The Emergence of modern zoogeographic distribution in East Asia and its climatic and tectonic mechanisms

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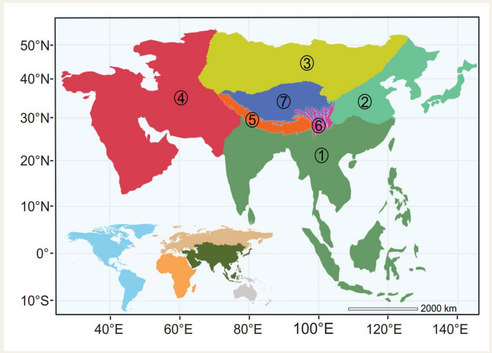
Introduction

The East Asian continent is characterized by a complex and contrasted distribution of climate and biota. Not only is there a stark north–south zoogeographic division between the Indomalayan and Palearctic realms, but also an east–west zoogeographic division controlled by the East Asia Monsoon.



The seven zoogeographic regions in Asia:
Indomalayan
1. Southern Asia
Palearctic
2. Eastern Asia
3. Northern Asia
4. Western Asia
5. Himalayas
6. Hengduan
7. Qinghai-Tibet Plateau

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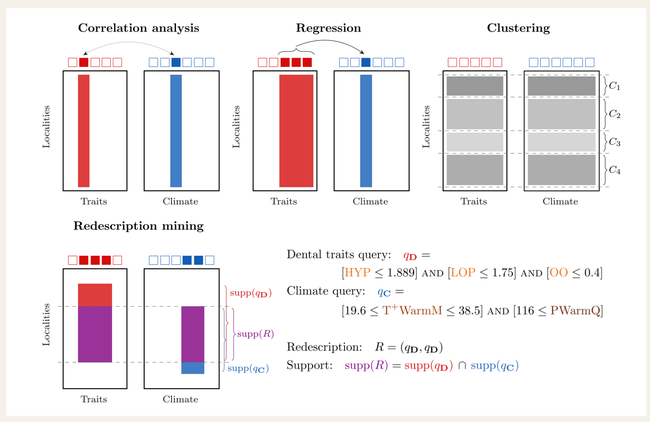
Object

To track changes of mammalian distribution pattern and their climatic contexts in the deep past.

The emergence of the modern biogeographical regions have been linked to the topographic rise of the Tibetan Plateau, monsoon circulation and transformations of the global climate. Due to the sparsity and incompleteness of fossil records in terms of both space and time, and the lack of methods allowing to delineate biogeographical regions in the past, the timing of these changes and their controlling mechanisms are still debated and have been key questions in the field of paleontology.

Method

We apply a recently developed computational data analysis technique, called **redescription mining**, to investigate the associations between the prevailing herbivore dental traits of mammalian communities and climatic conditions in present, and then track these spatiotemporal phenomena during the Neogene.



Redescription mining is the process of automatically identifying a subset and statistically evaluating its limiting conditions. For our study case, a redescription then consists of a pair of queries, here respectively over dental traits and climatic variables, that select similar subsets of localities, thereby capturing a pattern of association between the involved variables and value ranges.
Example for redescription mining in the above figure:
There are two queries to identify the purple subset: a query over the climatic variables requires the mean annual temperature (TMeanY) to be lower than 15.4◦C, on the other hand, a query over the dental traits requires the fraction of species with structural fortification of cups cusps (SF) to be lower than 22.2% and the fraction of bunodont species (BU) to be lower than 35.7%. This redescription selects the localities where the prevalence of structural fortification of cups and cusps and the prevalence of bunodonty are both low, mean while the mean annual temperature is low as well.

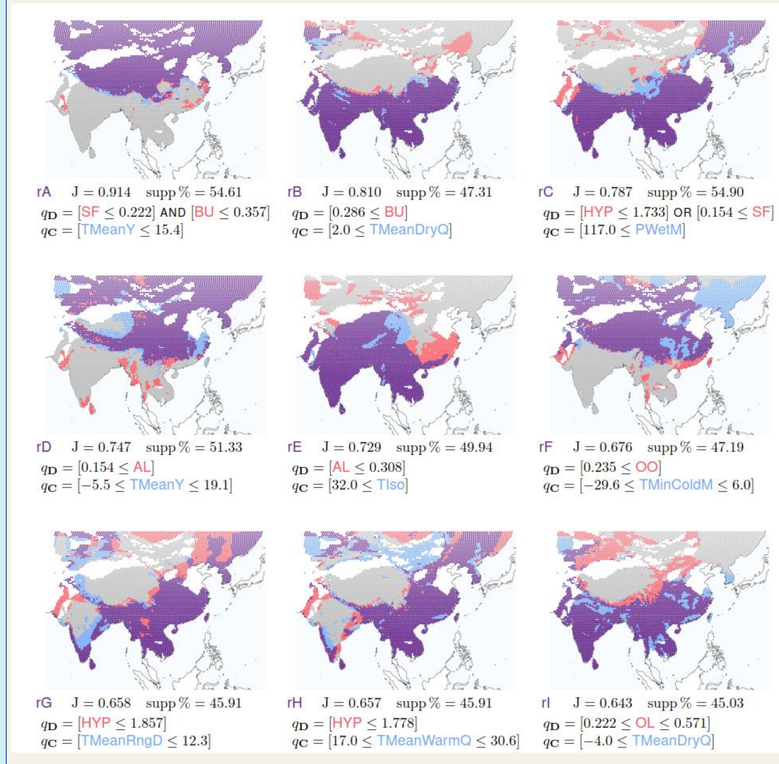
Analyzed variables and data resources

Dental traits variables	
HYP	Average ordinated hypsodonty
AL	Fraction of taxa with acute lophs
OL	Fraction of taxa with obtuse lophs
SF	Frac. of taxa with structural fortification of cusps
OT	Frac. of taxa with flat occlusal topography
OO	Frac. of taxa with exclusively obtuse lophs
BU	Frac. of taxa without any lophs (bunodonts)

Bioclimatic variables		
TMeanY	$Bio1$	Mean Annual Temperature
TMeanRngD	$Bio2$	Mean Diurnal Range
TIso	$Bio3$	Isothermality
TSeason	$Bio4$	Temperature Seasonality
TMaxWarmM	$Bio5$	Max Temperature of Warmest Month
TMinColdM	$Bio6$	Min Temperature of Coldest Month
TRngY	$Bio7$	Annual Temperature Range
TMeanWetQ	$Bio8$	Mean Temperature of Wettest Quarter
TMeanDryQ	$Bio9$	Mean Temperature of Driest Quarter
TMeanWarmQ	$Bio10$	Mean Temperature of Warmest Quarter
TMeanColdQ	$Bio11$	Mean Temperature of Coldest Quarter
PTotY	$Bio12$	Annual Precipitation
PWetM	$Bio13$	Precipitation of Wettest Month
PDryM	$Bio14$	Precipitation of Driest Month
PSeason	$Bio15$	Precipitation Seasonality
PWetQ	$Bio16$	Precipitation of Wettest Quarter
PDryQ	$Bio17$	Precipitation of Driest Quarter
PWarmQ	$Bio18$	Precipitation of Warmest Quarter
PColdQ	$Bio19$	Precipitation of Coldest Quarter

Present-day species occurrence data come from the list of the International Union for Conservation of Nature (IUCN).
Fossil species occurrence data is downloaded from the New and Old Worlds (*NOW*) database.
The present bioclimatic data comes from *Bioclim*.
The past paleoclimate data is simulated by paleoclimate models.
We use square grid cells of 50 × 50 km as units of analysis.

Results from present data

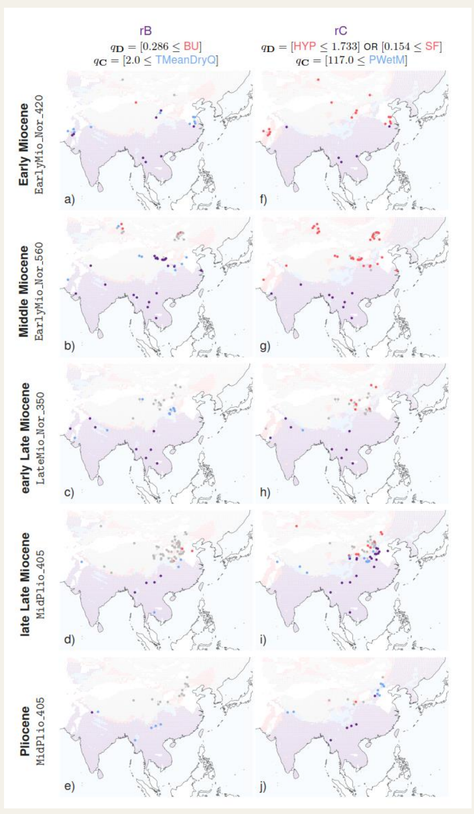


We selected 9 best accurate redescriptions, denoted as rA–rI, and shown them in the above figure. For each redescription, we list the query over dental traits variables (qD), the query over bioclimatic variables (qC), the accuracy (J) as well as the size of its support as a percentage of the total number of present-day localities (supp %). The status of each redescription across the study area is visualized as a map, with a dot for each present-day locality, whose color indicate whether the queries of the considered redescription are satisfied at that locality: purple where both the dental traits query and the climate query are satisfied; red where the dental traits query is satisfied but the climate query is not; blue where the climate query is satisfied but the dental traits query is not; gray where neither the dental traits query nor the climate query are satisfied. The support of each redescription, defined as the set of localities where both queries are satisfied, is hence drawn in purple.

We see that the redescriptions delineate areas corresponding to prominent ecoregions and notable mammalian distribution patterns in present-day Asia (figure in left top). Especially, Redescriptions rA and rB best capture the north–south zoogeographic (temperature controlled) division of the present day, Redescriptions rC best captures the southeast–northwest zoogeographic distributional pattern (precipitation controlled) of the present day.

Results from past data

We take two redescriptions rB and rC from the present-day and evaluate them on our dataset from the past, which combines data from the fossil record with paleoclimate model simulations, aiming to track the emergence of these modern zoogeographical regions during the Neogene.



Left panel (temperature division)
Mammalian communities with high bunodonty (BU) expanded northern Asia during the warm Early and Middle Miocene, and disappeared permanently from high and middle latitudes and retreated to tropical and subtropical regions (purple background) in the Late Miocene and Pliocene. This suggests that the modern Indomalayan realm was established most likely in the end of Middle Miocene.

Right panel (precipitation division)
During the Middle Miocene and early Late Miocene the prevalence of hypsodonty across mammalian communities is similar between west and east China. From the late Late Miocene, a disparity appears between northwestern and southeastern China, which strengthens during the Pliocene, indicates a modern-like East Asian monsoon pattern have established.

Links to global climatic and Tibetan tectonic changes

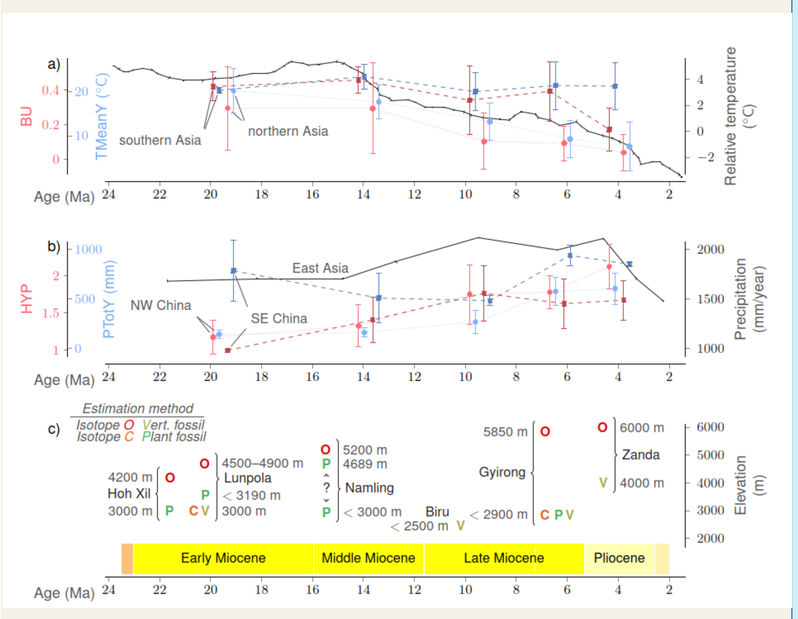


Figure caption. Tmperature, precipitation, elevation, bunodonty and hypsodonty trends through the Neogene. a) Global temperature trend (Zachos et al., 2001) and average bunodonty values in northern and southern Asia. b) Modeled mean annual precipitation for East Asia (Farnsworth et al., 2019) and average hypsodonty values in northwestern (NW) and southeastern (SE) China. c) Elevation estimates for the Tibetan Plateau

The dynamics of bunodonty (red line in BU panel) in Asia during the Neogene follow global temperature changes.

The dynamics of hypsodonty (red line in HYP panel) is comparable and undergoes a similar increase across mammalian communities of northwestern and southeastern China during the Middle Miocene and early Late Miocene . From the late Late Miocene (ca. 7 Ma), a disparity appears between northwestern and southeastern China, suggested the onset or intensification of summer monsoon in East Asia and aridity in central Asia as a result of the significant uplift or lateral extension of the Tibetan Plateau around this time.

Our results don't support a high Tibetean Plateau before the late Miocene suggested by *isotopes*O and are consistant with most biotic evidences.

Conclusion

1. The global climate change and Tibetan Plateau topographic change significantly impact the terrestrial biota in East Asian.

2. The modern latitudinal zoogeographic (Palearctic-Indomalayan) division emerged after the Middle Miocene climatic transition, ca. 15-13 Ma.

3. The modern monsoonal zoogeographic pattern emerged during the late Late Miocene, ca. 7 Ma, and suggests a crucial high Tibetan Plateau.

4. The presence of a montane forest biodiversity hotspot in the Hengduan Mountains alongside Alpine fauna on the Tibetan Plateau suggests that the Asian modern zoogeographic distribution has been fully established since the Pliocene.

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