

Some genomic insights into the spatio-temporal dynamics of domestication and dispersal of sheep.

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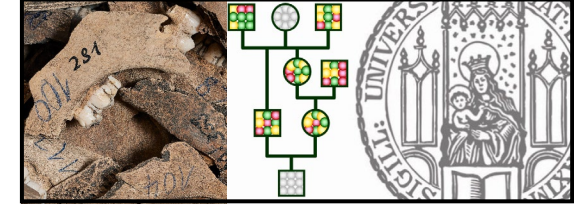
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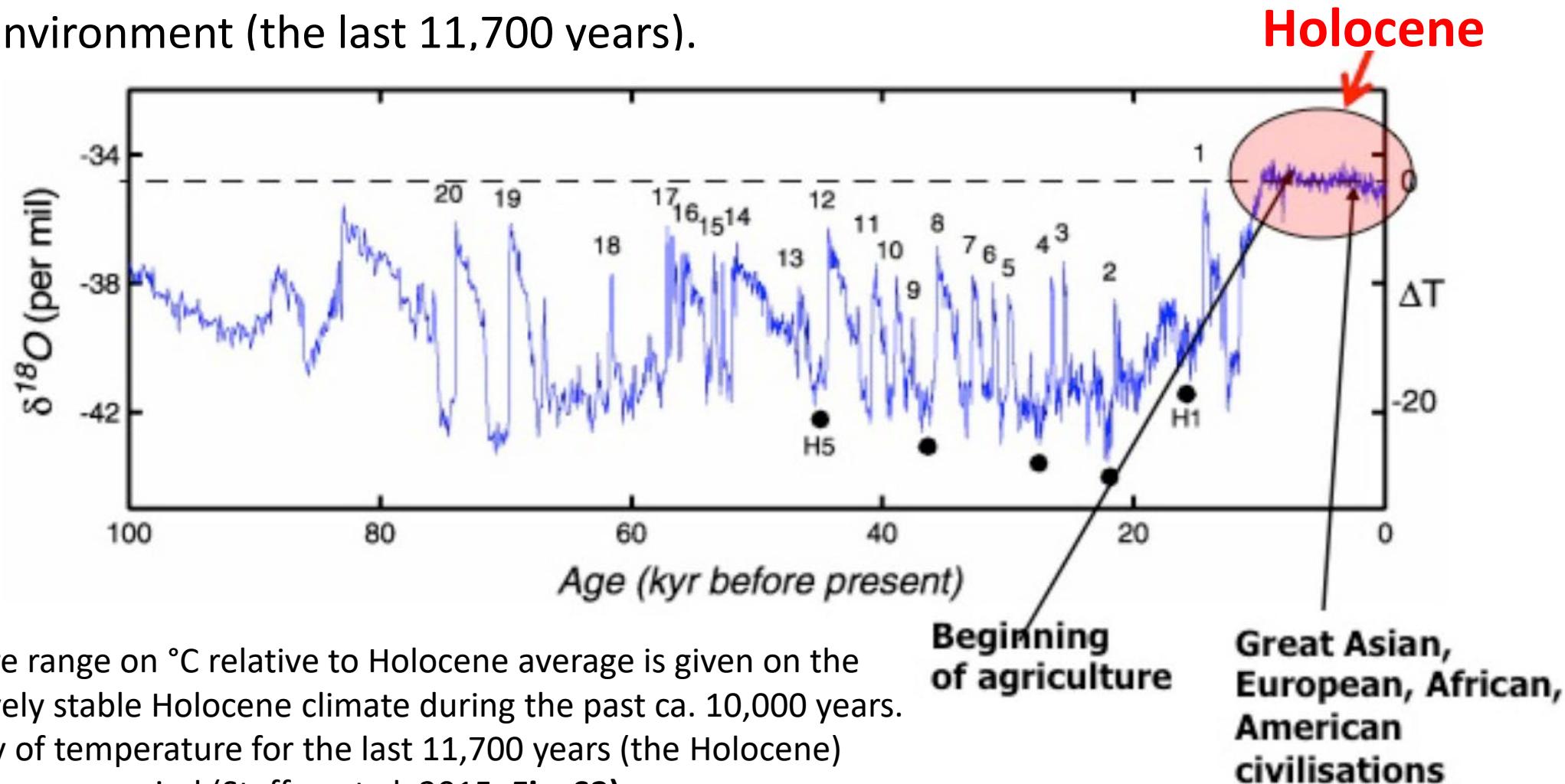
Bavarian Natural History Collections^(Director General)

ArchaeoBioCenter^{LMU}

The transition from the Pleistocene to the Holocene



The only environment we are relatively comfortable with is the Holocene environment (the last 11,700 years).



Approximate temperature range on $^{\circ}\text{C}$ relative to Holocene average is given on the right, showing the relatively stable Holocene climate during the past ca. 10,000 years. Note the relative stability of temperature for the last 11,700 years (the Holocene) compared to the earlier ice age period (Steffen et al. 2015: **Fig. S2**).



Limitation of demographic analyses

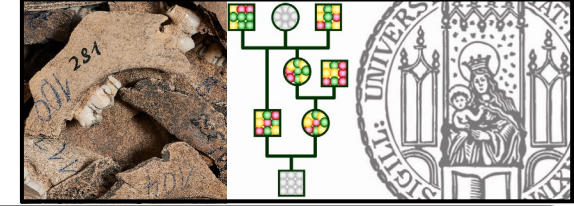


The area is very arid and
DNA is very poorly preserved



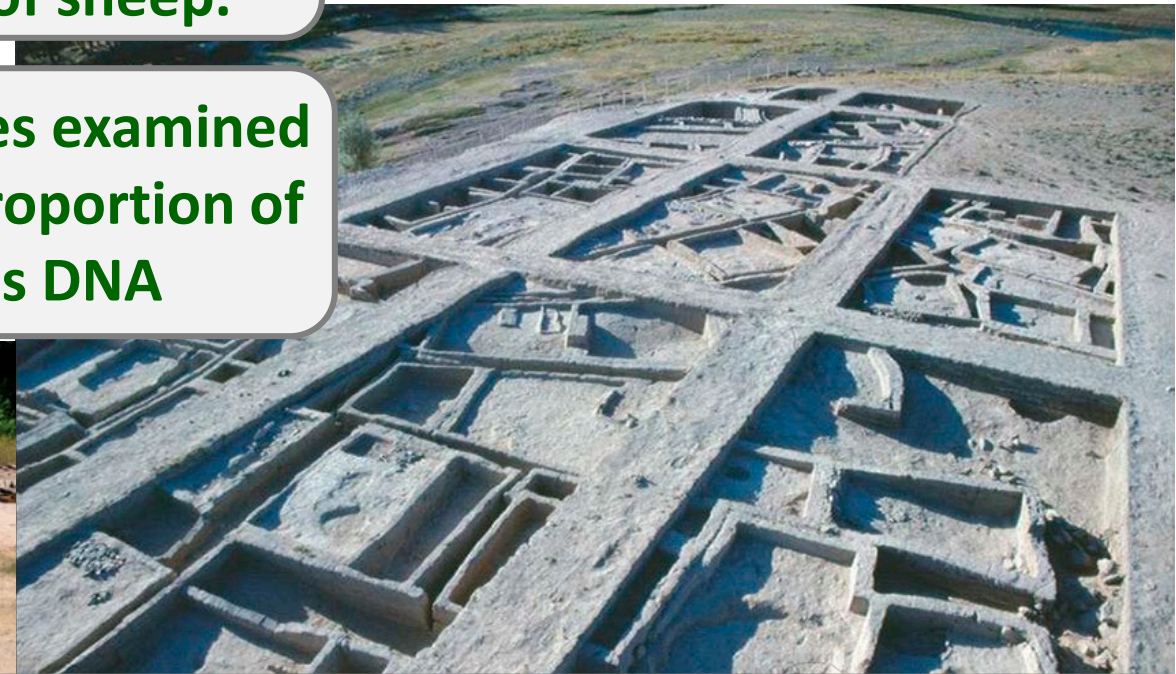


Central Anatolia



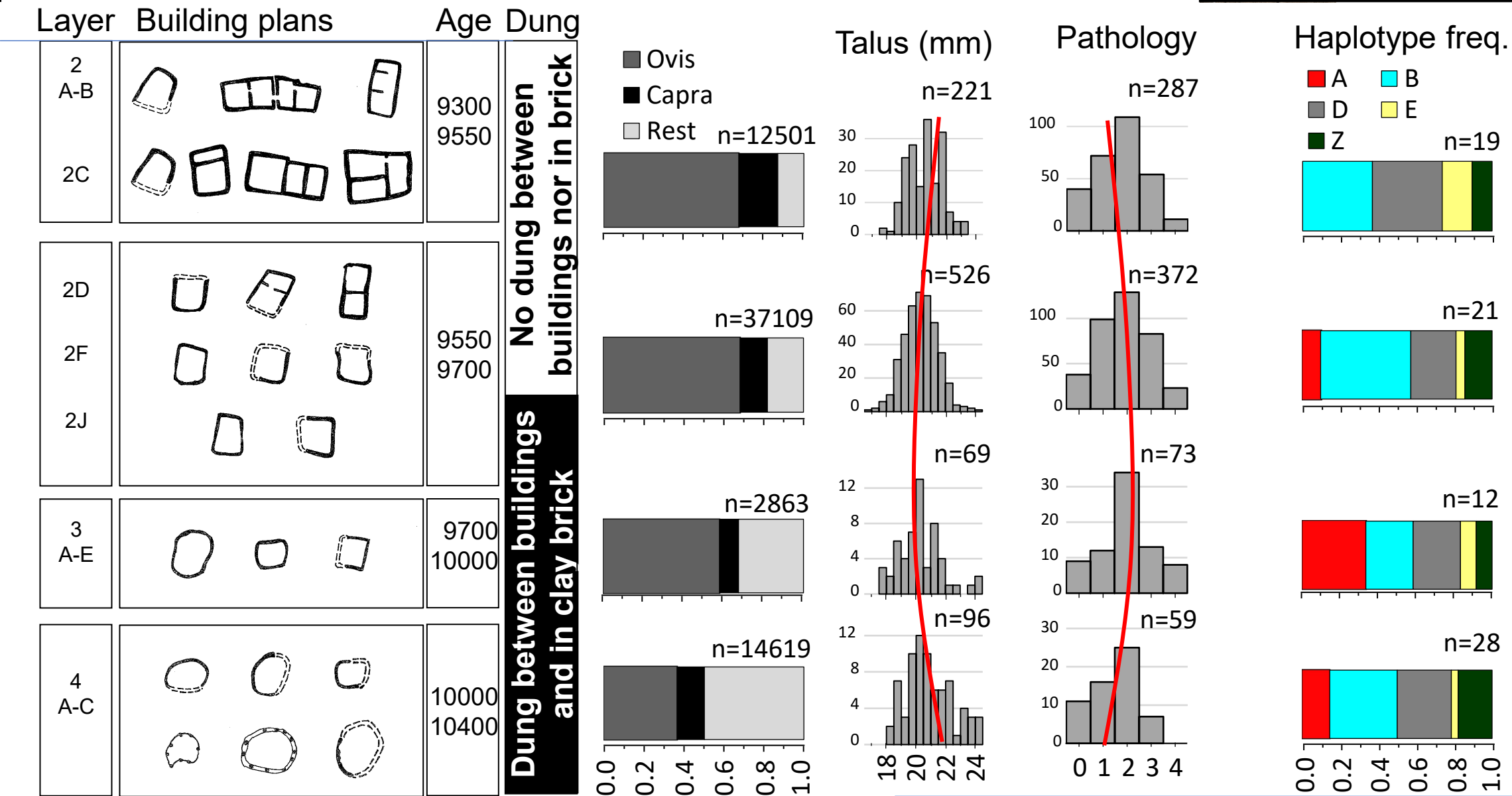
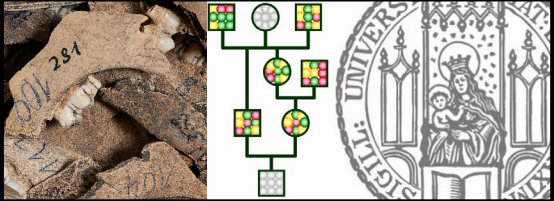
Compared to these eastern Anatolian and upper Mesopotamian Neolithic settlements, the central Anatolian Asıklı Höyük has several decisive advantages:

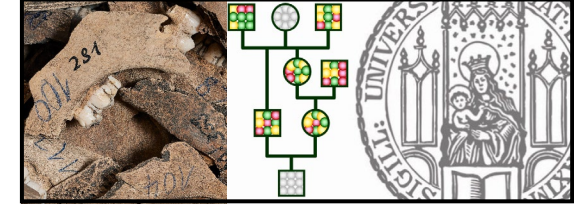
- 1 A continuity of over 1000 years
- 2 it covers a period from the beginnings to the complete domestication of sheep.
- 3 The unusually high-resolution zooarchaeological record.
- 4 The ancient bones examined contain a high proportion of endogenous DNA



In other words, archaeologists and geneticists have the opportunity to observe domestication as a dynamic process of 'learning by doing'.

Domestication as a dynamic process of ‘learning by doing’





After 600 years in captivity, the animals were obviously tame enough to switch to pasture farming.

But the domestication was NOT a large cross-generational project.

How the domestication process took place?

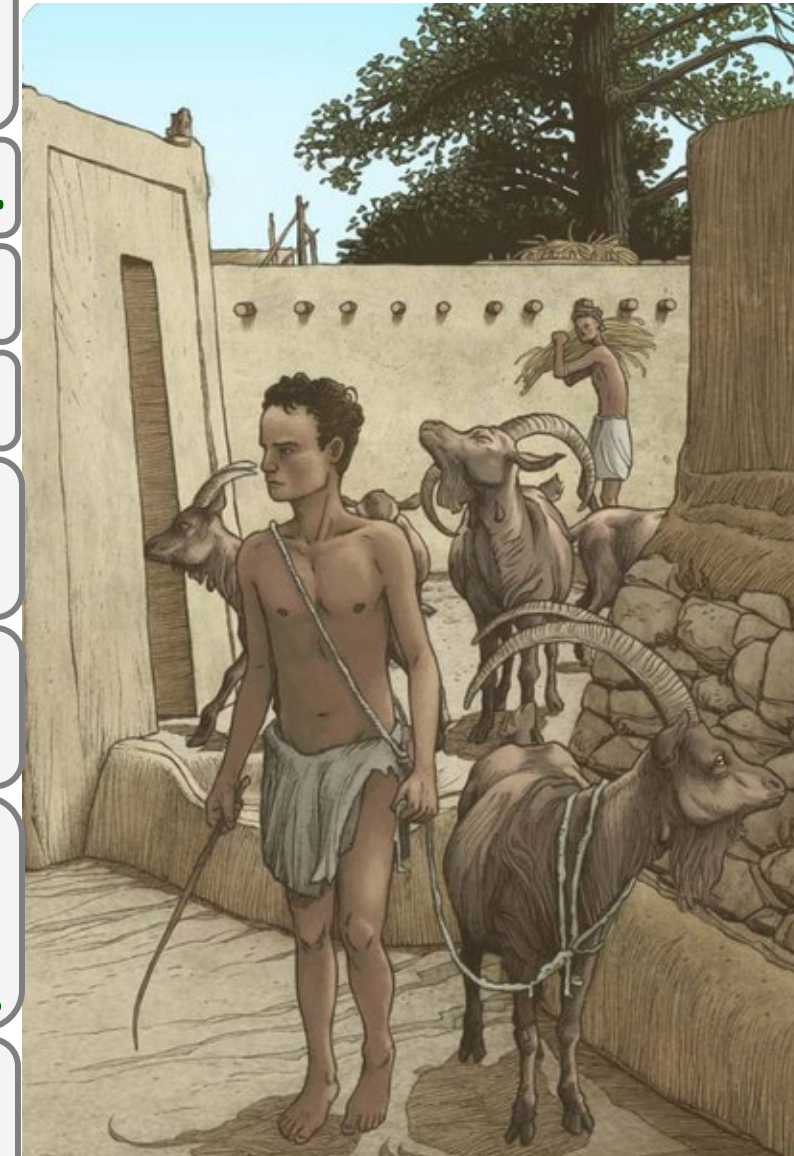
Kill dam catch-and-grow lamb (a living meat reserve)

If you have enough captive animals, which one will you kill first?
To which one you will tell: 'You're the next one in my pan!'

Answer: Animals constantly causing extra work and trouble:
young, hot-tempered, revolting, mostly male animals.

Result: Tame animals get the chance to reproduce. After 600 years, you can take them out to pasture. Those that escape during grazing also contribute to domestication (*Excluding oneself*).

This means that neolithic farmers have unintentionally bred animals that are easier to handle.



Genetic evidence for 'learning by doing'

No HPG-C

No HPG-C

Aşıklı Höyük (aN)

Turkey (aNC)

Europe (aN)

Europe (aCM)

Georgia (aM)

Caucasus (c)

Europe (c)

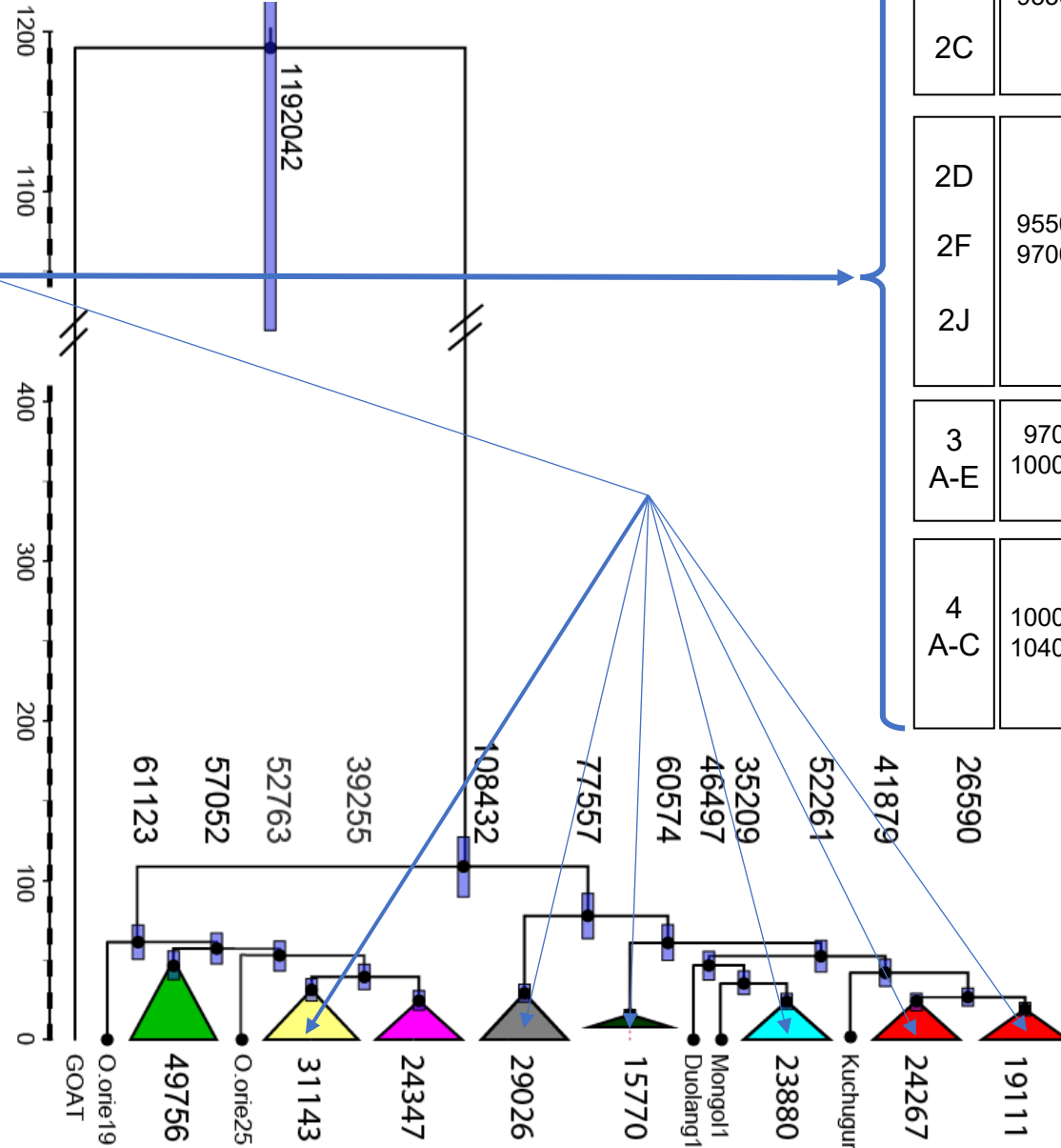
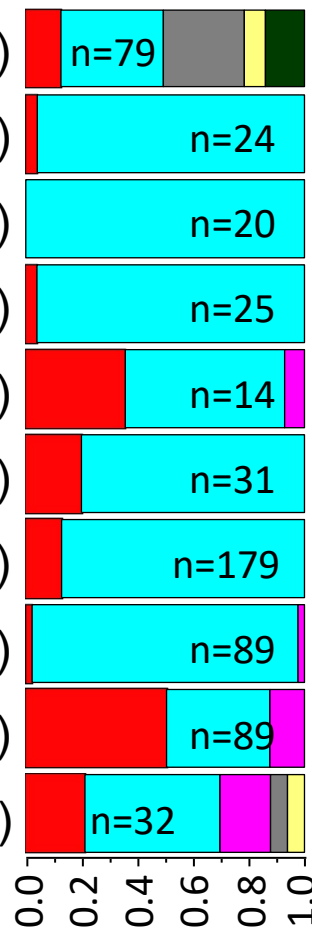
N. Africa (c)

Asia (c)

Mideast (c)

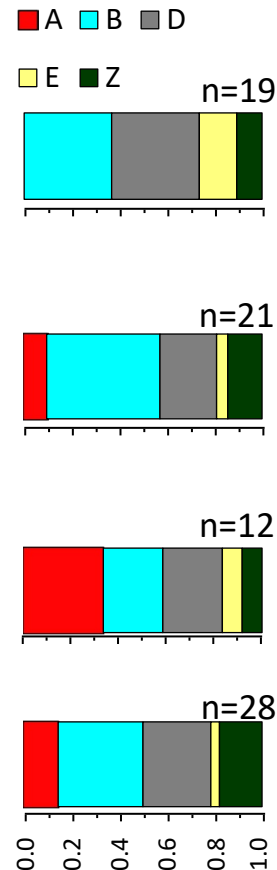
Haplotype freq.

A B C
D E Z

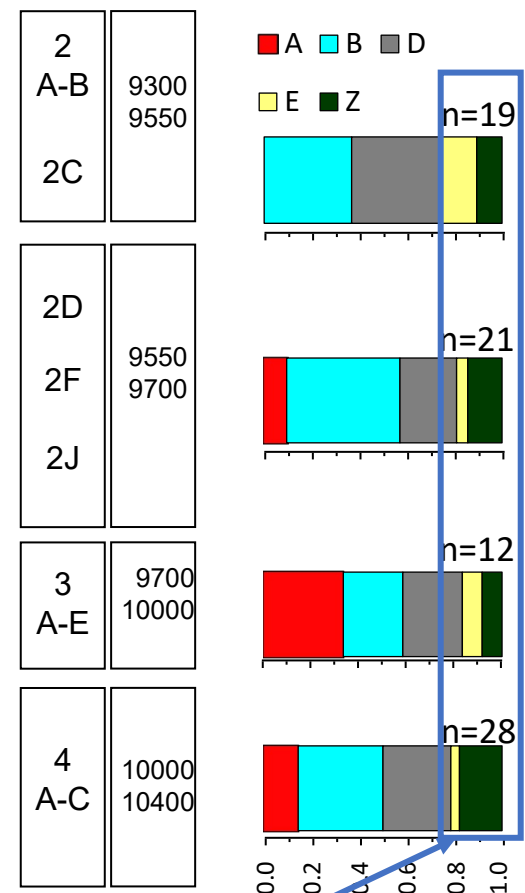
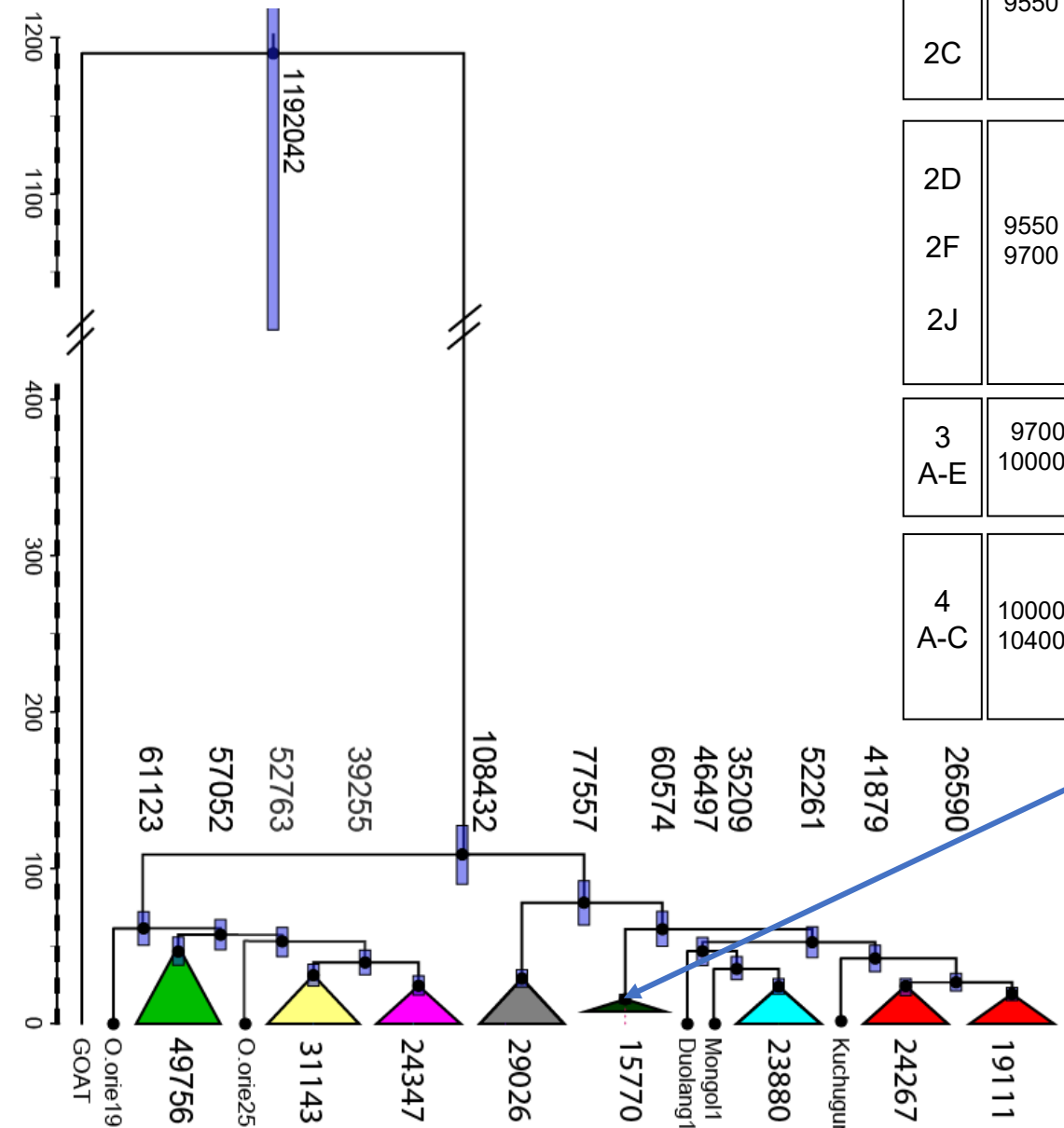
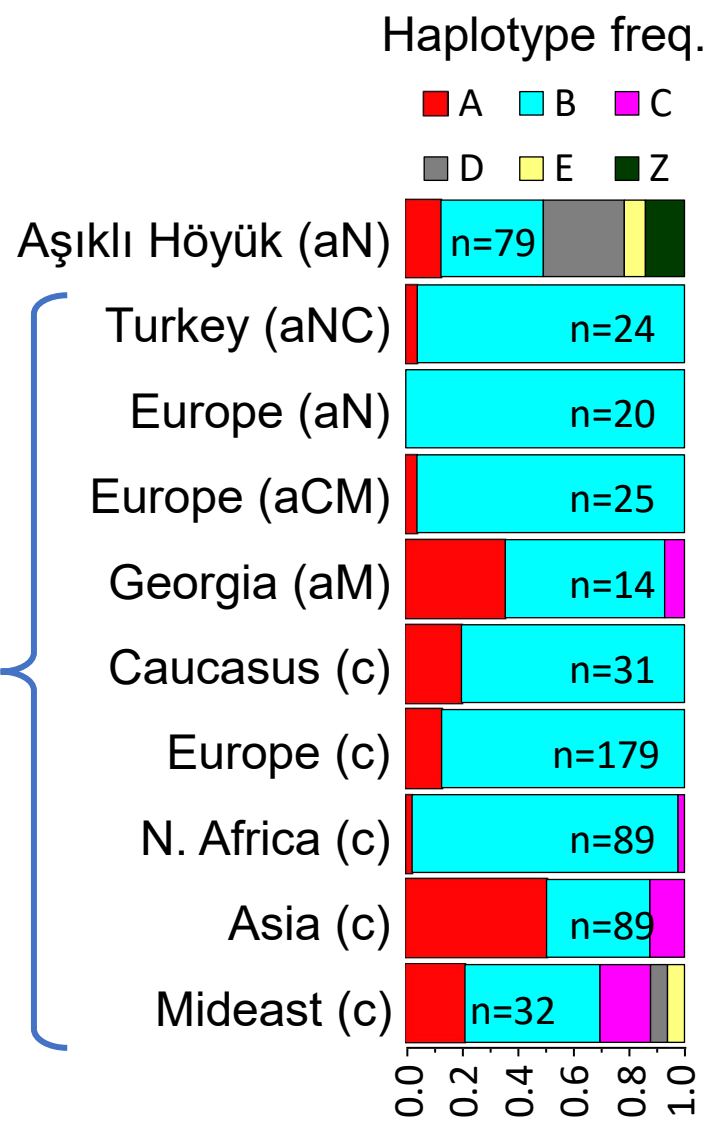


2	9300
A-B	9550
2C	
2D	
2F	9550
2J	9700
3	9700
A-E	10000
4	10000
A-C	10400

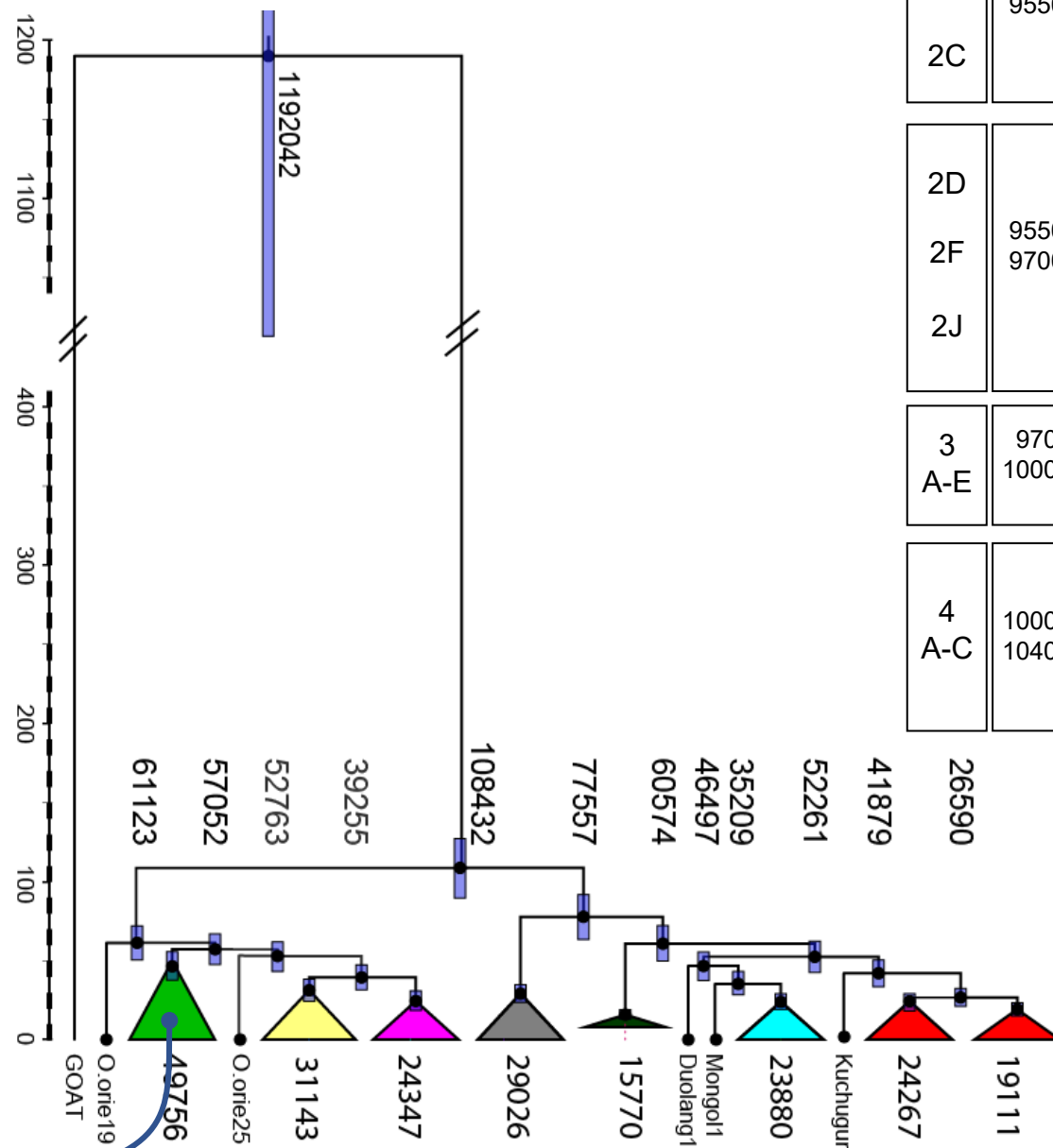
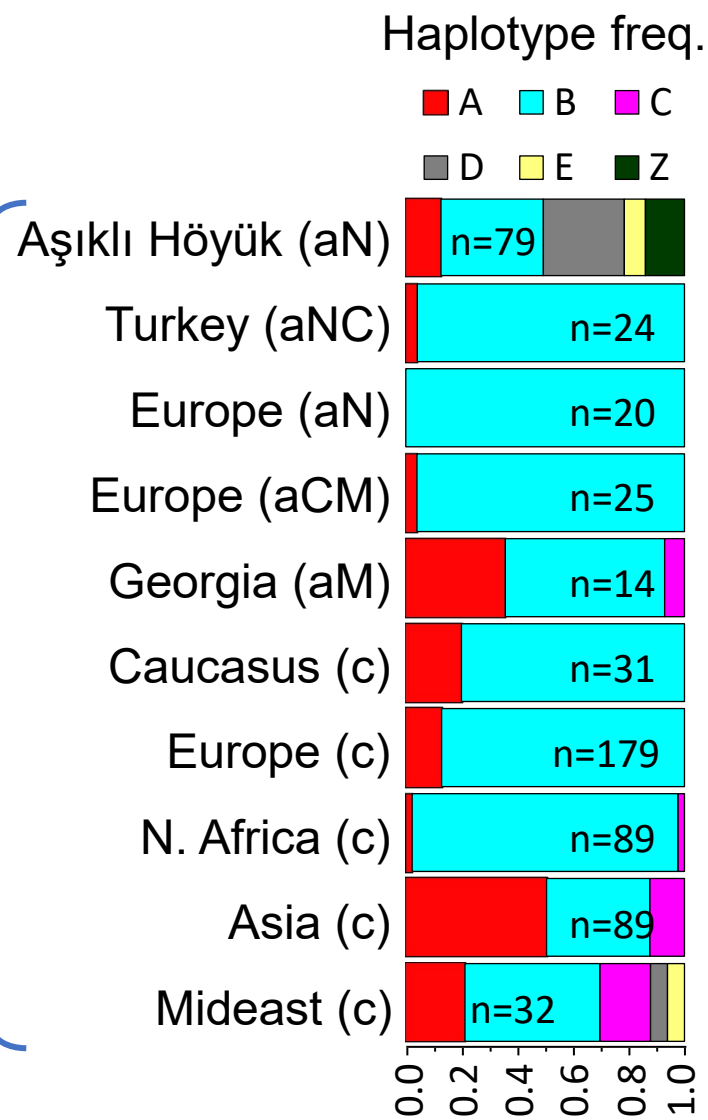
Haplotype freq.



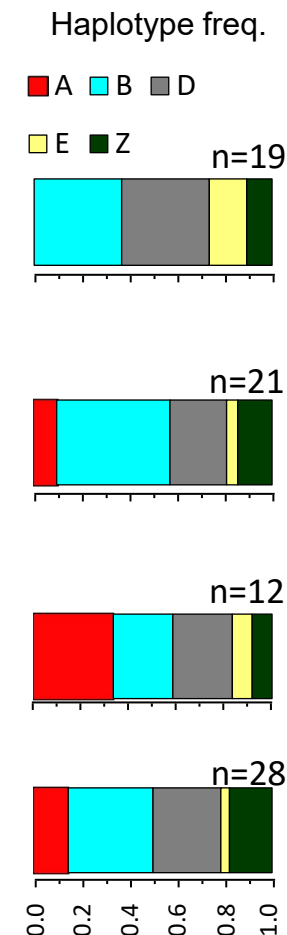
No HPG-Z



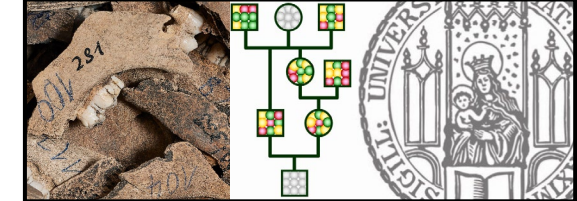
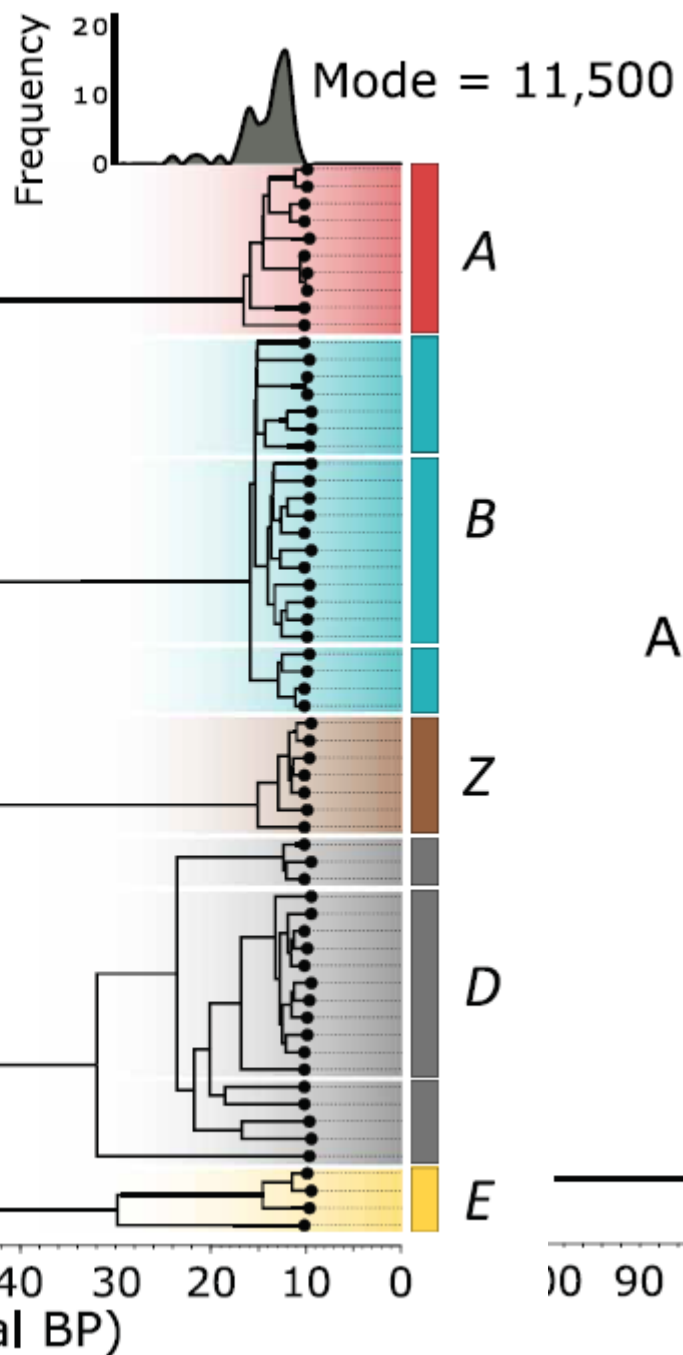
No GPG-G



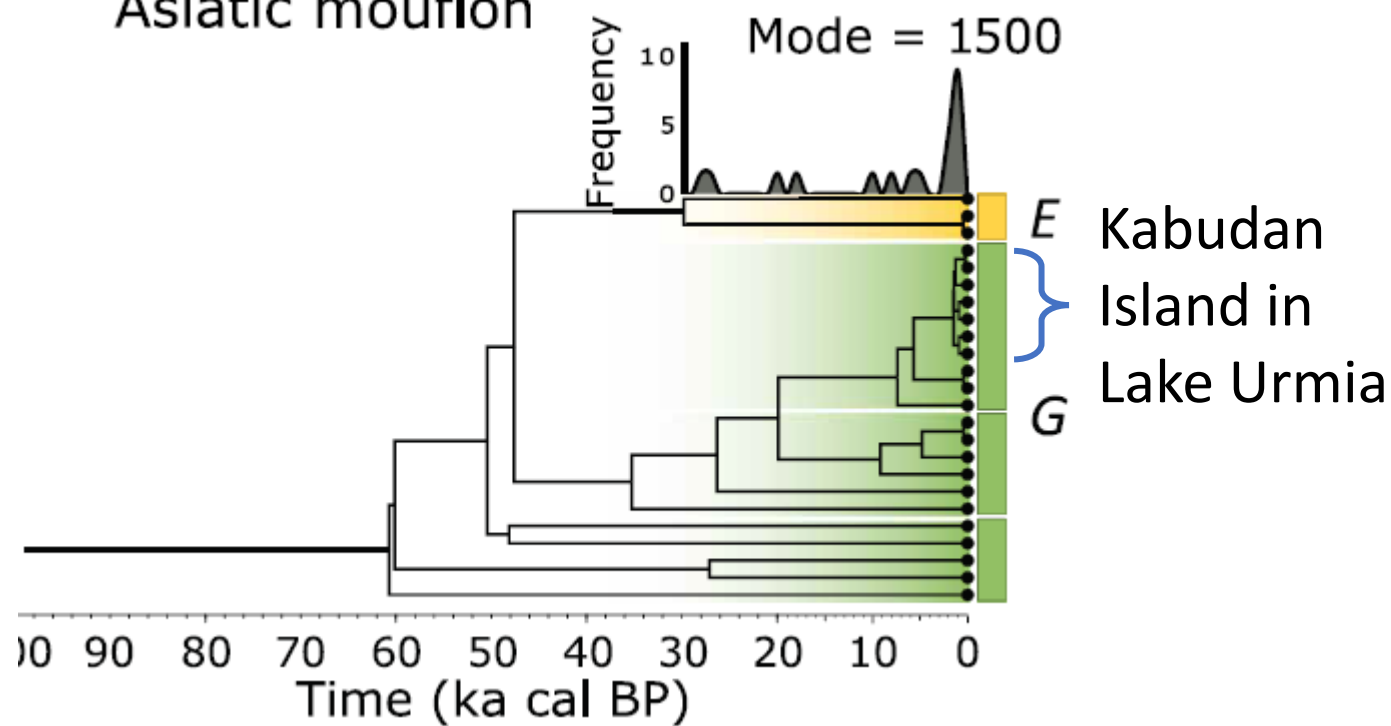
2	
A-B	9300 9550
2C	
2D	
2F	9550 9700
2J	
3	
A-E	9700 10000
4	
A-C	10000 10400



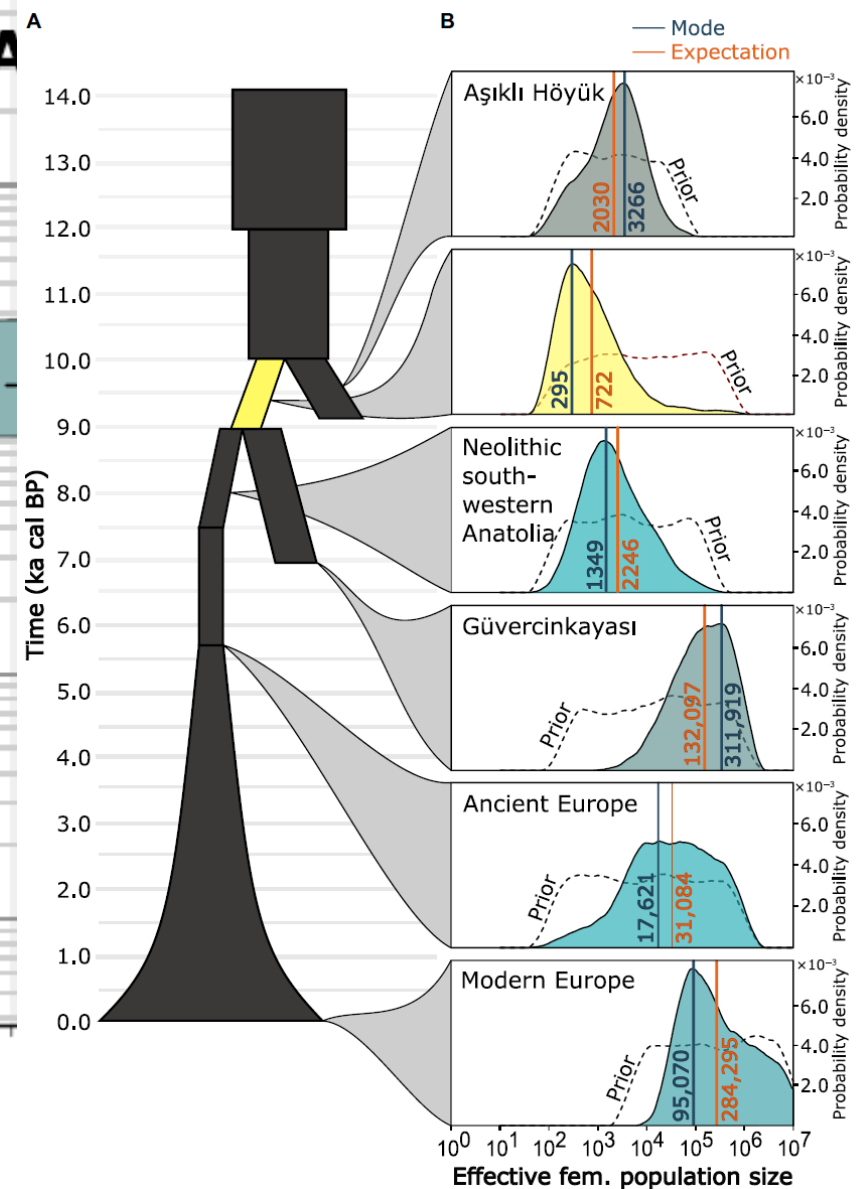
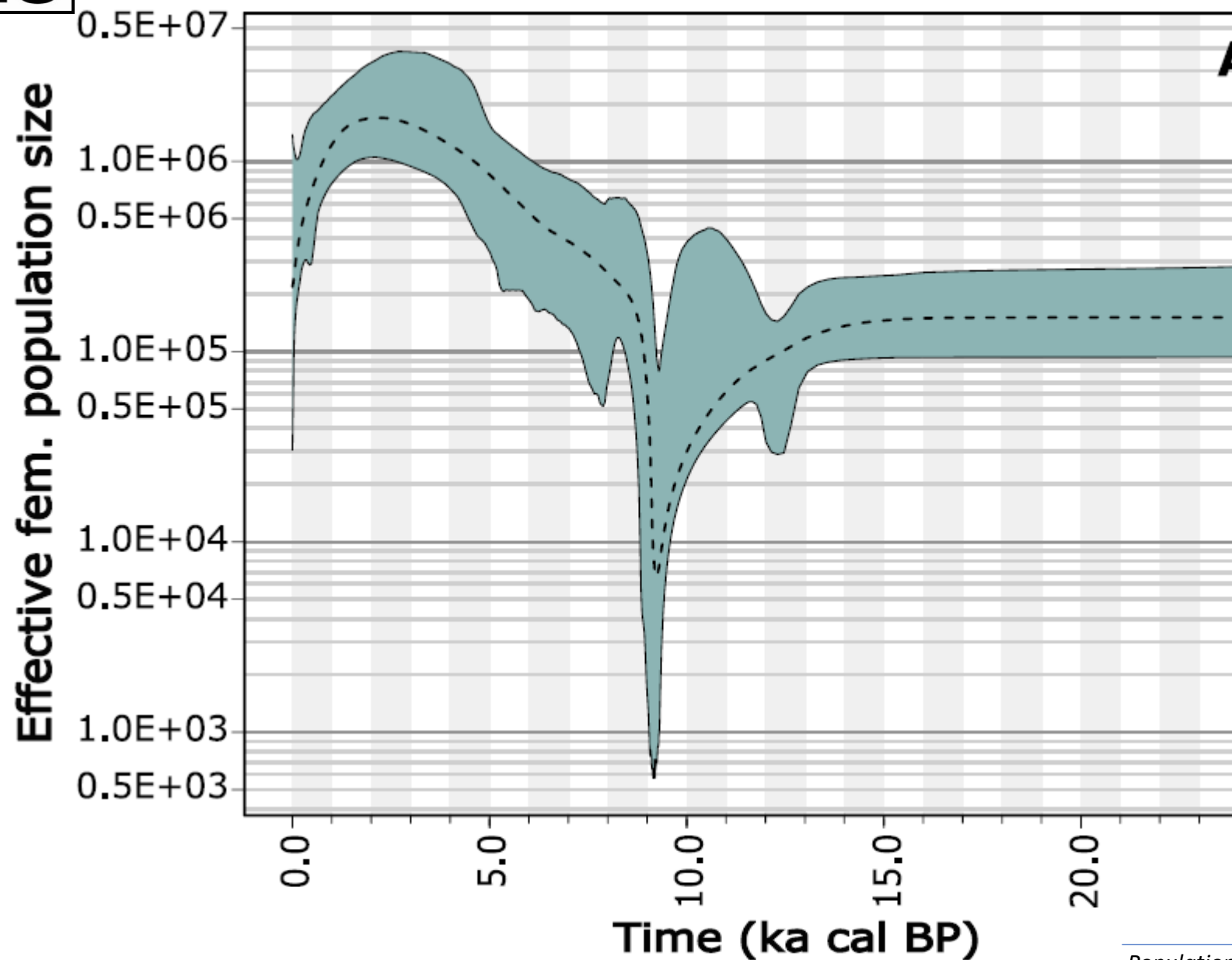
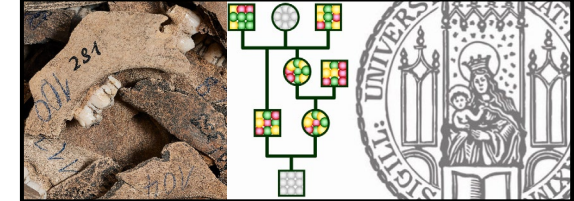
A Aşıklı Höyük



Asiatic mouflon



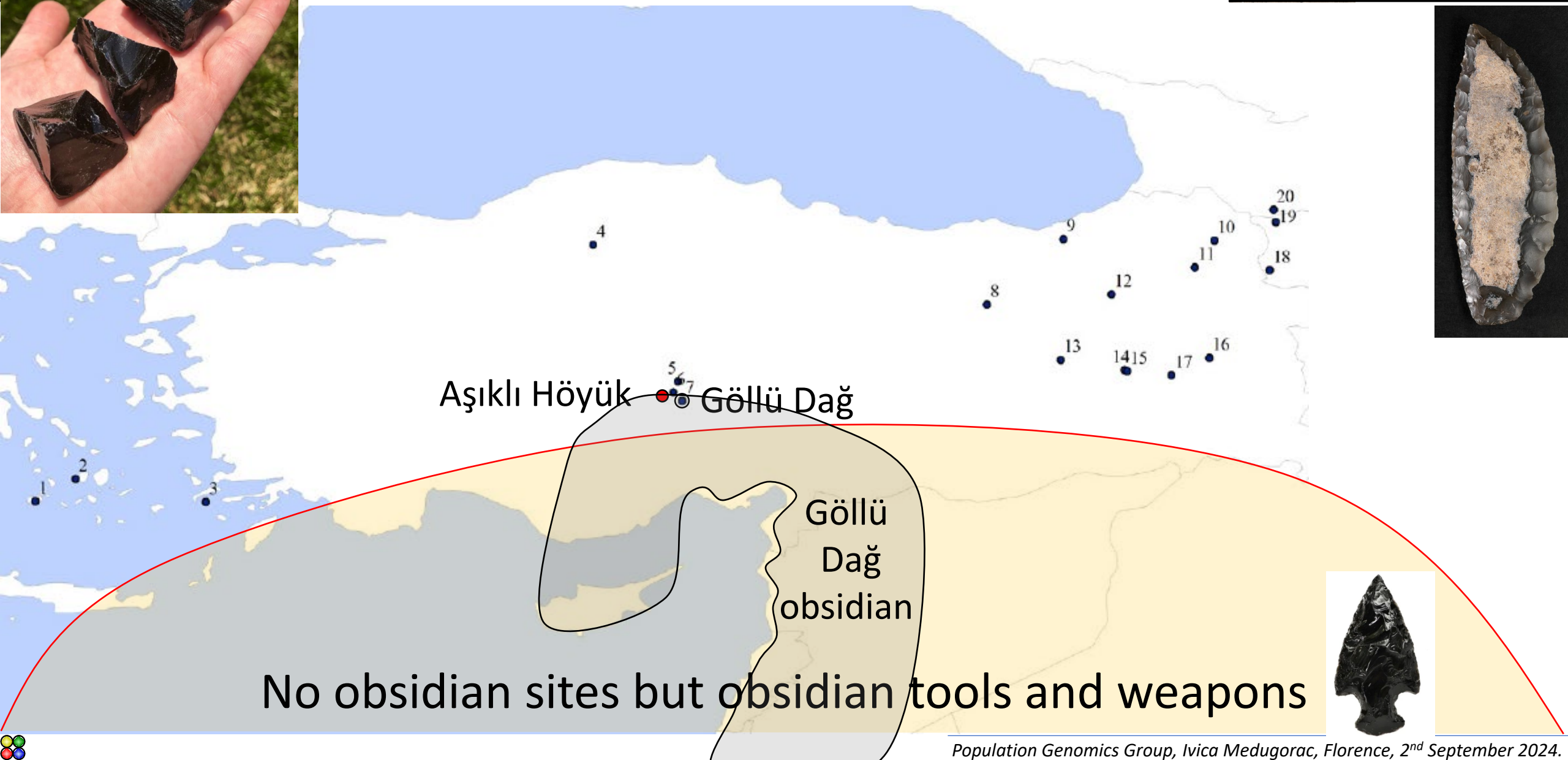
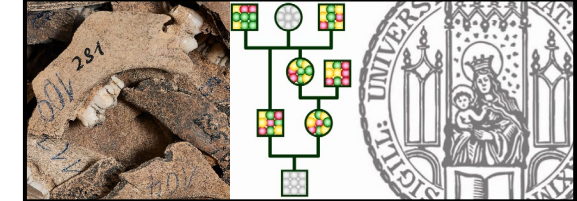
This severe bottleneck occurred in western Anatolia after the abandonment of the Aşıklı Höyük (9300 BP)

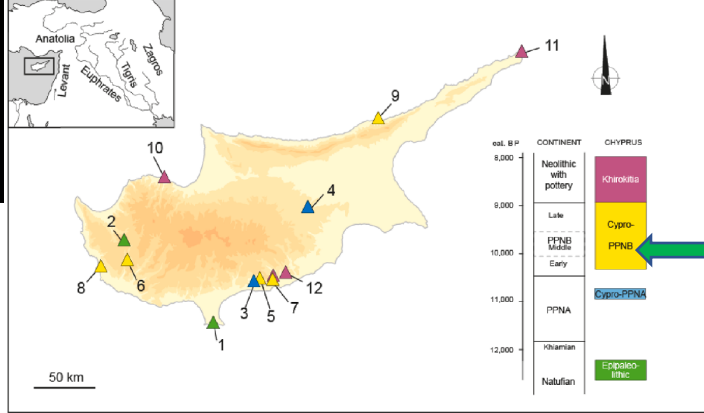


Possible influence of the Asıklı Höyük on the wider area



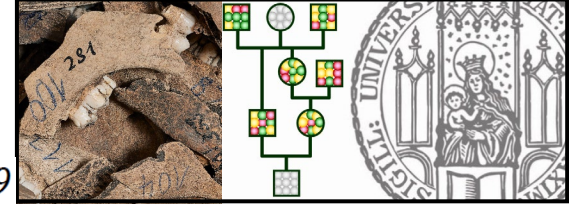
There are twenty obsidian (volcanic glass) sites in or near the Fertile Crescent





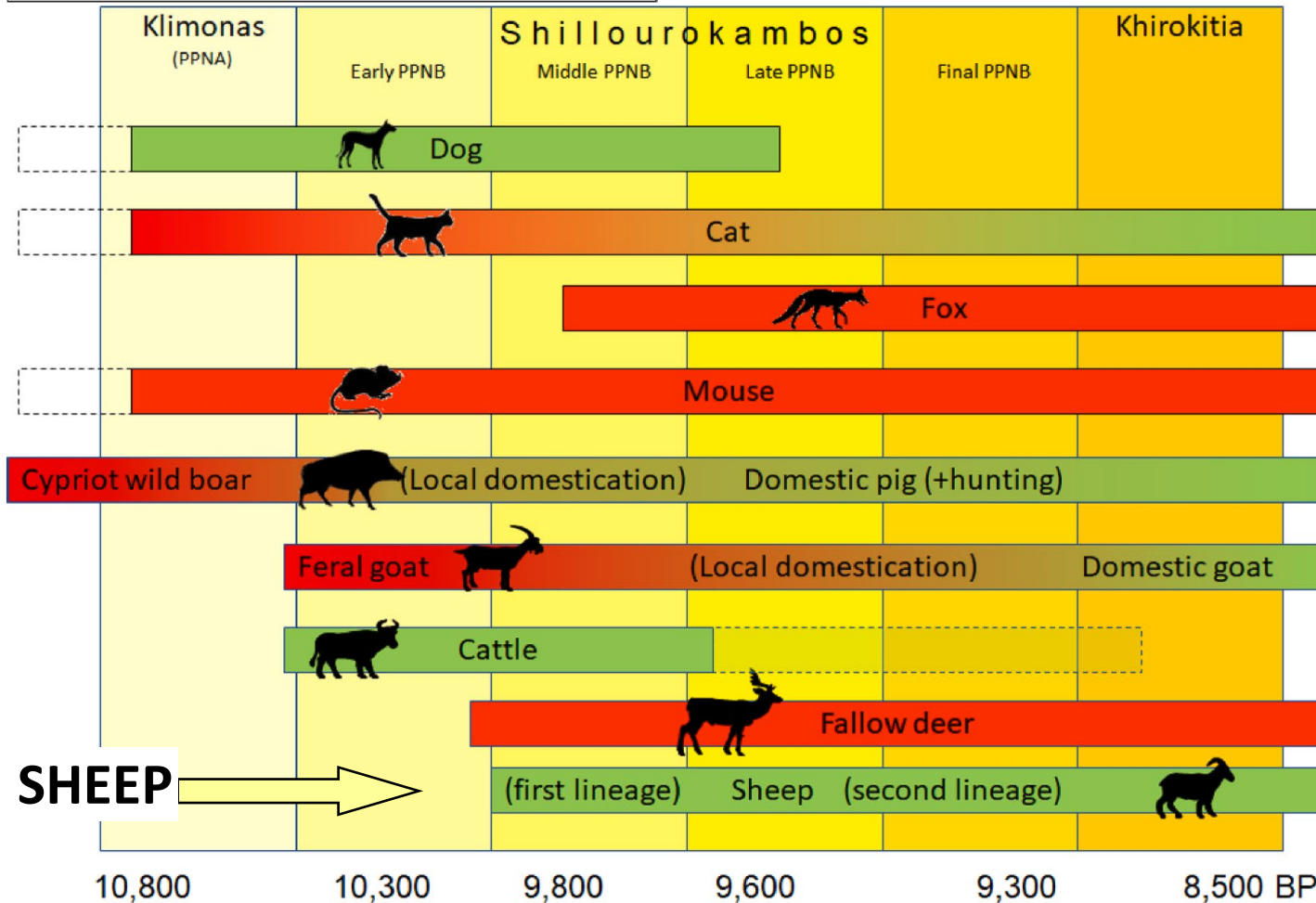
The story of Cyprus

J.-D. Vigne et al. Journal of Archaeological Science: Reports 50 (2023) 104049



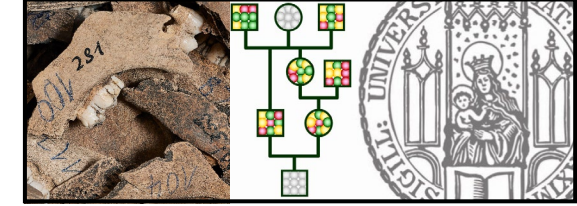
Sheep at early domestication is coming to the Cyprus at *Beginn des PPNB* (10500-10000).

The morphometric data indicate that they originate from the northern Levant (Damascus Basin) and not from Anatolia (*personal communication from J.D. Vigne*).



- The sheep were **NOT** released into the wild.
- The sheep became feral much later , ~9200-8800
- The sheep came to Cyprus in two waves.
- The second wave is around ~9500 BP.
- Zoological data also point to Syria (Aswad, east of Damascus) as the origin of the second wave too.
- The Cypriot mouflon is most likely a feral sheep of the second wave.
- The colonising peoples use obsidian from Göllü Dağ.
- Long-distance trade in volcanic glass is much easier than trade in living animals.
- Göllü Dağ volcanic glass in Cyprus cannot be used as an argument in favour of the Anatolian origin of the animals.

The story of Cyprus

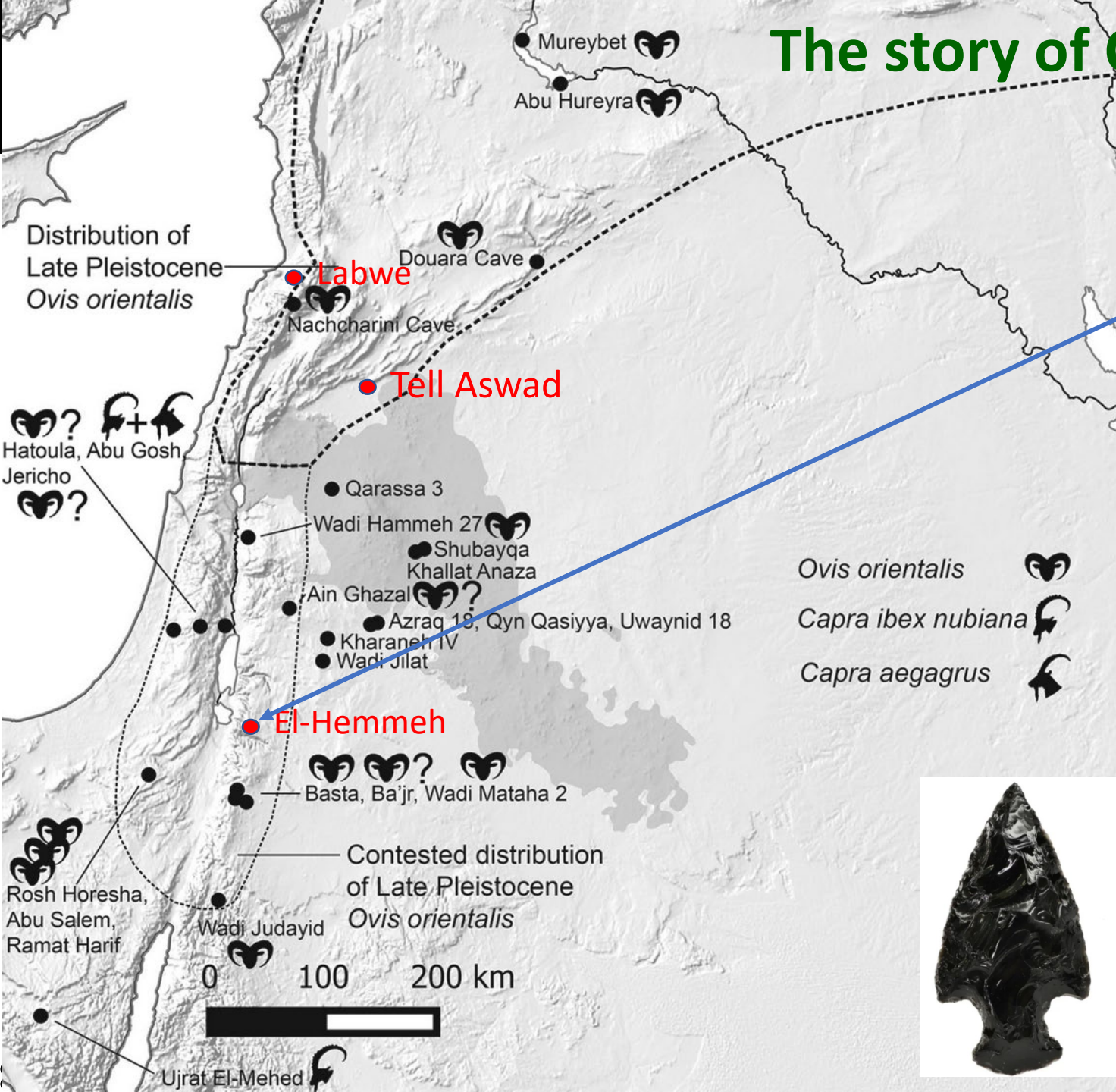


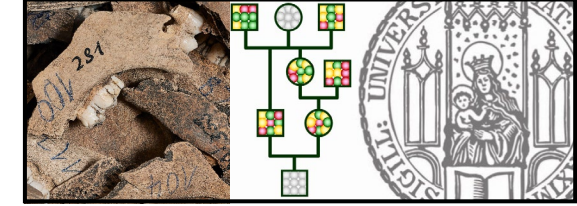
Several studies (e.g. Carter et al. 2023) show that obsidian from the Göllü Dağ was traded as far as the southern Levant.

These studies (e.g. Yeomans et al. 2017) also show that there was a mouflon population in the Lebanon Mountains at this time.

Cyprus is also accessible from the Levant (80 km), and some PPNA peoples had already mastered navigation techniques and boat building (Vigne et al., 2014).

Therefore, Levantine communities could be the source of Göllü Dağ obsidian and Levantine animals.





The epipalaeolithic (ca. 12000 BP) Nachcharini Cave is a camp specialized in sheep hunting (Rhodes et al. 2020).

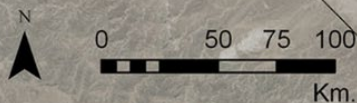
Nachcharini PPNA hunters may have been engaged in some form of early herd management (*probably catch-and-grow strategy*).

The domestication itself took place at sites near Nachcharini (e.g. Aswad) in the PPNB period.

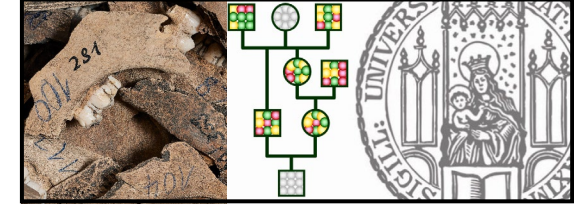
We (Daly et al., in review) have examined many sheep bones from the Nachcharini Cave and were successful with three of them.

We combined ancient mtDNA genomes from the Fertile Crescent with different contemporary mouflon populations and domestic sheep in a phylogenetic analysis.

- | | |
|------------------|------------------------------------|
| 1. Wadi Tumbaq | 7. Gilgal, Netiv Hagdud, Salibiyah |
| 2. Gesher | 8. Hatula |
| 3. Bir al Maksur | 9. Ain Darat |
| 4. 'Iraq ed-Dubb | 10. Dhra |
| 5. Huzuk Musa | 11. El-Hemmeh |
| 6. Tzur Nathan | 12. Wadi Feynan 16 |



Maximum Likelihood Tree of 158 selected complete mtDNA genomes.



Whole mtDNA genomes from 50 Cypriot mouflons in combination with ancient and modern, wild and domesticated sheep from a broad region show the following:

★ Epipalaeolithic mouflon from Nachcharini cave (Lebanon Mouflon)

● Epipalaeolithic mouflon from central and east Anatolia (Kortik Tepe and Pinarbasi)

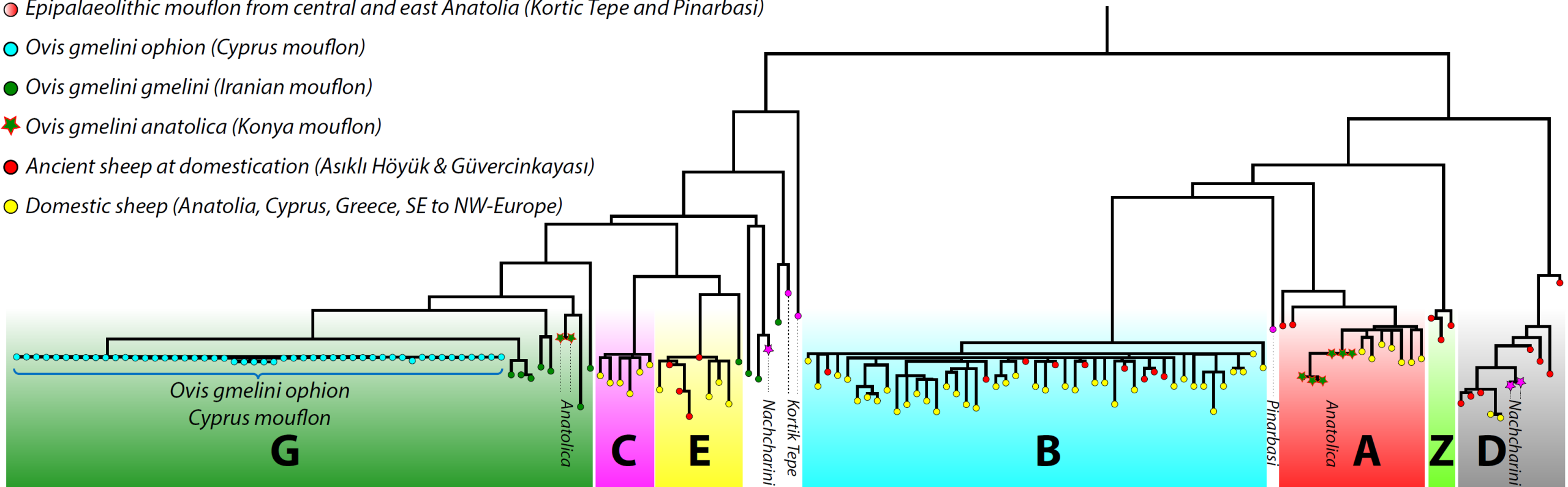
● *Ovis gmelini ophion* (Cyprus mouflon)

● *Ovis gmelini gmelini* (Iranian mouflon)

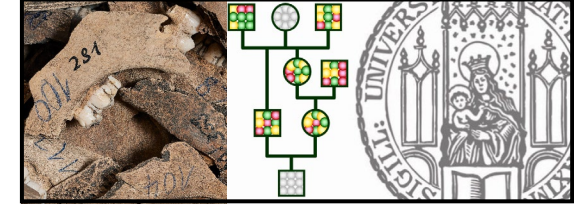
★ *Ovis gmelini anatolica* (Konya mouflon)

● Ancient sheep at domestication (Asıklı Höyük & Güvercinkayası)

● Domestic sheep (Anatolia, Cyprus, Greece, SE to NW-Europe)



Maximum Likelihood Tree of 158 selected complete mtDNA genomes.



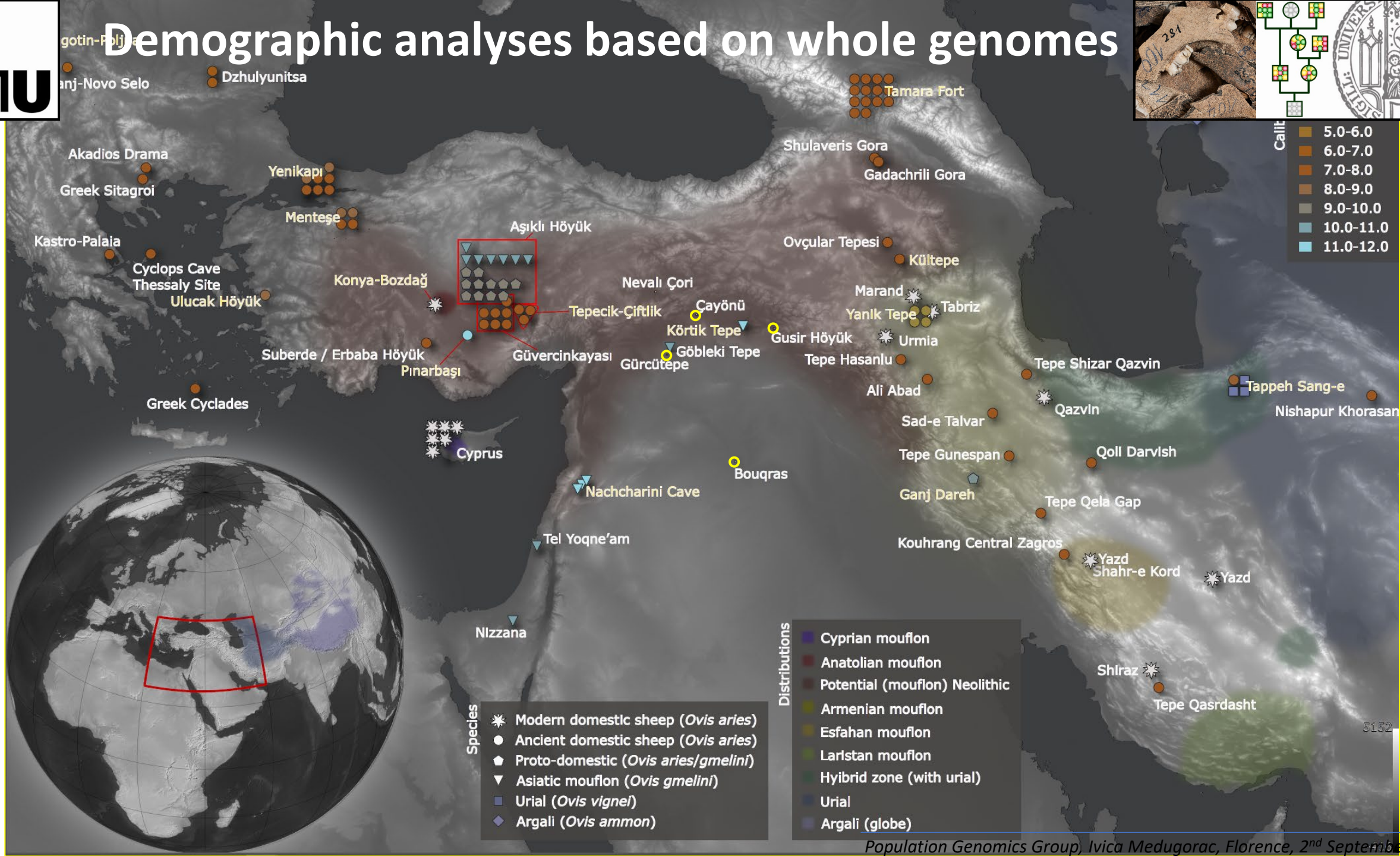
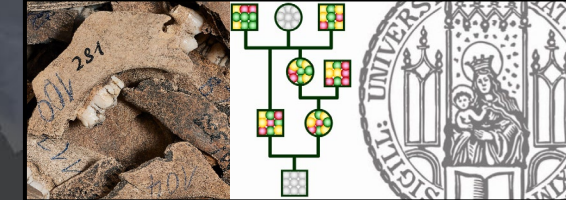
Whole mtDNA genomes from 50 Cypriot mouflons in combination with ancient and modern, wild and domesticated sheep from a broad region show the following:

- 1 All 50 Cypriot mouflons belong to haplogroup G (HPG-G)
- 2 The HPG-G is typical of Armenian mouflons from north-west Iran.
- 3 The HPG-G was not found in any domesticated sheep sequenced yet.
- 4 The HPG-G was not found in sheep at domestication in Asıklı Höyük?
- 5 Domesticated sheep from Cyprus (n=16) belong to HPG-A and B.
- 6 No sign for hybridization between Cypriot sheep and Cypriot mouflon?
- 7 Two Anatolian mouflons belong to HPG-G and six to HPG-A
- 8 One Levantine mouflon is HPG-G, but is closely related to the Iranian population
- 9 Two Levantine mouflons are HPG-D and closely related to Asıklı population.

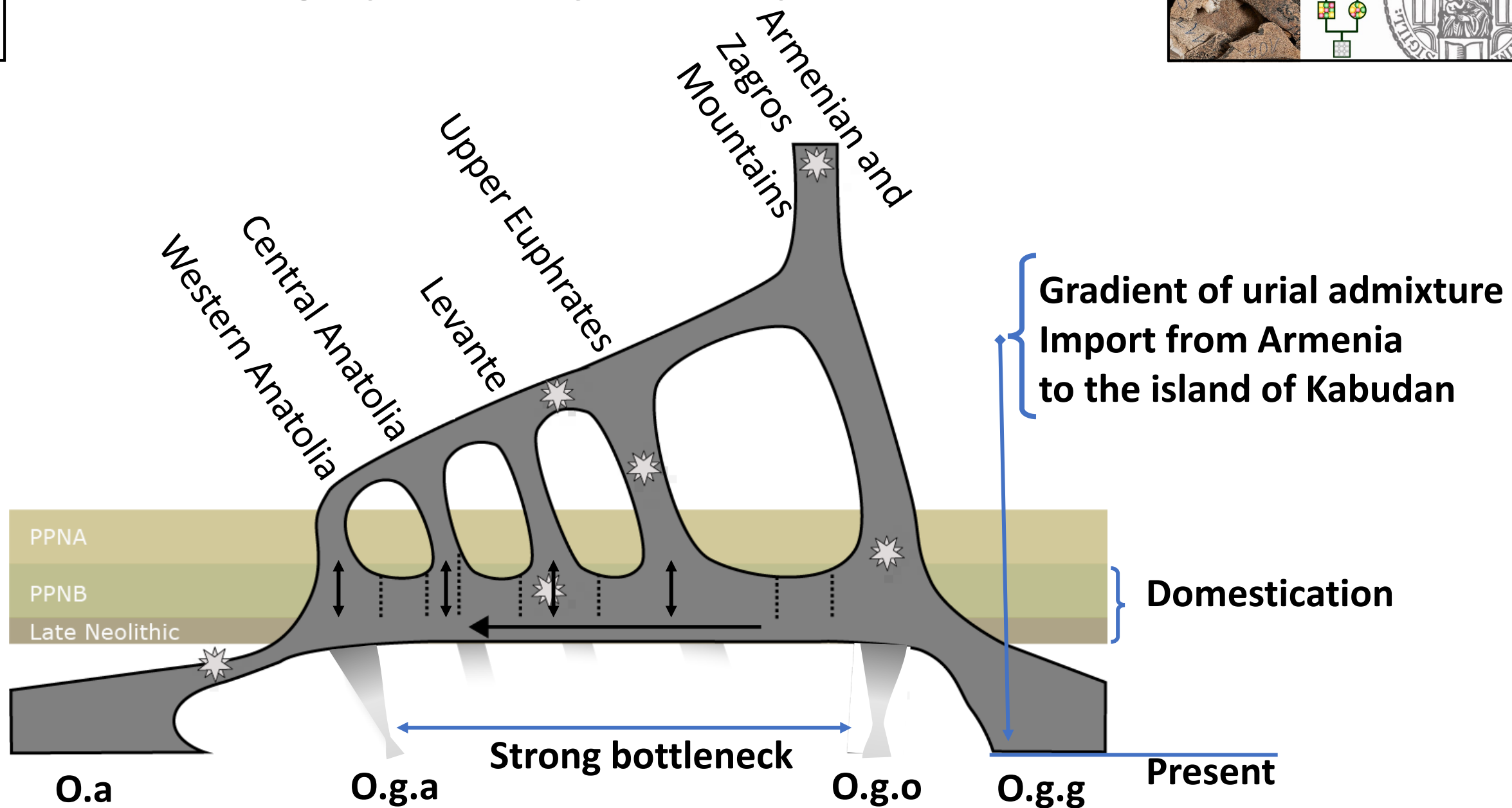
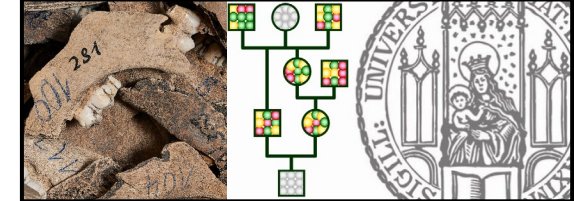
● *Ovis gmelini gmelini* (Iranian mouflon)

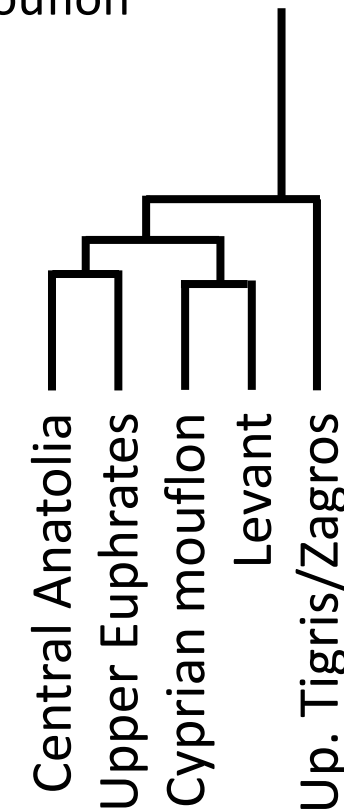
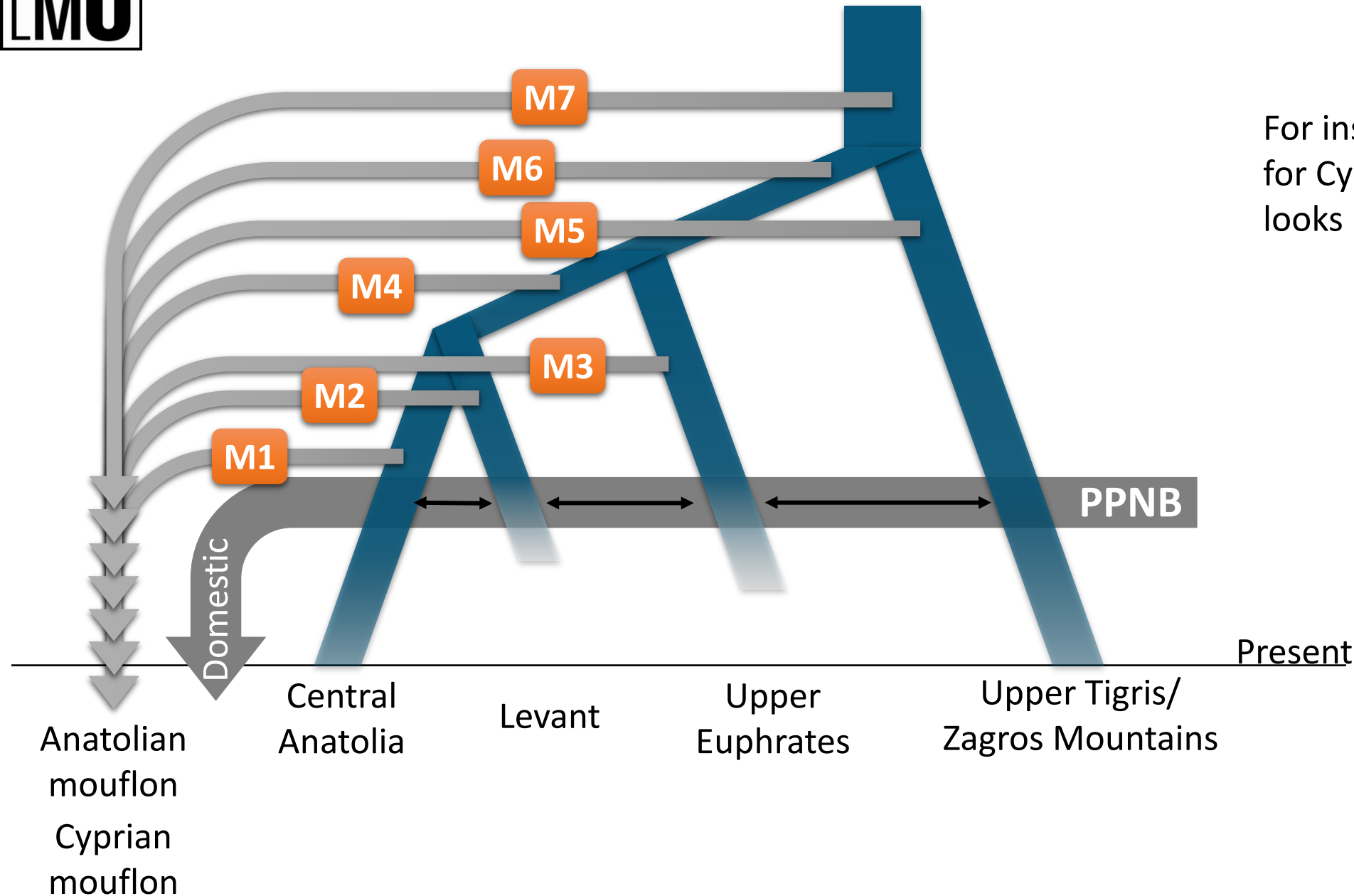
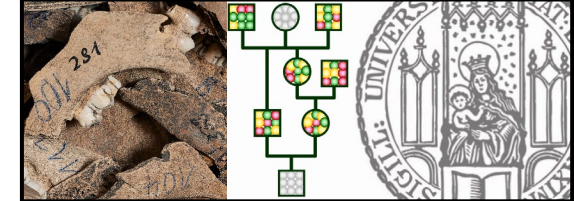
**Analyses of the maternal sheep genomes
DO NOT
resolve the history of the Cypriot mouflon,
but in combination with new archaeological evidence,
they help us to establish a limited number of
hypotheses that should be tested.**

Demographic analyses based on whole genomes

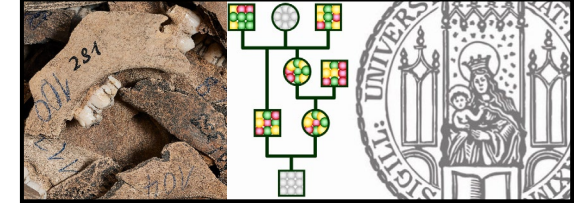


Demographic analyses on Sparse Data





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Dr. Pedro Morell Miranda
Dr. Maulik Upadhyay
Dr. Neza Pogorevc
Dr. Stefan Krebs

**Bavarian Natural History Collections,
Munich, Germany**
Dr. Nadja Pollath

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Prof. Jean-Denis Vigne**

**Middle East Technical University,
Ankara, Türkiye**
Prof. Mehmet Somel

Trinity College, Dublin, Ireland
Prof. Daniel G. Bradley
Dr. Kevin G. Daly
Dr. Victoria E. Mullin
Dr. Andrew J. Hare
Dr. Valeria Mattiang

**Justus Liebig University of Gießen,
Gießen, Germany**
Prof. Gesine Luhken

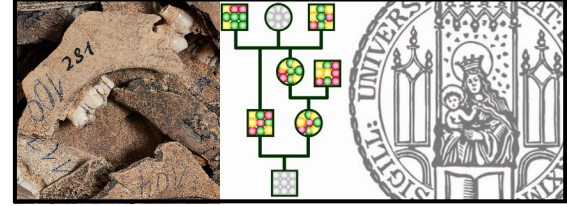
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Dr. Katerina Trantalidou

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Nikos Kassinis

**Mimar Sinan Fine Arts University
Istanbul, Türkiye**
Prof. Guneş Duru



Some of our recent results are published in this paper, which does not include the genomes of mouflons from Cyprus, the Levant and Anatolia.

Sandoval-Castellanos *et al.*, *Sci. Adv.* **10**, eadj0954 (2024) 12 April 2024

SCIENCE ADVANCES | RESEARCH ARTICLE

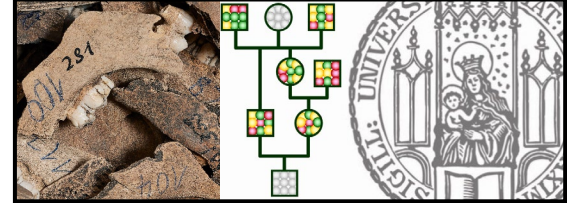
EVOLUTIONARY BIOLOGY

Ancient mitogenomes from Pre-Pottery Neolithic Central Anatolia and the effects of a Late Neolithic bottleneck in sheep (*Ovis aries*)

Edson Sandoval-Castellanos^{1,2*†}, Andrew J. Hare^{3†}, Audrey T. Lin^{4,5}, Evangelos A. Dimopoulos^{4,6}, Kevin G. Daly^{3,7}, Sheila Geiger², Victoria E. Mullin³, Ingrid Wiechmann², Valeria Mattiangeli³, Gesine Lühken⁸, Natalia A. Zinovieva⁹, Petar Zidarov¹⁰, Canan Çakırlar¹¹, Simon Stoddart¹², David Orton¹³, Jelena Bulatović¹⁴, Marjan Mashkour¹⁵, Eberhard W. Sauer¹⁶, Liora Kolska Horwitz¹⁷, Barbara Horejs¹⁸, Levent Atici¹⁹, Vecihi Özkaya²⁰, Jacqui Mullville²¹, Michael Parker Pearson²², Ingrid Mainland²³, Nick Card²³, Lisa Brown²⁴, Niall Sharples²¹, David Griffiths²⁵, David Allen²⁶, Benjamin Arbuckle²⁷, Jordan T. Abell²⁸, Güneş Duru²⁹, Susan M. Mentzer³⁰, Natalie D. Munro³¹, Melis Uzdurum³², Sevil Gülçur³³, Hylke Buitenhuis³⁴, Elena Gladyr⁹, Mary C. Stiner³⁵, Nadja Pöllath^{36,37}, Mihriban Özbaşaran³³, Stefan Krebs³⁸, Joachim Burger³⁹, Laurent Frantz^{40,41}, Ivica Medugorac^{1,37*}, Daniel G. Bradley^{3*}, Joris Peters^{2,36,37*}

Occupied between ~10,300 and 9300 years ago, the Pre-Pottery Neolithic site of Aşıklı Höyük in Central Anatolia went through early phases of sheep domestication. Analysis of 629 mitochondrial genomes from this and numer-

The Iranian mouflon population is complex



Armenian mouflons transferred to Kabudan Island in Lake Urmia in 1895 and 1906.

