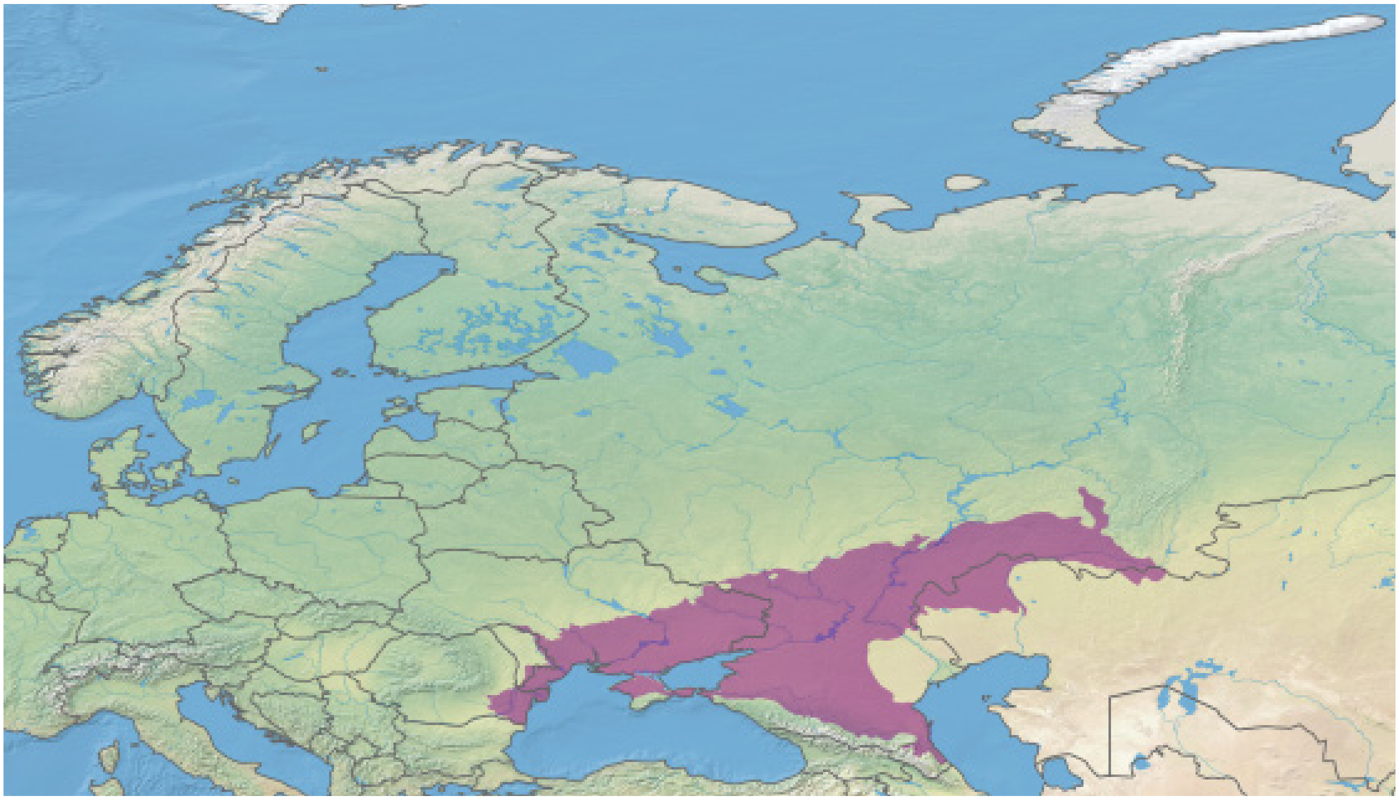

Figure 2: The general location of the Pontic-Caspian Steppe, which is the region from which the Yamnayan culture groups originated. From "Ecoregion PA0814.svg" by Terpischores licensed under CC BY-SA 3.0.

in much higher frequencies than their contemporary European counterparts.[26]

The Yamnayans brought not only their pastoral herding skills, but also their technology and cultural practices. They were apparently quite skilled at metallurgy, for instance, and possibly introduced the linguistic ancestor of some modern European languages.[27] The timing of the arrival of the Yamnaya Steppe herders coincides almost perfectly with the apparent rise in frequency of rs4988235 within Europe. These facts indicate that Yamnayan contributions to Europe were immense and potentially promoted the most sweeping changes to European life since the advent of agriculture. The rapid nature of the Yamnayan spread (especially its genetics and language) lends further credence to the proposed violent character of their migrations. If so, here is a curious example of gene-culture coevolution, as the adoption of dairying by Europeans was not a natural development on their part but instead one possibly foisted onto them by a conquering people. The relatively sudden injection of rs4988235 into the European gene pool by migrating Yamnayans allowed for dairying by a group of people who previously had no reason to do so. In either case, violent or non-violent, it is possible European LP traces its origins to Central Asia.

Genetics of Modern Swedes and Lactase Persistence

The Pitted Ware Culture (PWC) seems to have begun ca. 3300 BCE in Sweden, well after the emergence of the Trichterbecherkultur (TRB), meaning hunter-gatherers and agriculturalists existed in parallel for close to a millennium in the region.[28] Yet the PWC has left little to no trace on the genetic makeup of modern Swedes, while agriculturalist groups, primarily the TRB, have been conclusively shown to be major genetic contributors to modern Swedes.[29] The lack

26 Goldberg et al., "Ancient X Chromosones," 2661.

27 Viktor I. Klochko, "Yamnaya Culture Hoard of Metal Objects, Ivanivka, Lower Murafa: Autogenesis of 'Dniester Copper/Bronze Metallurgy,'" *Baltic-Pontic Studies* 22, no. 1 (August 2018): 226, https://doi.org/10.1515/bps-2017-0027; Wolfgang Haak et al., "Massive Migration from the Steppe was a Source for Indo-European Languages in Europe." *Nature* 522, no. 7555 (June 2015): 207, https://doi.org/10.1038/nature14317.

28 Malmström et al., "Ancient DNA," 1758.

29 Malmström et al., "Ancient DNA," 1759.

of genetic input from the PWC can imply that the current proliferation of LP among Swedes is directly attributable to the TRB. This comes despite the Swedes' and PWC's proximity, which lasted for centuries. Genetic admixture between them apparently did not occur, certainly not in any meaningful way. It is likely that the PWC was not absorbed into the TRB; they did not adopt agricultural practices and were replaced by agriculturalists.[30]

The lack of PWC genetics in modern Sweden, against their previously lengthy coexistence with an agriculturalist group, strongly implies that LP provided a major advantage to the TRB that enabled them to outcompete their hunter-gatherer counterparts. This advantage, whatever its nature, led to the PWC's end. A hypothetical reconstruction of events can be outlined: LP was infrequent in Europe during most of the time that the two groups shared a range. However, when the condition was introduced—possibly by force—by technologically-advanced Yamnayan Steppe herders, PWC hunter-gatherers disappeared relatively quickly. This is attributable directly to the rapid proliferation of LP and simultaneous adoption of dairying by early European peoples. The long-established lifestyle of farming and animal husbandry accommodated dairying exceedingly well, providing an environment of strong positive selection for LP. Because of their lifestyles the PWC, and other hunter-gatherers by extension, prohibited LP from spreading easily. Perhaps the PWC lost enough territory to the expanding TRB population that they were left with little land to forage or hunt on. As a result, the PWC were eventually outcompeted by groups who could take advantage of LP.

Conclusion

Research has established the correlation between the disappearance of hunter-gatherers and the spread of LP, using the Pitted Ware Culture as an example. However, it is possible that this correlation is illusory. Despite the evidence presented here, it is not apparent whether LP conferred any adaptive benefit to early Europeans. While it would seem highly likely that the ability to consume dairy products did confer advantages to individuals with LP—especially considering the apparent benefit dairy would provide in terms of caloric content, vitamins, nutrients, and hydration—the fact that many modern Central Asian cultures have never seen the same spread of rs4988235, despite dairy products being a large part of their diet, points to the possibility that the single-nucleotide polymorphism (SNP) does not necessarily contribute an evolutionary benefit.[31]

LP was likely introduced to Europe by Steppe nomads from Central Asia. Paramount to this paper's entire discussion is a "chicken-or-egg" question regarding whether pastoralism emerged before or after the SNP became common among those people. This question opens other avenues for future research. For example, the Botai culture, a separate prehistoric culture originating in modern Kazakhstan, practiced nomadic pastoralism, with evidence showing that they relied on mare's milk as an important dietary source. However, modern Steppe herders, who rely heavily on dairy products and occupy the same general area the Botai lived in, have LP phenotypic frequencies of only 12–30%, considerably lower than Europe.[32] Additionally, the initial entry of LP into the gene pool of the Yamnayan steppe peoples is a mystery, as evidence mentioned previously shows that rs4988235 originated in the general area of the Balkans. Tracing its movements from there to the Pontic-Caspian steppe is a consideration for examination in a future paper.

Issues concerning the difficulties associated with limited evidence originating from prehistoric peoples prevent any definite statement concerning LP's origin. Due to many obstructing factors, such as DNA degradation, it remains

30 Helena Malmström et al., "High Frequency of Lactose Intolerance in a Prehistoric Hunter-Gatherer Population in Northern Europe." *BMC Evolutionary Biology* 10, no. 89 (March 2010): 2862036, 6, https://doi.org/10.1186/1471-2148-10-89.

31 Laure Segruel et al., "Why and When Was Lactase Persistence Selected for? Insights from Central Asian Herders and Ancient DNA." *PLoS Biology* 18, no. 6 (June 2020): e3000742, 2, https://doi.org/10.1371/journal.pbio.3000742.

32 Segruel et al., "Why and When Was Lactase Persistence Selected for?" e3000742, 2.

challenging to generate any conclusive image of the genetics of prehistoric Europe, whether concerning migration patterns or population-wide gene frequencies. However, this paper's close analysis and careful synthesis of the information currently available shows a powerful correlation between LP and the fate of hunter-gatherer cultures.

Glossary

Autosomal dominant trait: A physical, observable trait of an organism that is expressed even if only one gene in a pair of chromosomes contains the DNA sequence that causes it

Beta-glycosidic bond: A type of chemical bond that links one sugar molecule to another

Bronze Age: A period marked by the extensive use of bronze in material culture; occurred in northern Europe ca. 2000 BCE

Galactose: The most abundant simple sugar (or monosaccharide); extremely important for energy metabolism

Genetic admixture: The "shuffling" of genes resulting from interactions between two previously isolated or physically separated groups

Glucose: A monosaccharide that combines with glucose to form lactose, the primary sugar component of dairy products

Lactase nonpersistence (LNP): A condition where the enzyme lactase stops being produced after childhood, leading to lactose intolerance

Lactase persistence (LP): A condition marked by continuous synthesis of lactase after childhood, leading to lactose tolerance

Lactase-phlorizin hydrolase: Also simply lactase; an enzyme responsible for breaking down lactose, a milk sugar, to make it possible to digest lactose

LCT: The gene that is responsible for producing lactase, and therefore, digestion of lactose

Linearbandkeramik (LBK): A prehistoric culture that probably introduced agriculture to Europe ca. 5500 BCE; originated in and around modern Hungary

Neolithization: A process defined by the adoption of agriculture and animal husbandry that led to major social and cultural change; began in Europe roughly 6000 BCE

Pitted Ware Culture (PWC): A prehistoric hunter-gatherer culture inhabiting northern Europe until ca. 2000 BCE; seemingly the last hunter-gatherer group to exist in the region

Preproprotein: A gene product that must be chemically "processed" to create a functional protein

Single-nucleotide polymorphism (SNP): An alteration in a DNA sequence that occurs when one nucleotide base is substituted for another and is present in at least 1% of a given population

Trichterbecherkultur (TRB): The first known agricultural group in Scandinavia ca. 4000 BCE, known in English as Funnel Beaker Culture

Author's Note

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Nicholas Mays ('21) from Tampa, Florida, has lived in Harrisonburg for the last eight years. He graduated from James Madison University with a degree in Biology and a minor in Mathematics. He is currently working on a master's degree in molecular biology at George Mason University in Fairfax, Virginia. Nicholas hopes to become a neurogenetic researcher specializing in the genetics of psychosis-related disorders, primarily schizophrenia.

Nicholas is also a history buff and at one point was a history major at JMU. His favorite topic is medieval Europe, and he has a particular interest in the British Isles.

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