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Formation of three great Asian plateaus, climate change, and biodiversity

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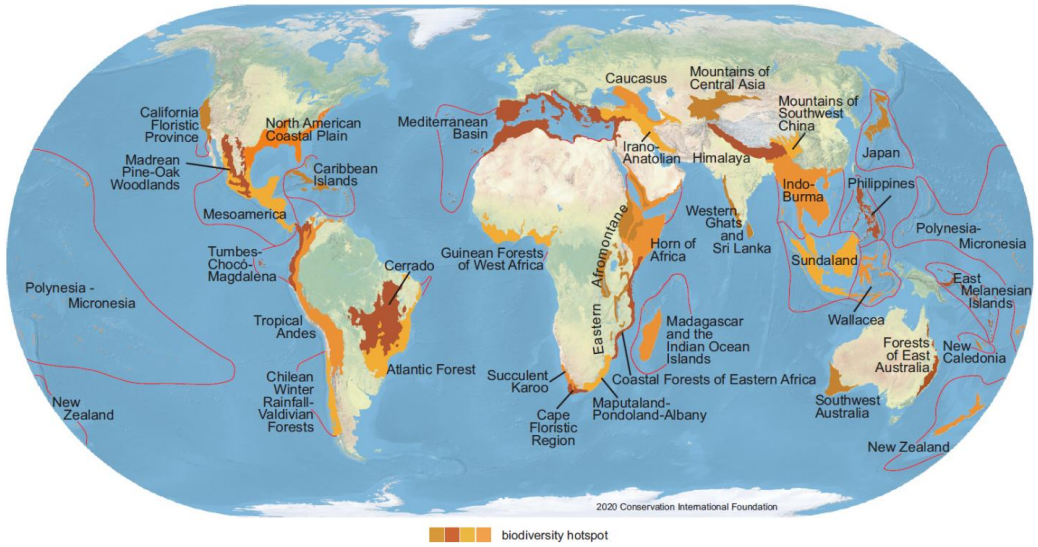
Harbin

Mountain biodiversity

Biodiversity is very unevenly distributed across the planet, and largely concentrated in mountain regions;

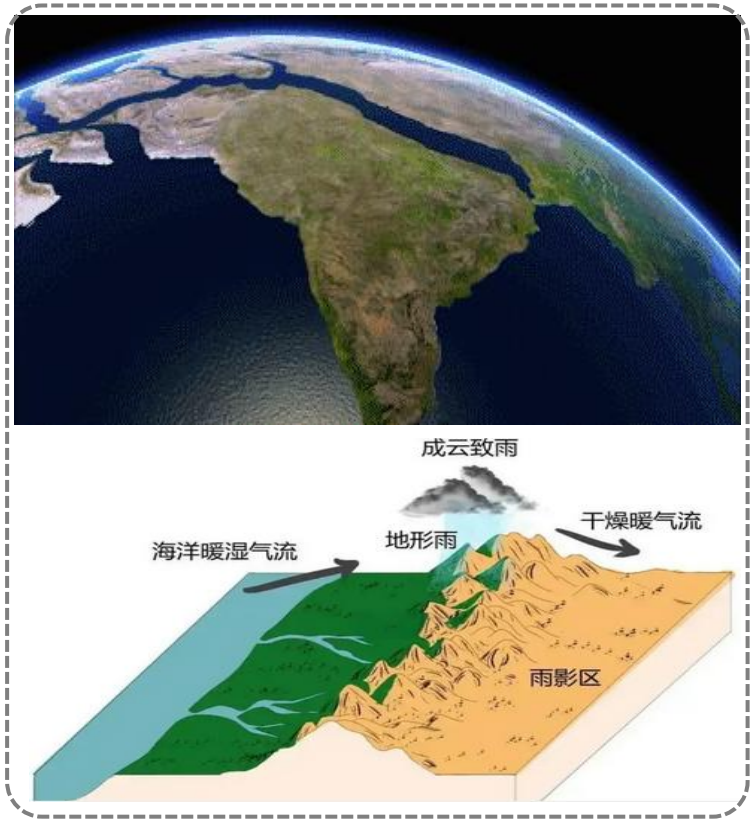
Mountain regions cover only about one-eighth of all land area outside Antarctica, but are home to nearly one-third of terrestrial species.

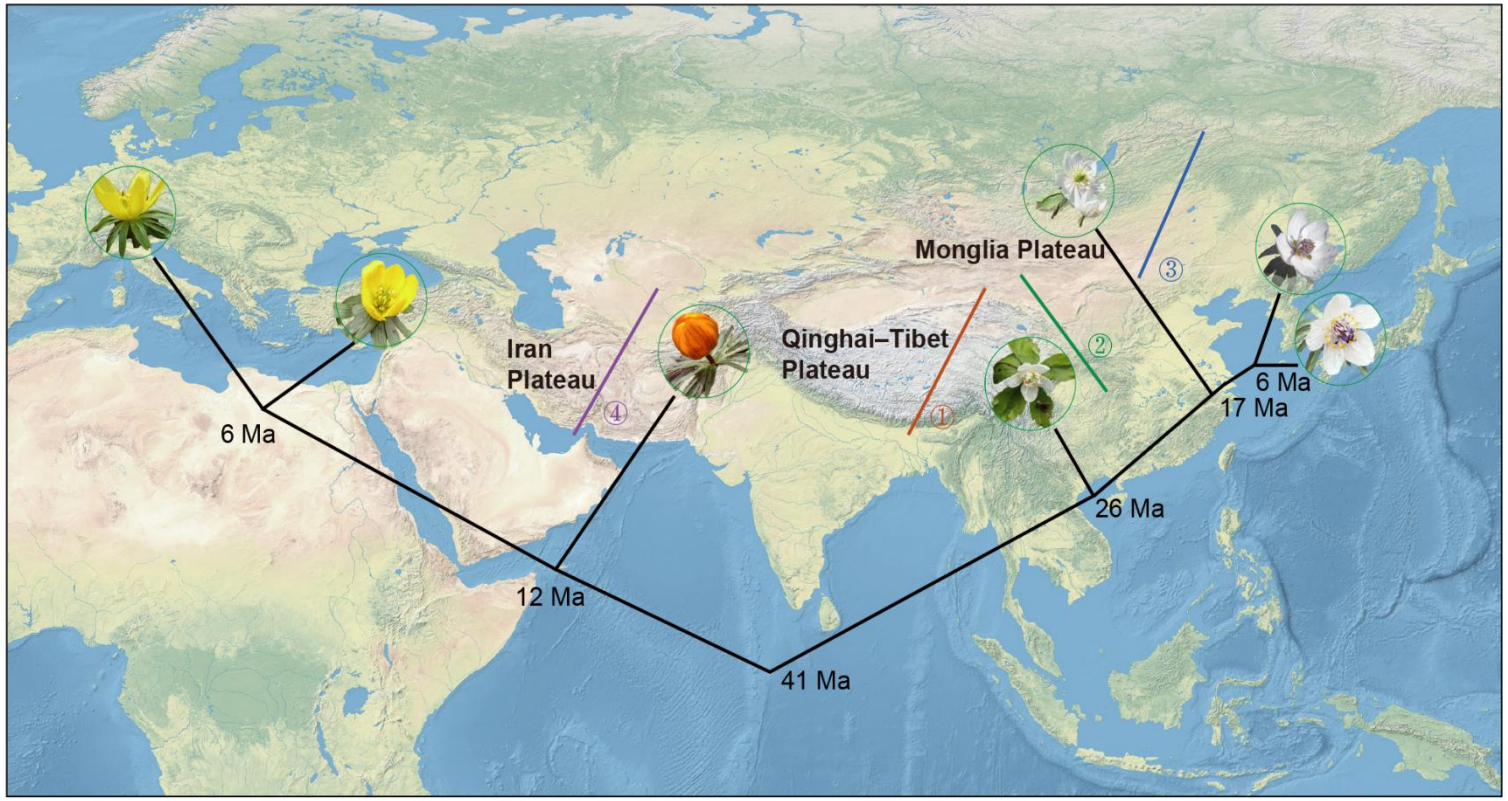




Myers et al., 2000. *Nature*; Spehn et al., 2011. *Plant Ecol Divers;* https://www.euratlas.net/geography/world/mountains/index.html

Mountain biodiversity





Mountain building and associated climate change have a profound effect on biotic evolution: vicariance, diversification, and extinction

Antonelli et al., 2018. *Nat Geosci*; Xiang et al., 2021. *Proc R Soc B*

Three great Asian plateaus

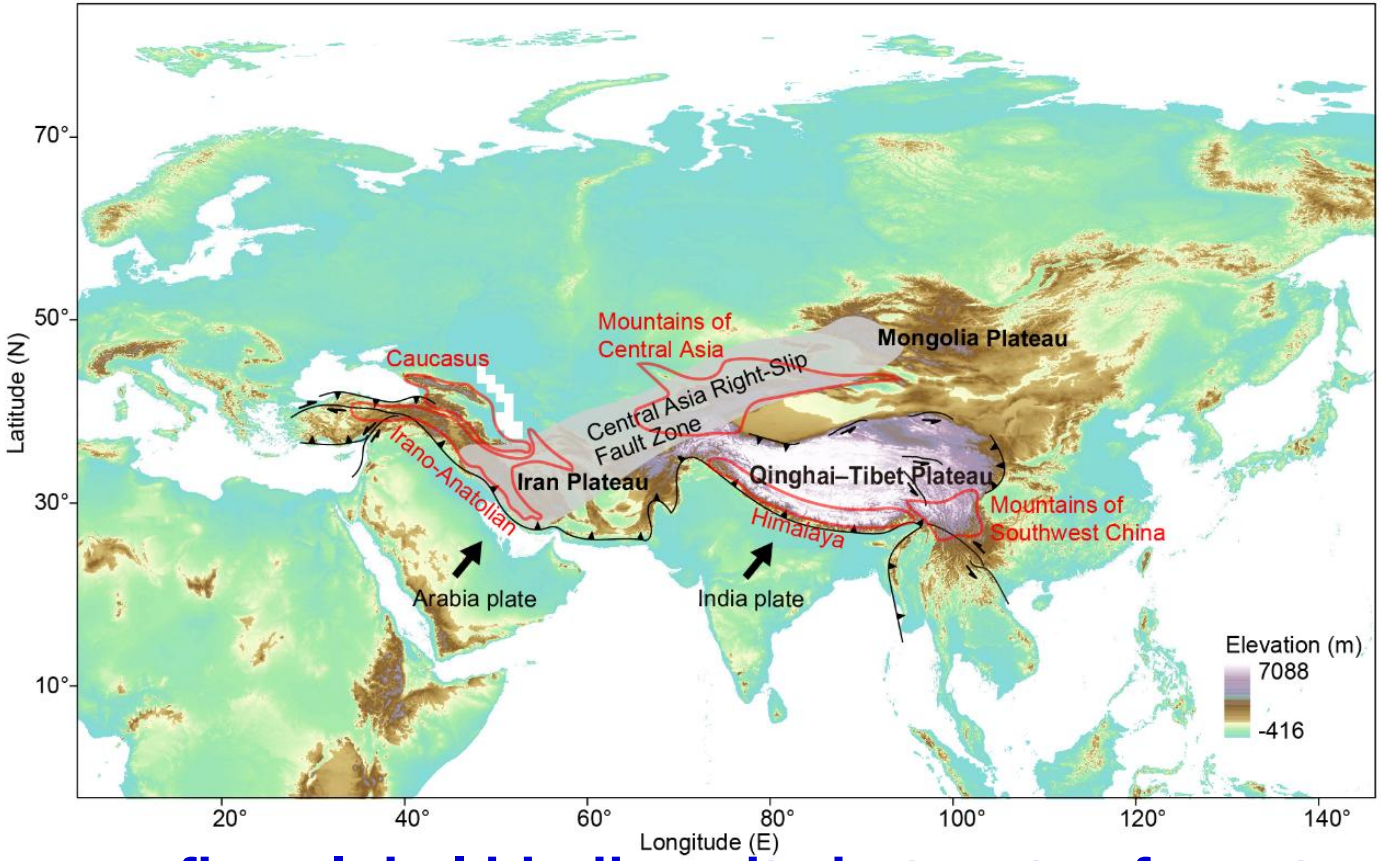
Three great Asian plateaus:

Qinghai–Tibet Plateau (QTP)

Iran Plateau (IP)

Mongolia Plateau (MP)

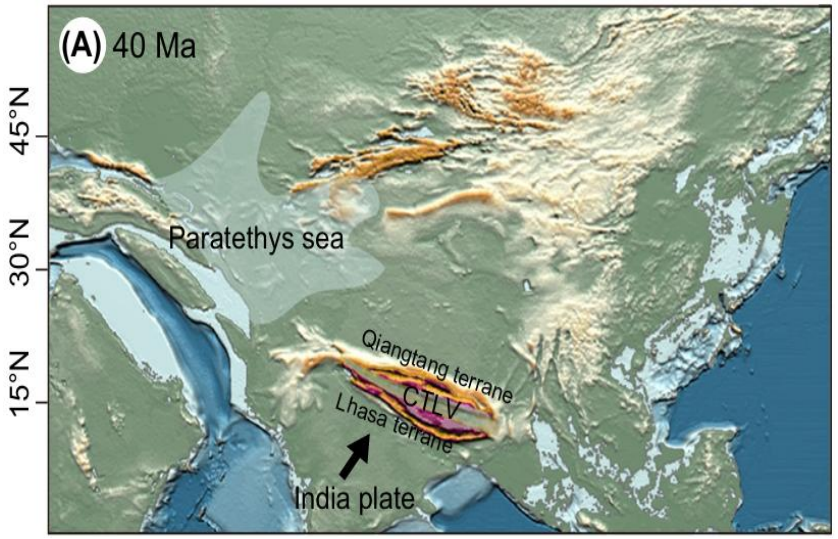
Constituting the largest continuous mountain belt on Earth and host the world's richest alpine biotas.

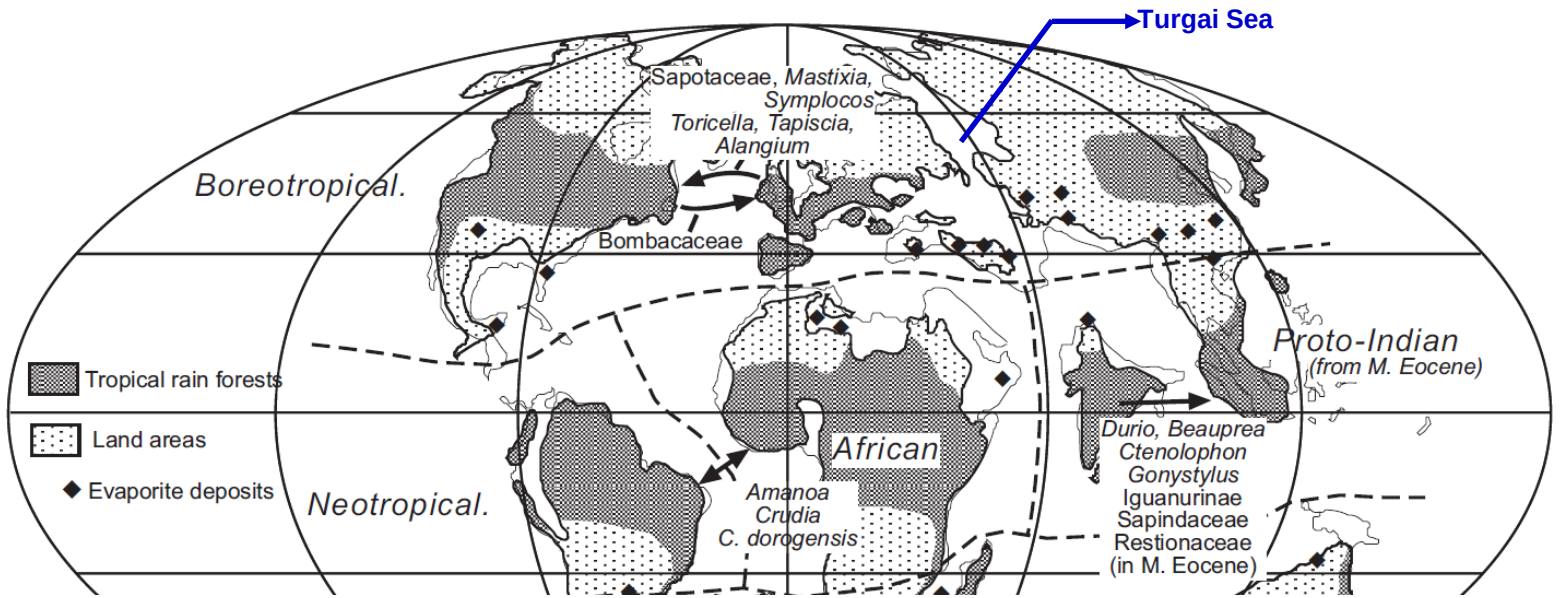


This continuous mountain belt houses five global biodiversity hotspots of great conservation value, and is especially sensitive to global warming

Xiang et al., 2021. *Proc R Soc B*

Asian landscape by the Eocene





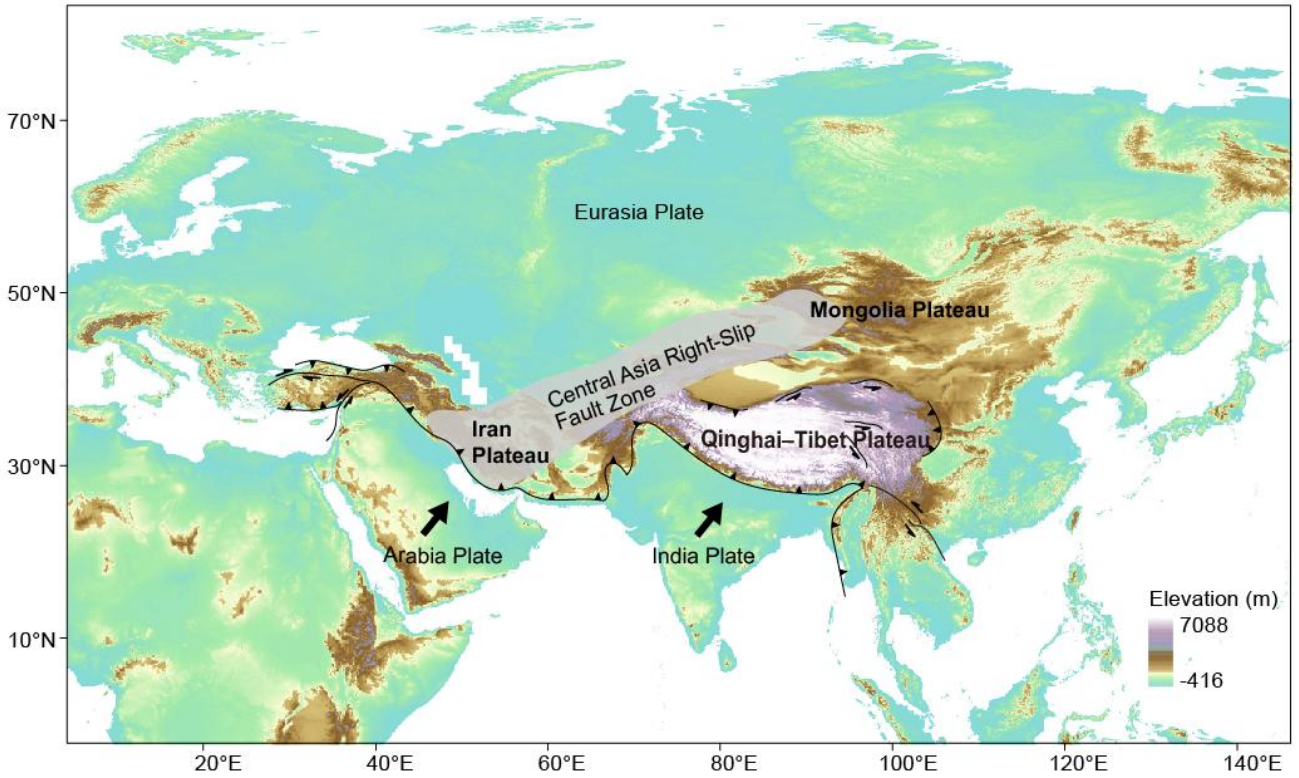
A proto-Tibetan highland existed and was separated by an east-west oriented elongated lowland; many tropical or subtropical elements occurred there.

Through the lowland and island chains, thermophilic populations might have migrated across Eurasia and even further through the Northern Hemisphere, resulting in the formation and development of "the boreotropical flora".

Wolfe, 1975. *Ann MO Bot Gard*; Morly, 2003. *PPEES*; Lian et al., 2020. *Mol Phylogenet Evol*

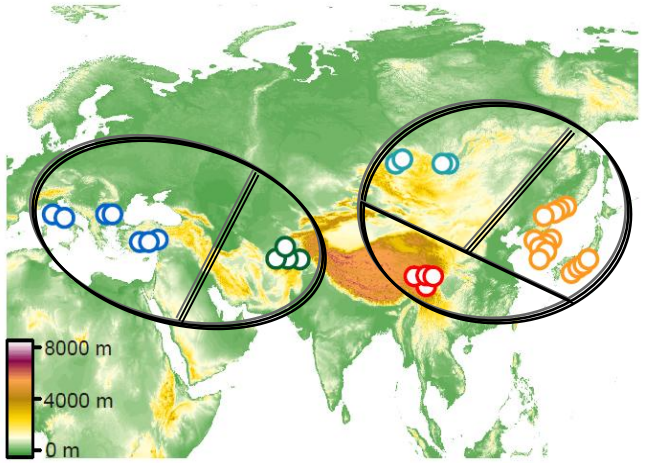
Formation of the three great Asian plateaus



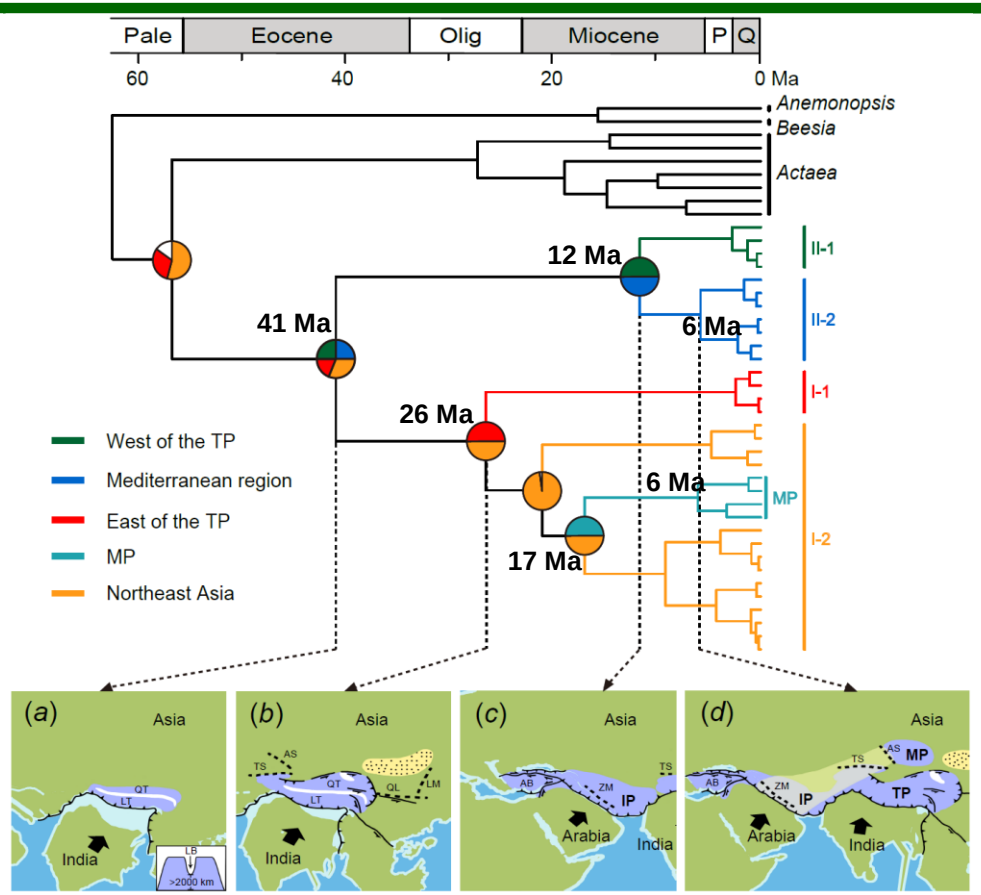


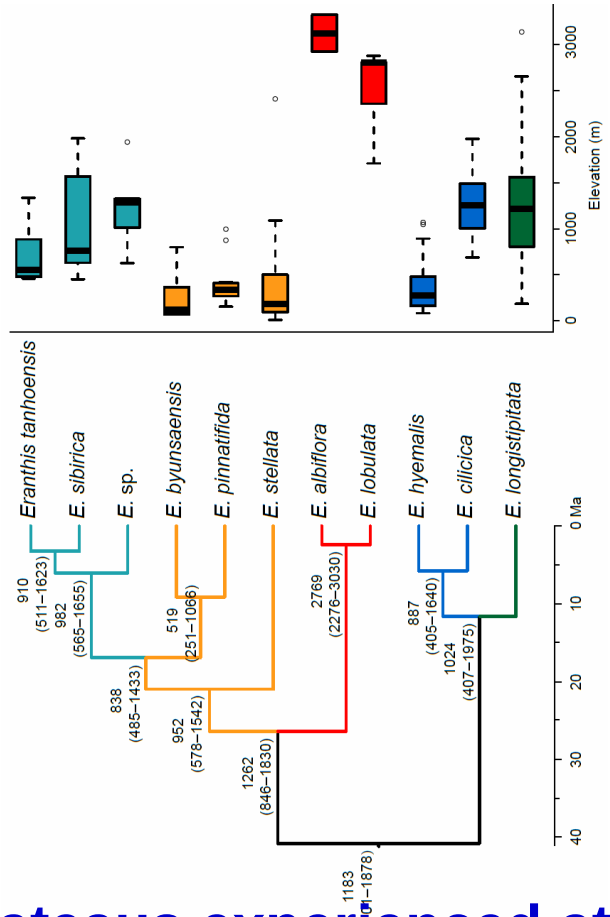
The collisions of the India plate with Eurasia in the east and Arabia plate with Eurasia in the west are two important tectonic events in Asia, resulting in the formation of the three great Asian plateaus

Formation of the three great Asian plateaus









The biogeography of *Eranthis* reveals all three great Asian plateaus experienced at least twice major uplifts.

Xiang et al., 2021. *Proc R Soc B*

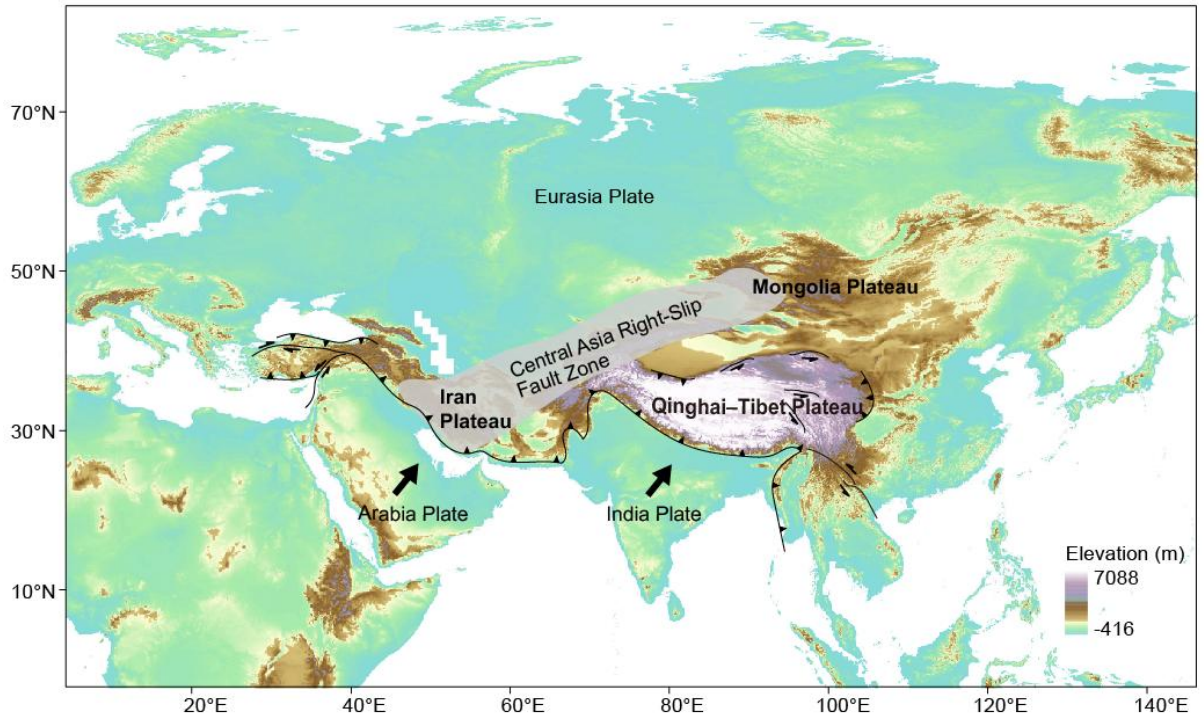
Formation of three great Asian plateaus, climate change, and biodiversity

- review the formation processes of the three great Asian plateaus;
- explore the evolutionary origins of biodiversity by integrating geological, ecological, and paleontological evidence as well as dated phylogenetic data;
- provide inspiration for future research on their biodiversity by integrating geological, ecological, biogeographical, and conservation studies.

Formation processes of the three great Asian plateaus

The two collisions reorganized Asian topography and landscape

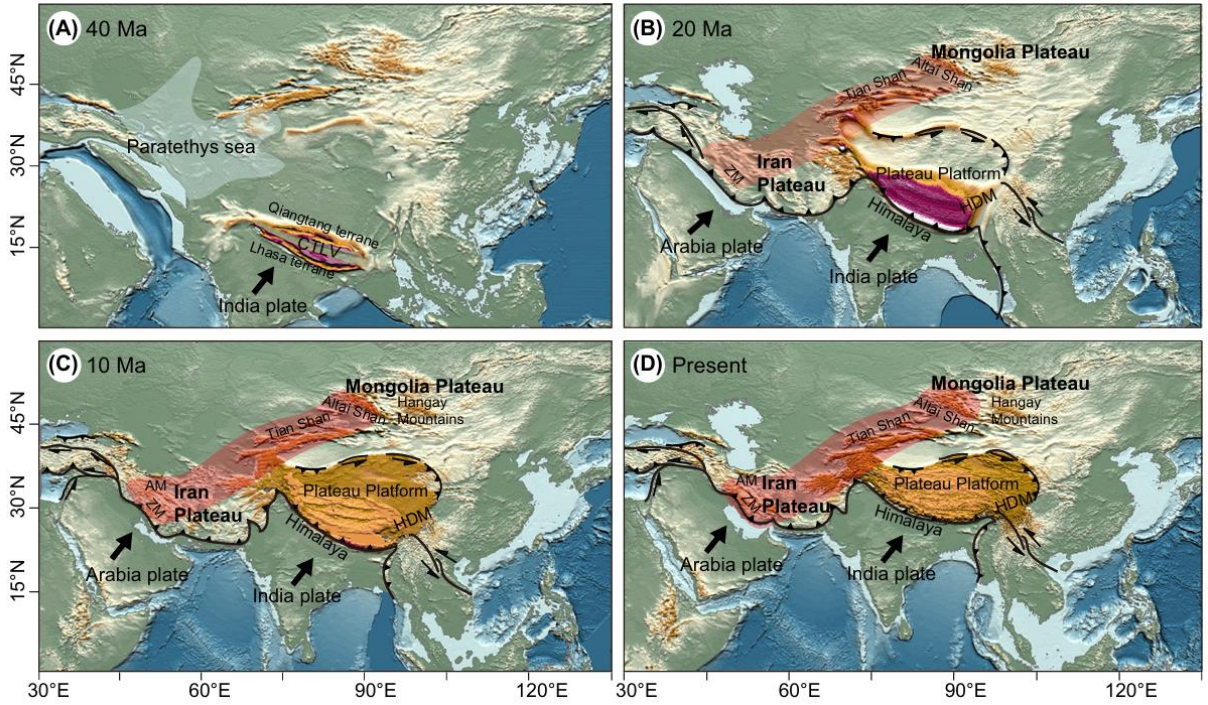
- **India–Eurasia collision** started at ~61 Ma and subsequently caused the deformation and uplift of the QTP;
- **Arabia–Eurasia collision** started at ~35 Ma and caused the deformation and uplift of the IP;
- **The interaction of the two collisions** generated the Central Asia Right-Slip Fault Zone and resulted in the far-field deformation and uplift of the MP.



Formation processes of the three great Asian plateaus

Multi-stage uplifts of the three great Asian plateaus

1) 45–35 Ma: Initial uplift of the QTP;
2) 30–20 Ma: Synchronous first uplift of the QTP, IP and MP;
3) 17–12 Ma: Synchronous second uplifts of the QTP, IP and MP;
4) 8–5 Ma: Near-modern topography of the QTP, IP and MP.



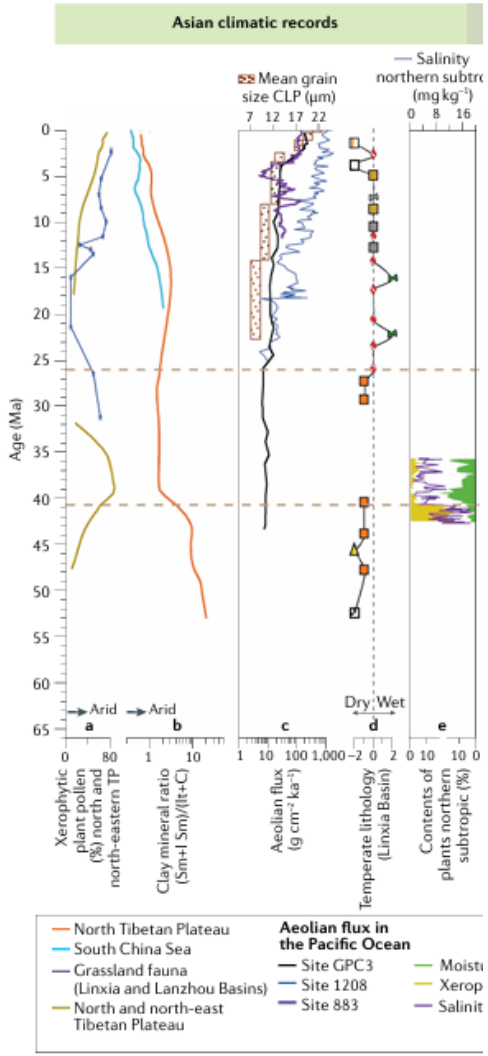
During the Cenozoic, the multi-stage uplifts and outward growths of the three great Asian plateaus have had a profound impact on regional to global climates and environments.

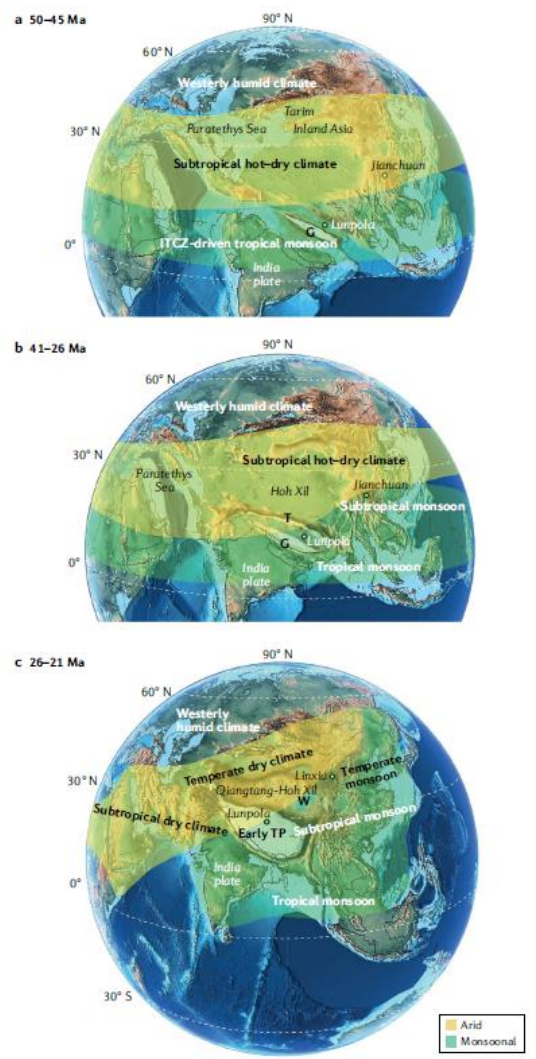
Cao et al., 2025. *TREE*

Climate change in Asia during the Cenozoic

Multi-stage evolution of Asian monsoon

1) ~41 Ma: Asian Monsoon advanced northwards from the tropic to the southern subtropical regions;
2) ~23 Ma: Asian Monsoon expanded northwards into temperate regions (equivalent to the present-day Asian Monsoon boundary);
3) ~12–4 Ma: Asian Monsoon further intensified.



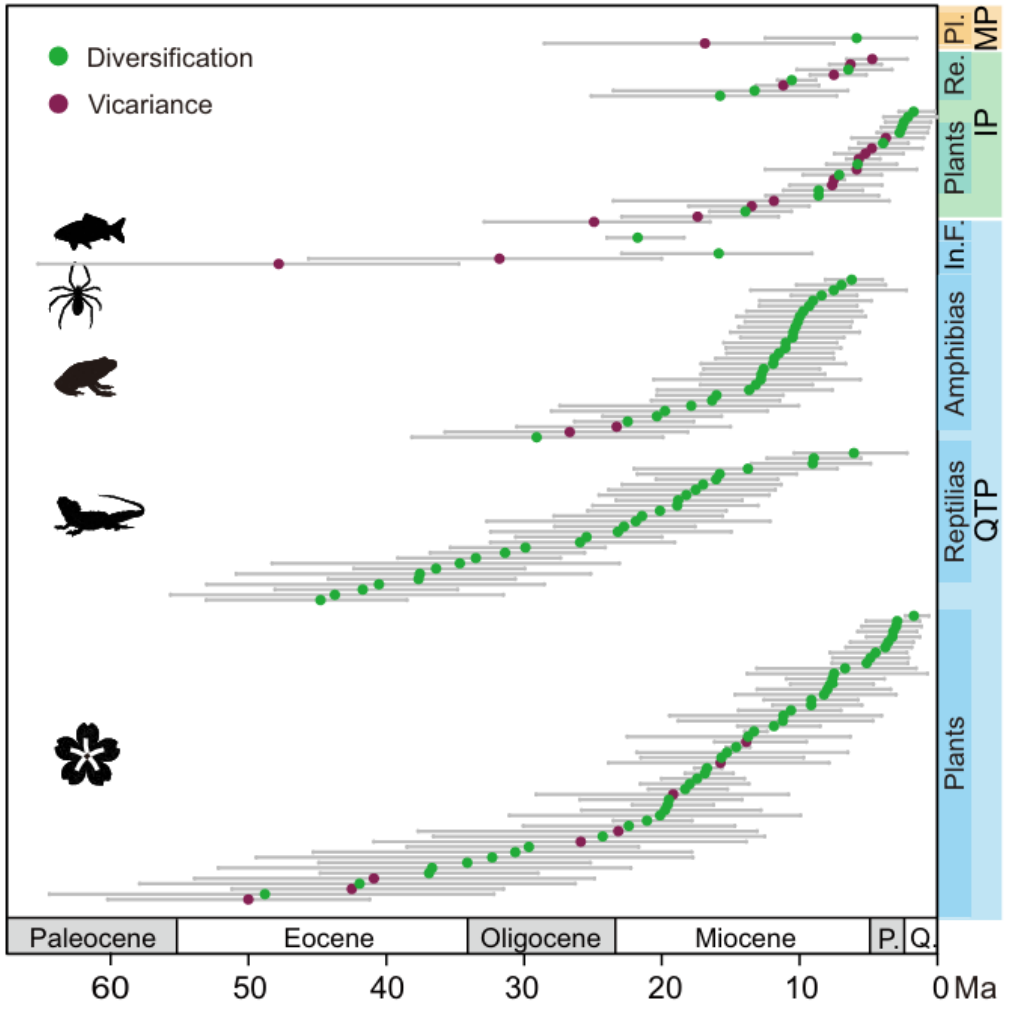


Wu et al., 2022. *Nat Rev Earth Env*

Formation of the three great Asian plateaus and biotic evolution

We selected 45 clades (30 plants, 7 amphibians, 6 reptiles, 1 invertebrate, and 1 fish), and identified 123 diversification and 28 vicariance events.

We obtained ~4000 fossil records
QTP: 2188
IP: 215
MP: 1507



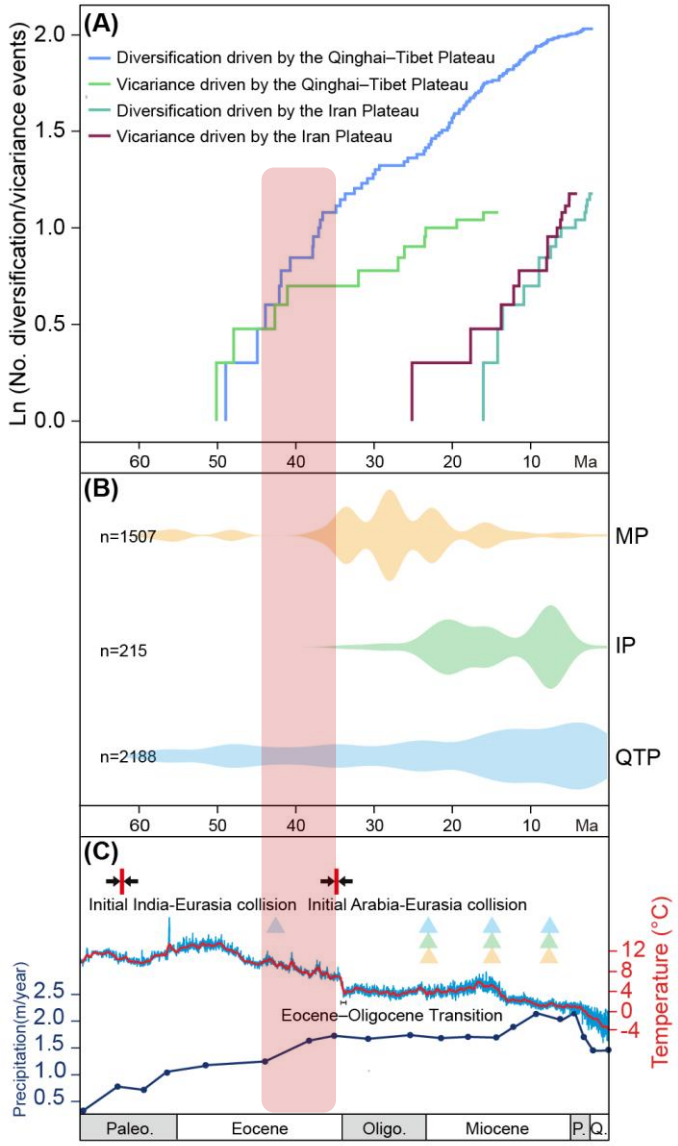
Cao et al., 2025. *TREE*

Formation of the three great Asian plateaus and biotic evolution

Middle-Late Eocene (45–35 Ma)

- Phylogenetic separations between east and west QTP occurred; biotic diversification on the QTP also happened;
- The prototype of East Asian subtropical evergreen broadleaved forests had emerged;
- The aridification of the northeastern QTP occurred, thus driving the development of a steppe-desert ecosystem there.

Driven by the first uplift of the QTP

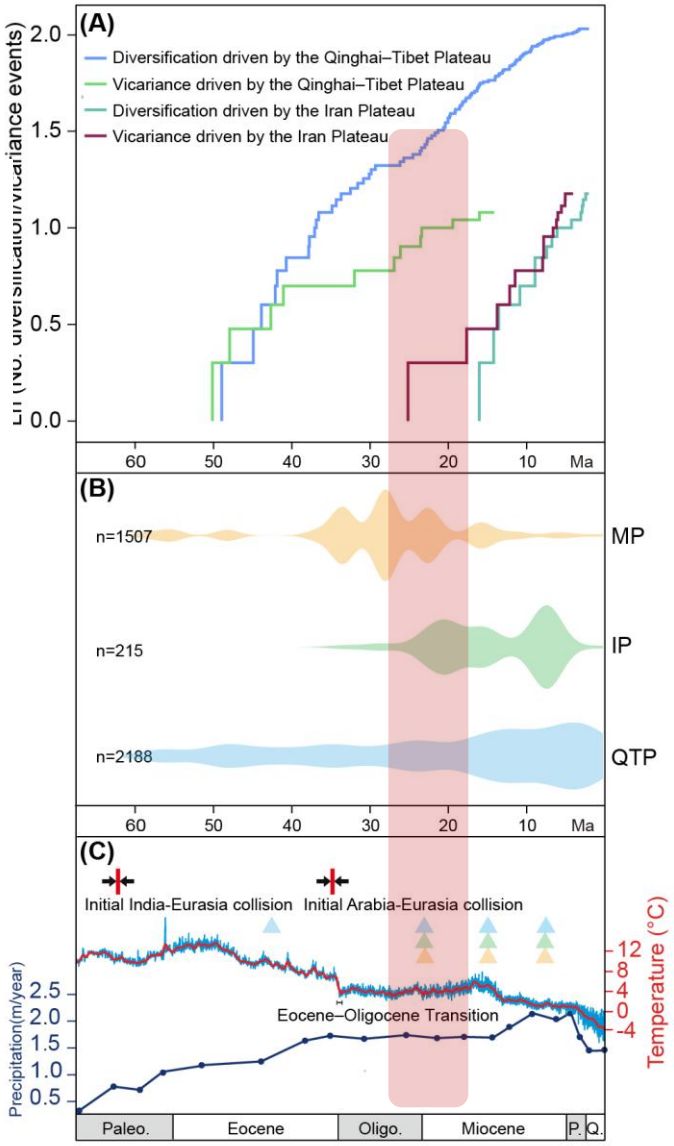


Formation of the three great Asian plateaus and biotic evolution

Late Oligocene–Early Miocene (30–20 Ma)

- Biotic lineages in the QTP and adjacent lowlands underwent vicariance; *in situ* diversification and fossil diversity increased;
- Biotic lineages in the IP and adjacent lowlands underwent vicariance; fossil diversity increased;
- The MP flora experienced an abrupt increase in herbaceous taxa; mammal diversity reached a peak.

Driven by the second uplift of the QTP and the first uplifts of the IP and MP

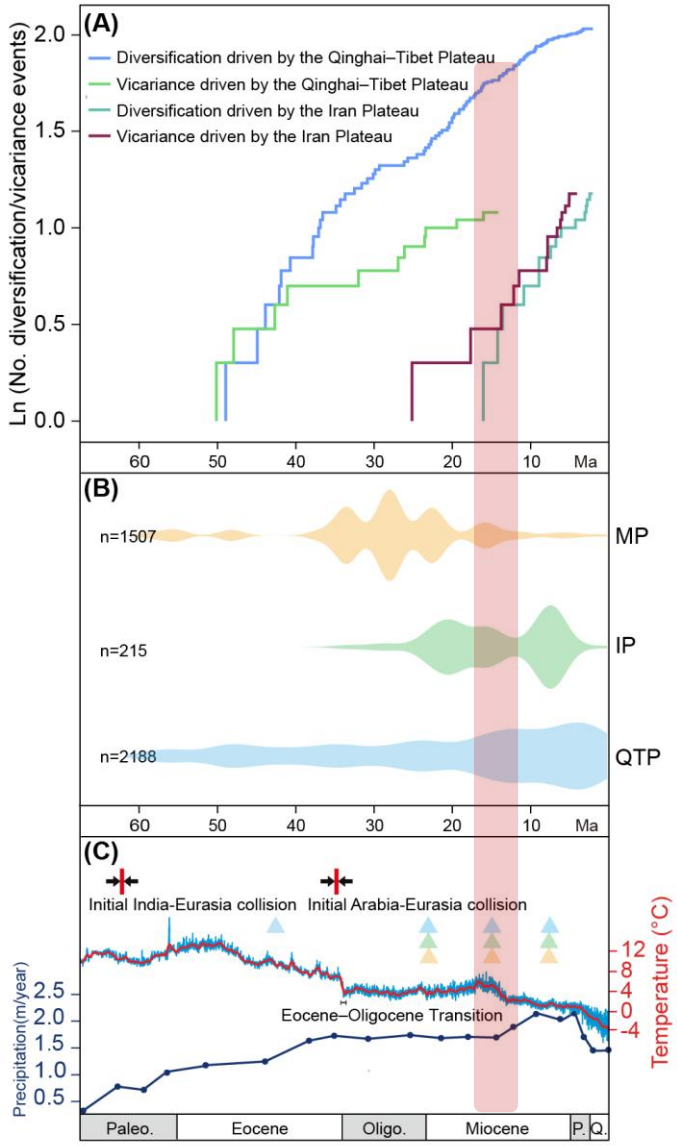


Formation of the three great Asian plateaus and biotic evolution

Middle Miocene (17–12 Ma)

- Vicariance and diversification events increased on the QTP, and fossil diversity increased;
- Vicariance events between the IP and surrounding regions increased, and the arid-adapted taxa experienced a burst of diversification;
- Phylogenetic separation between the MP clade and its northeast Asian sister occurred; avian diversity reached a peak.

Driven by the third uplift of the QTP and the second uplifts of the IP and MP

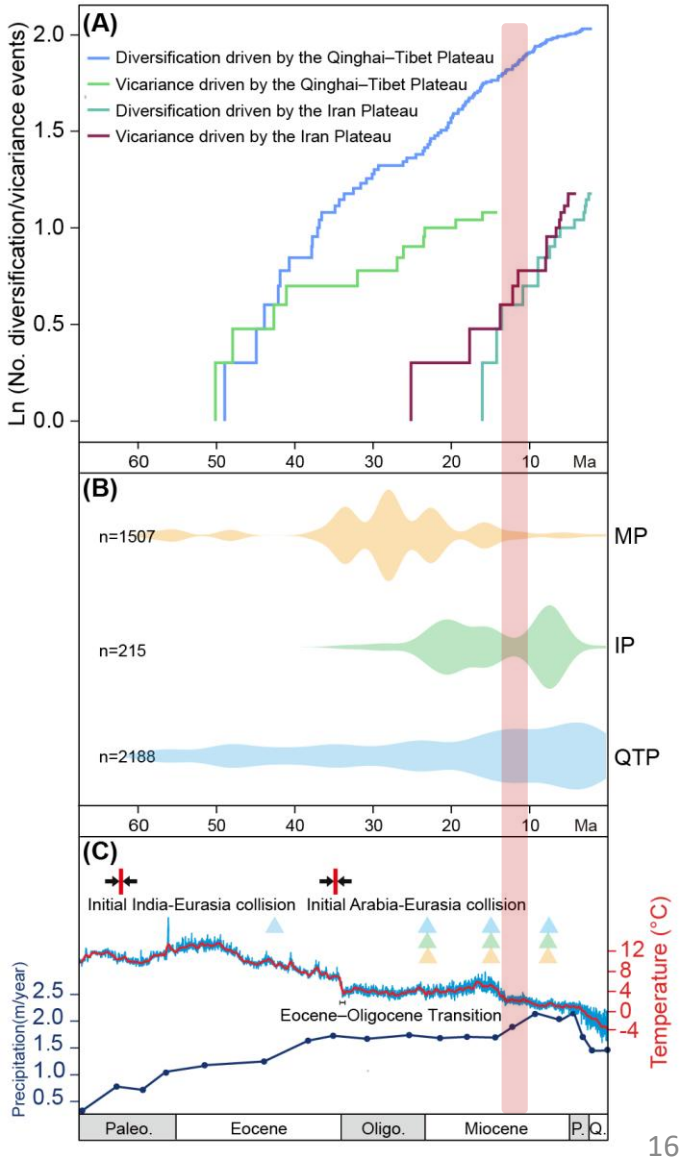


Formation of the three great Asian plateaus and biotic evolution

Late Miocene (8–5 Ma)

- Rapid accumulation of QTP lineages took place;
- Accumulation of vicariance events caused by the IP uplift significantly increased, and the diversification events on the IP simultaneously increased;
- The MP *Eranthis* started to diversify, and mammalian and avian diversity on the MP significantly diminished.

Driven by the fourth uplift of the QTP and the third uplifts of the IP and MP



Formation of the three great Asian plateaus and biotic evolution

- **The three great Asian plateaus underwent multiple-stage uplift processes in the Cenozoic**
- **Biodiversity of the three great Asian plateau regions has experienced a long and complex evolutionary process**
- **Cenozoic geoclimatic changes have driven biotic evolution on the three great Asian plateaus and adjacent regions in four crucial periods**
- **The QTP has the most ancient evolutionary history, and therefore potentially hosts the oldest biotic components**

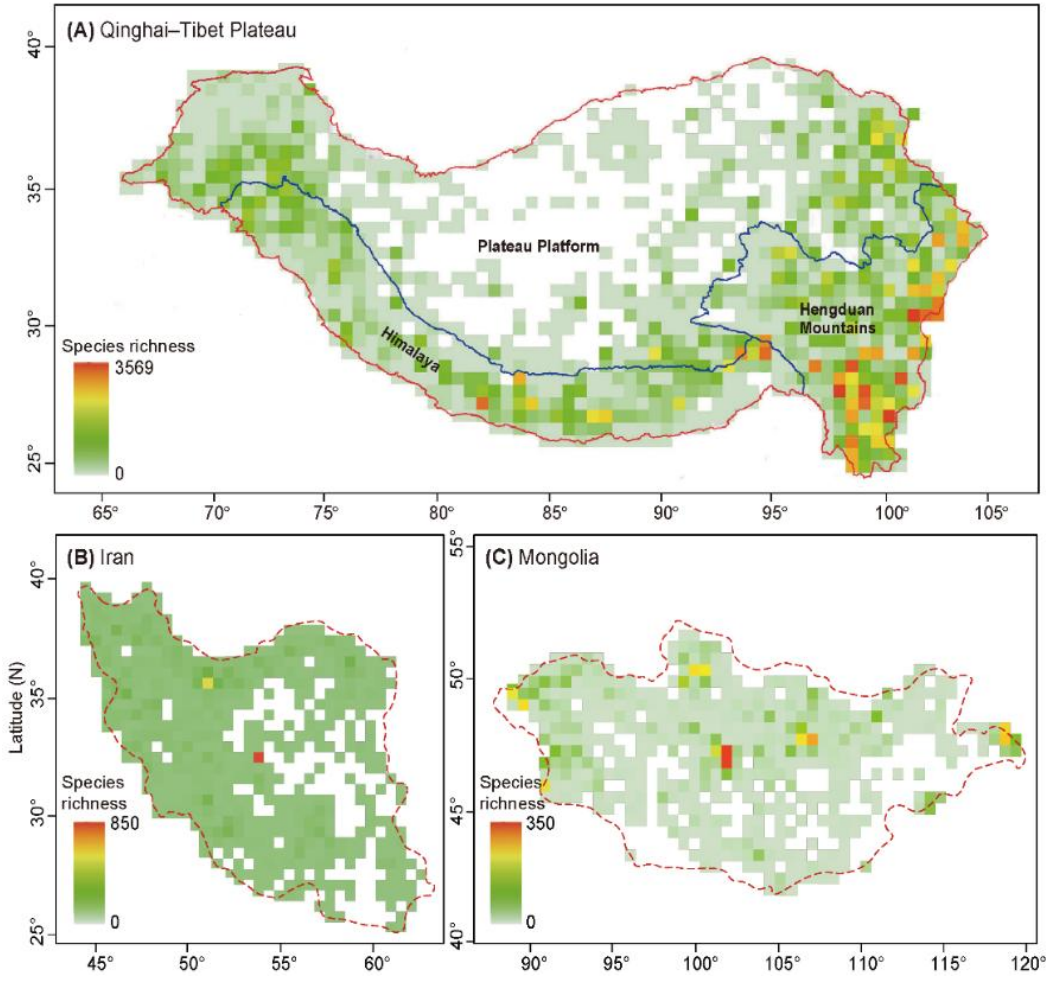
Cao et al., 2025. *TREE*

Vascular plant species diversity patterns on the three plateaus

Biodiversity disparity

The QTP has the highest species richness of vascular plants, followed by the IP and then the MP.

The highest species diversity of vascular plants is concentrated in southeastern HDM, eastern Himalaya, western Iran, and central Mongolia.



Cao et al., 2025. *TREE*

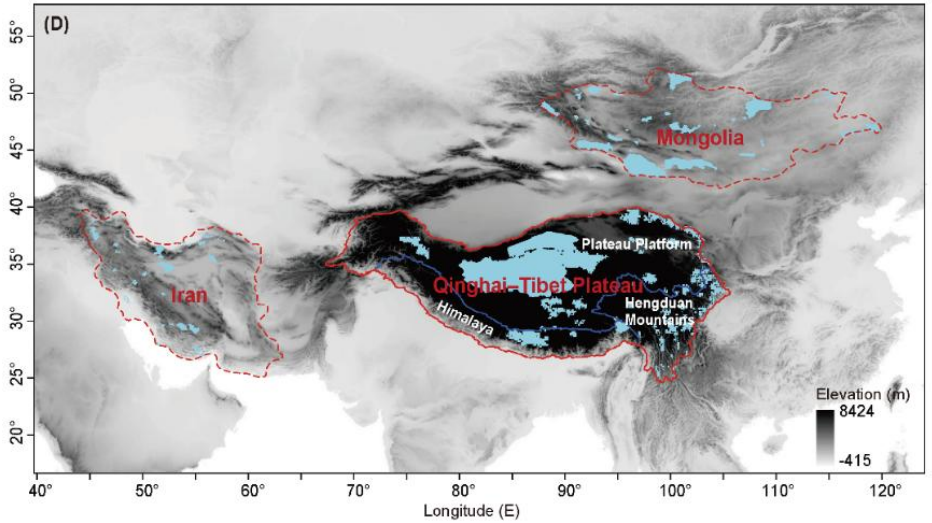
Vascular plant species diversity patterns on the three plateaus

The current protected areas may not fully include the hotspots of species diversity on the three plateaus.

The proportion of the protected areas doest not reach the Kunming-Montreal Global Biodiversity Framework targets (>30%).

It may be urgent to establish natural reserves in areas with high species diversity, especially across national protected areas.

Region	No. total species	No. species in protected areas	Proportion of species in protected areas (%)	Total area (km^2)	Protected area (km^2)	Proportion of protected area (%)
QTP						
HDM	13195	7550	57.22	5.87×10^5	9.23×10^4	15.73
Himalaya	9544	6266	65.65	6.62×10^5	1.41×10^5	21.31
PP	5465	2233	40.86	1.82×10^6	6.23×10^5	34.23
Iran	3861	623	16.14	1.57×10^6	3.50×10^5	22.30
Mongolia	2104	1370	65.11	1.65×10^6	1.65×10^5	10.00



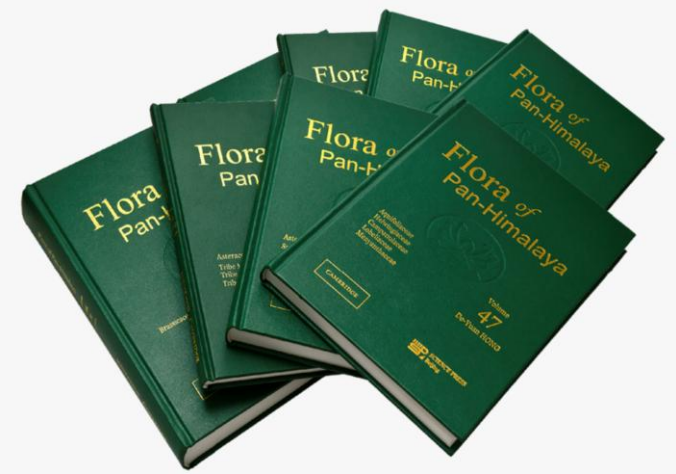
Cao et al., 2025. *TREE*

Future study

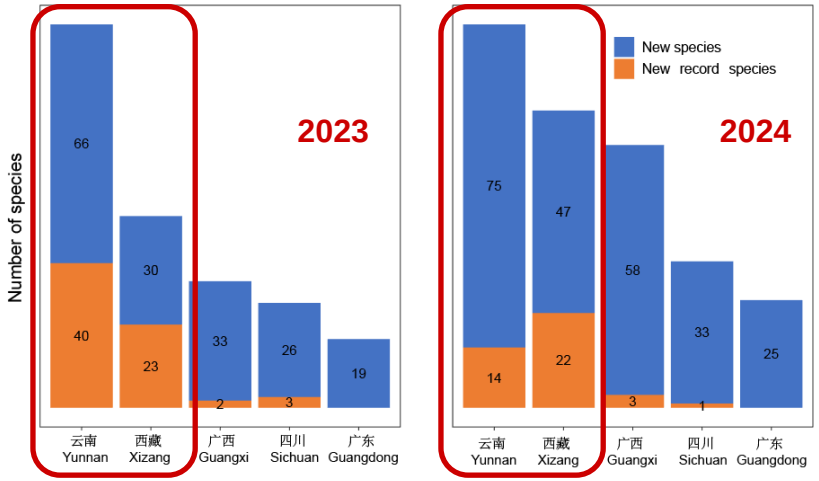
- **Expeditions, especially currently under-represented areas, and digitization of herbarium specimens should be prioritized.**

Biodiversity background data on the three Asian plateaus are still unclear

The Flora of Pan-Himalaya project was launched in 2010, involving 116 plant taxonomists from 15 countries, and described one third of the flora over the past 10 years.



Flora of Pan-Himalaya



Number of Chinese new species and records

Du et al., 2024. *Biodivers Sci*; Huang et al., 2025. *Biodivers Sci*

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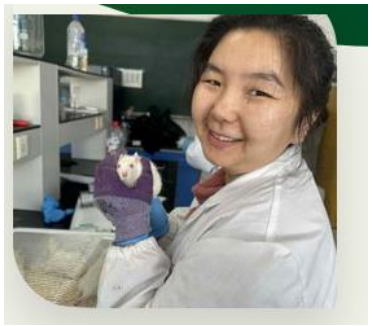
For the MP, the checklist of native vascular plants of the Mongolia was revised and updated in 2022, but occurrence records of only 73% species were digitized.

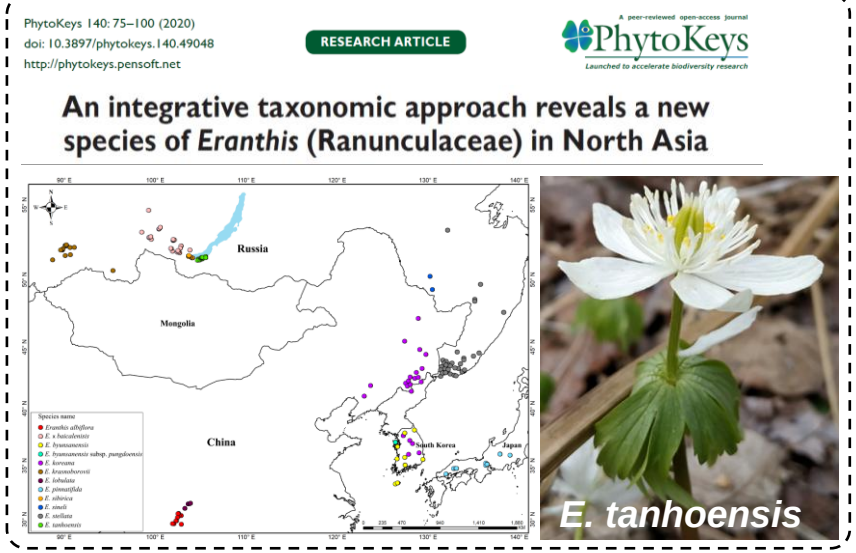


Solongo Khadbaatar



Flora of Mongolia

vol. 5: Ranunculaceae
2024



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For the MP, the checklist of native vascular plants of the Mongolia was revised and updated in 2022, but occurrence records of only 73% species were digitized.

The plant diversity of the IP is less known, partly owing to political and economic troubles.

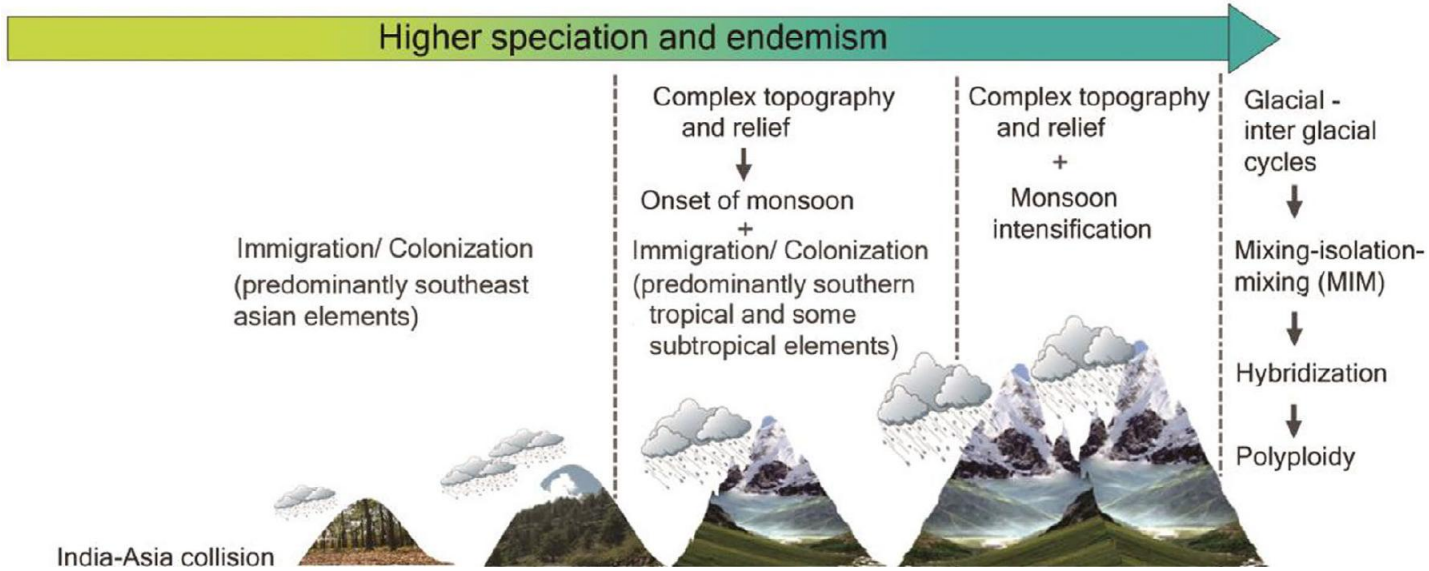
The species checklists of native non-vascular plants and animals in the three great Asian plateaus remain absent.

Future study

- **Expeditions, especially currently under-represented areas, and digitization of herbarium specimens should be prioritized.**

- **Multidisciplinary scientific collaboration will facilitate exploration of how abiotic and/or biotic factors have driven the evolution of their biodiversity.**

Species diversification is not only related to the plateau uplift and associated climate changes, but also results from the combined effects of geoclimatic changes along with microevolutionary processes (e.g., natural selection and hybridization).



Pandit et al., 2025. *J Biogeogr*

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- **Multidisciplinary scientific collaboration will facilitate exploration of how abiotic and/or biotic factors have driven the evolution of their biodiversity.**
- **Evolutionary studies related to molecular phylogenies and fossil assemblages should focus on species-rich but poorly sampled areas and/or taxa.**

Compared to the QTP, how IP and MP biodiversity was shaped over time has received less attention.





Future study

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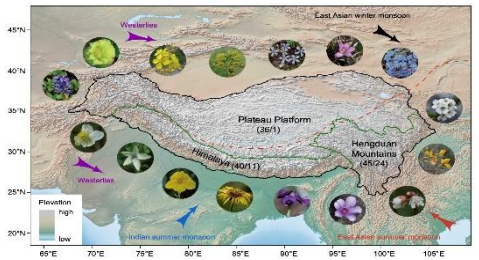
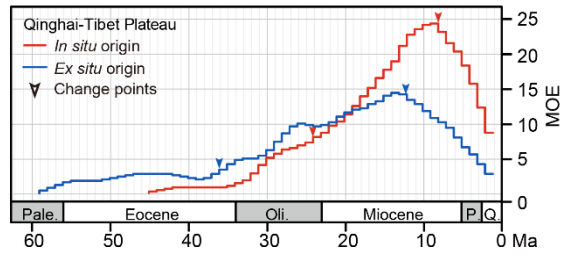
- **Evolutionary studies related to molecular phylogenies and fossil assemblages should focus on species-rich but poorly sampled areas and/or taxa.**
- **Relative contribution of *in situ* speciation and colonization to the biodiversity needs to be evaluated.**

Multi-taxon analysis is an effective approach.





Cao et al., 2025. *PNAS*

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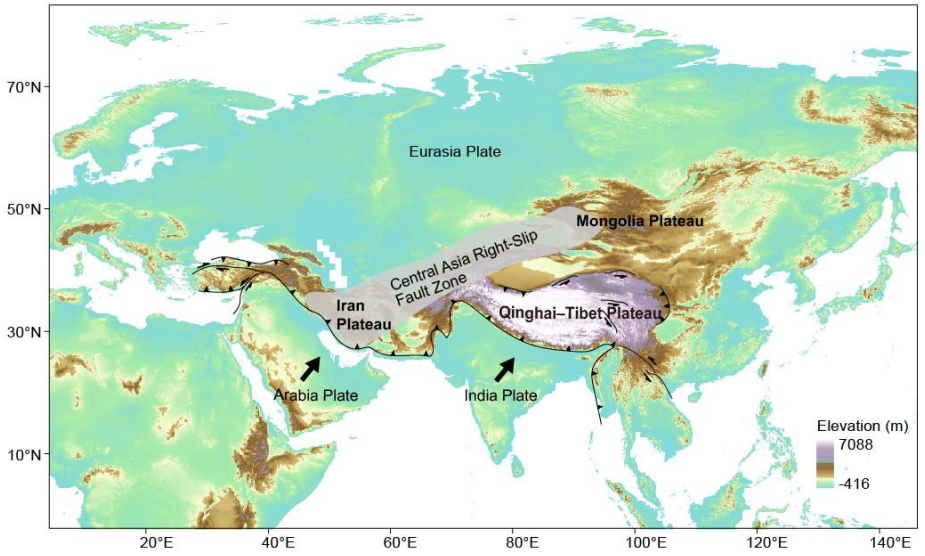
- **Relative contribution of *in situ* speciation and colonization to the biodiversity needs to be evaluated.**
- **Future research should be devoted to investigating possible relationships of the biodiversity among the three plateaus.**

Formation of three great Asian plateaus, climate change, and biodiversity

- The formation of the three great Asian plateaus is a major driver for change in Asian landscape and biotas;
- There are many outstanding research questions concerning the historical assembly and evolution of biodiversity on the three great Asian plateaus.





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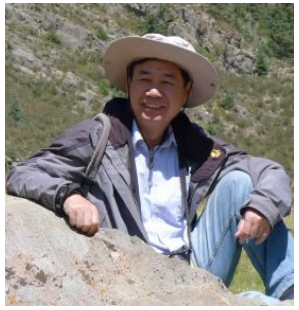
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Thank you!

