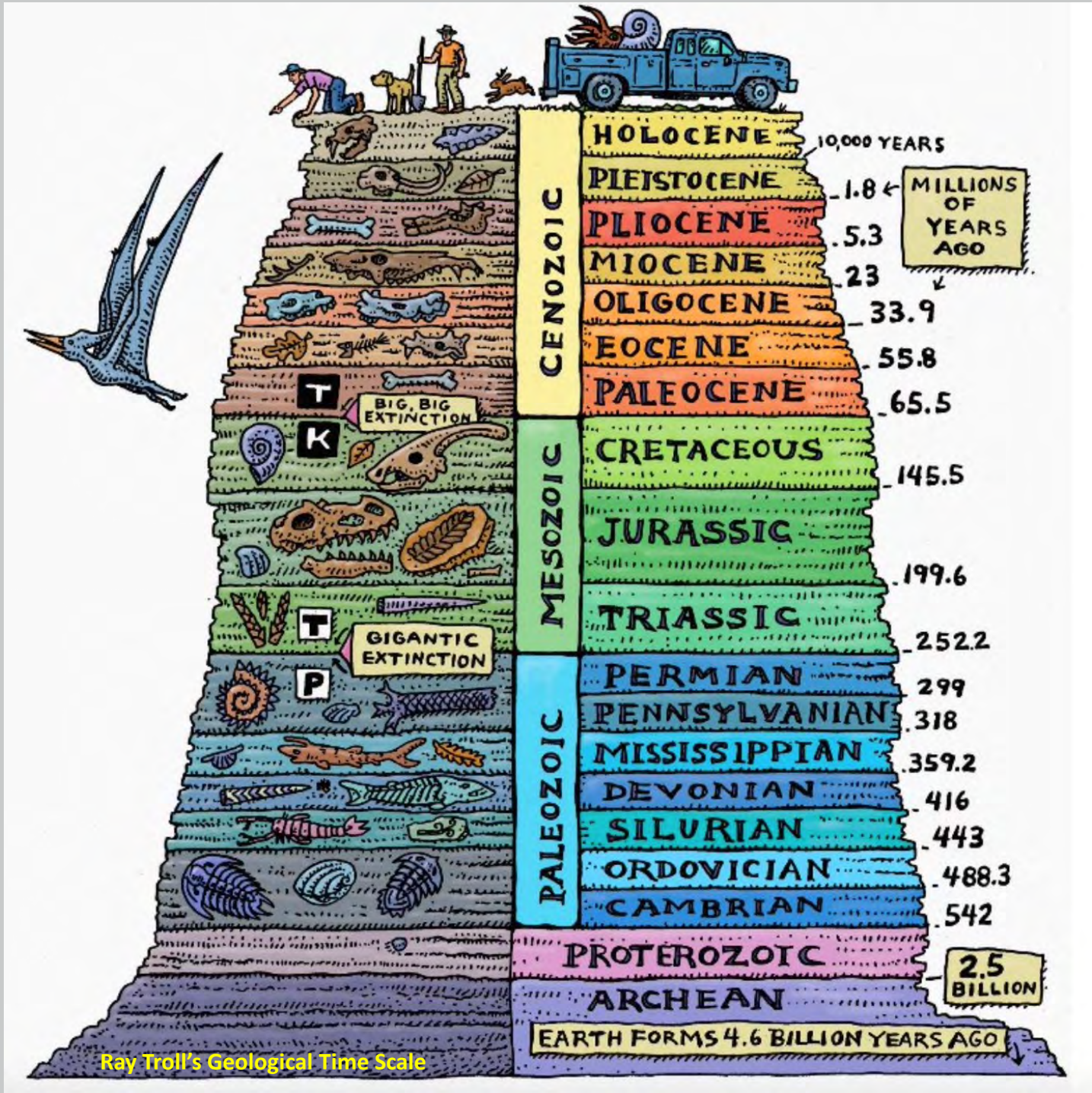
Applications of Geochronology in Key Evolutionary Events

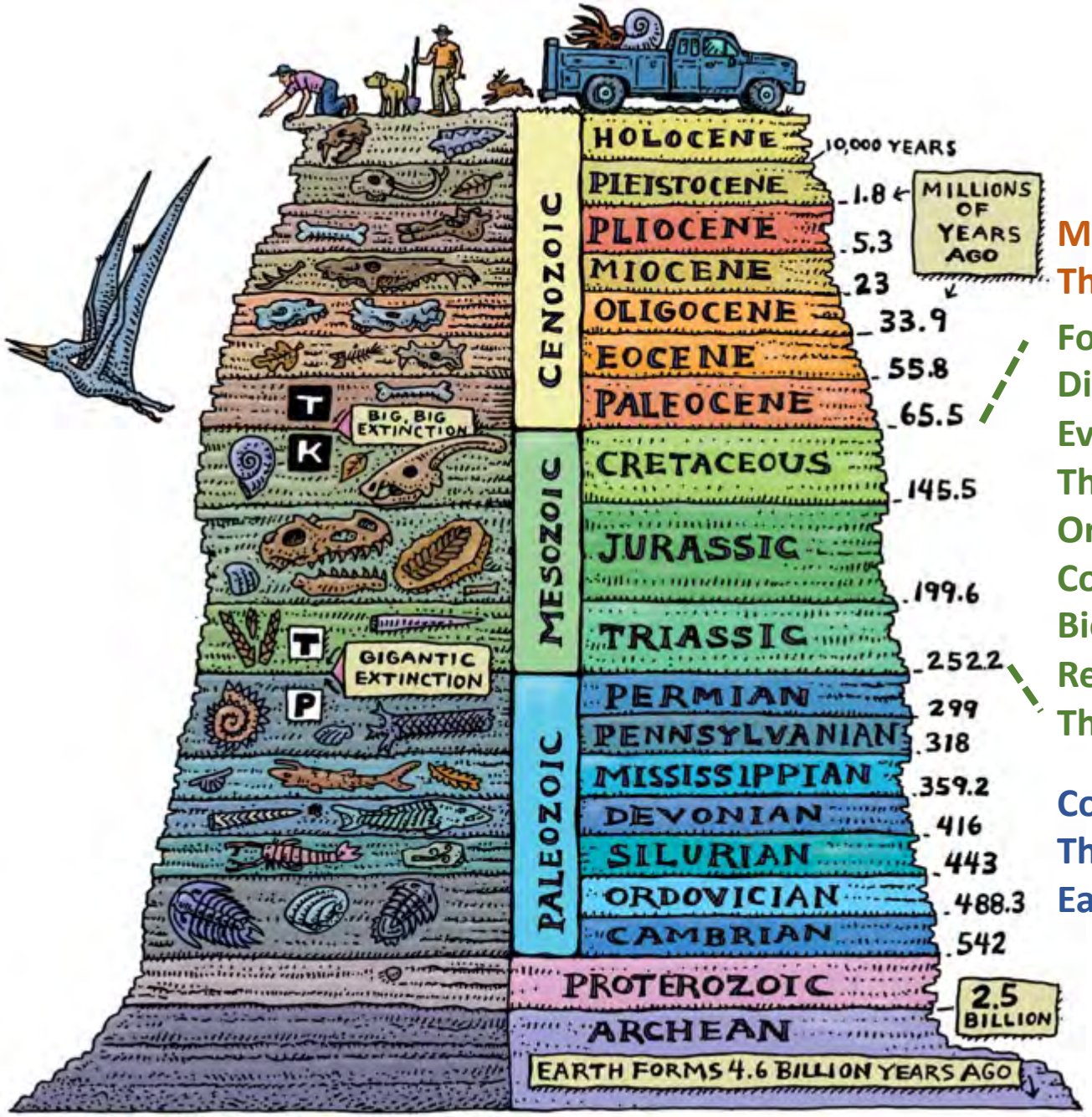
Su-Chin Chang
National Central University
March 24, 2023

As a geologist specializing in chronostratigraphic interpretation of fossil evidence, my research mainly uses the $^{40}Ar/^{39}Ar$ and U/Pb methods to constrain the time scale of biological evolution, mass extinction events, and global climate change.



Applications

In the past 12 years, my research team based at the University of Hong Kong has applied $^{40}Ar/^{39}Ar$ and U–Pb radio-isotopic dating techniques to refine the dates and durations of several key evolutionary events.



Ray Troll's Geological Time Scale

Major projects

Miocene limestone in Jaffna, Sri Lanka

The oldest tropical rainforest in China

Fossil-bearing ambers in Myanmar

Dinosaur eggs and footprints in East Asia

Everything about the Jehol Biota

The first flowering plants in Earth's history

Origin of salamanders from the Yanliao Biota

Co-evolution between plants and insects in Tabbowa, Sri Lanka

Biogeography of basal sauropod in SW China

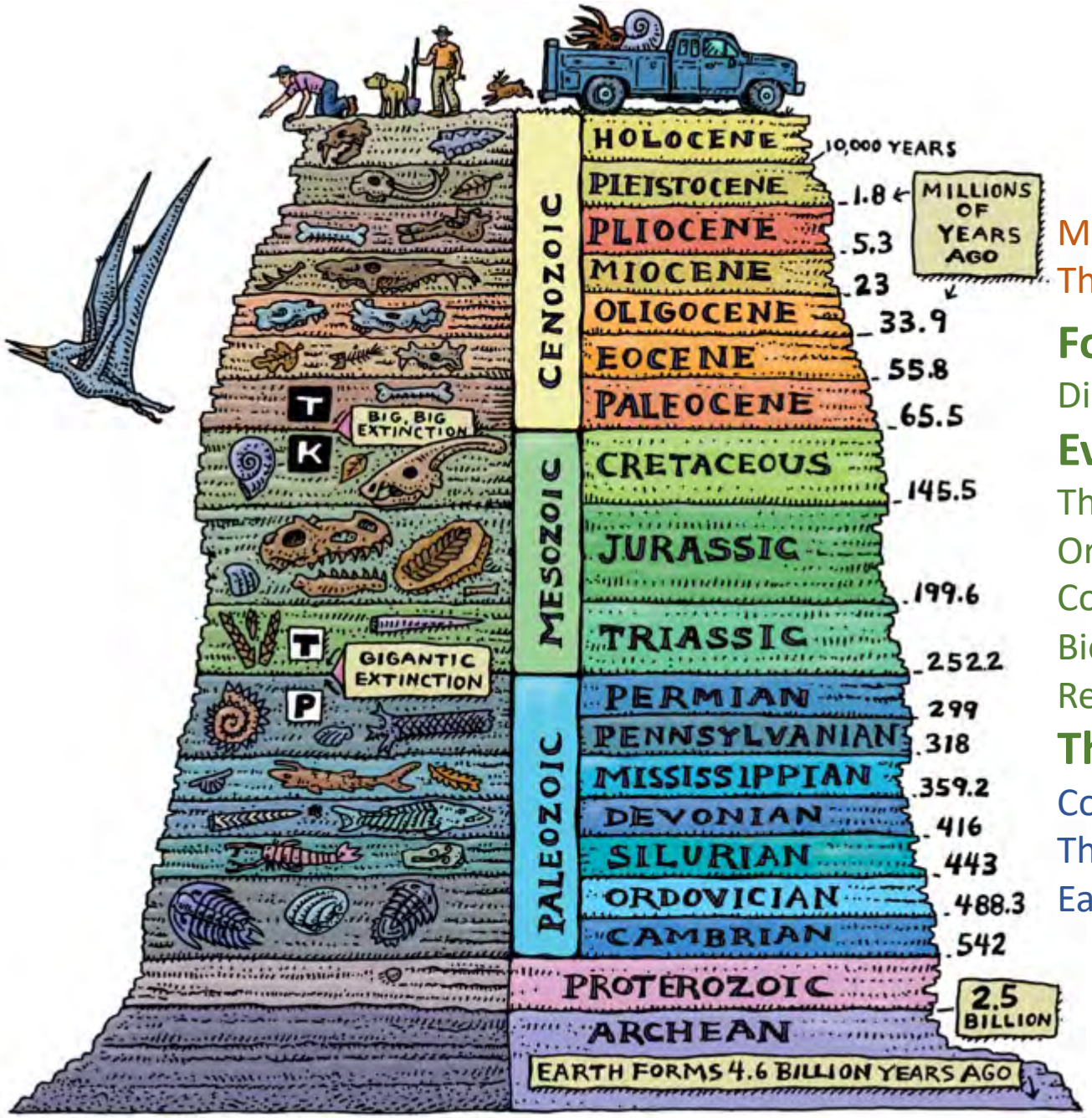
Recovery patterns of insects after the end Permian extinction

The largest marine reptile radiation in Earth's history

Correlations for the Permo-Triassic boundary

The oldest-known forest in Asia

Early land plants in NW China



Ray Troll's Geological Time Scale

Examples

Miocene limestone in Jaffna, Sri Lanka

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Fossil-bearing ambers in Myanmar

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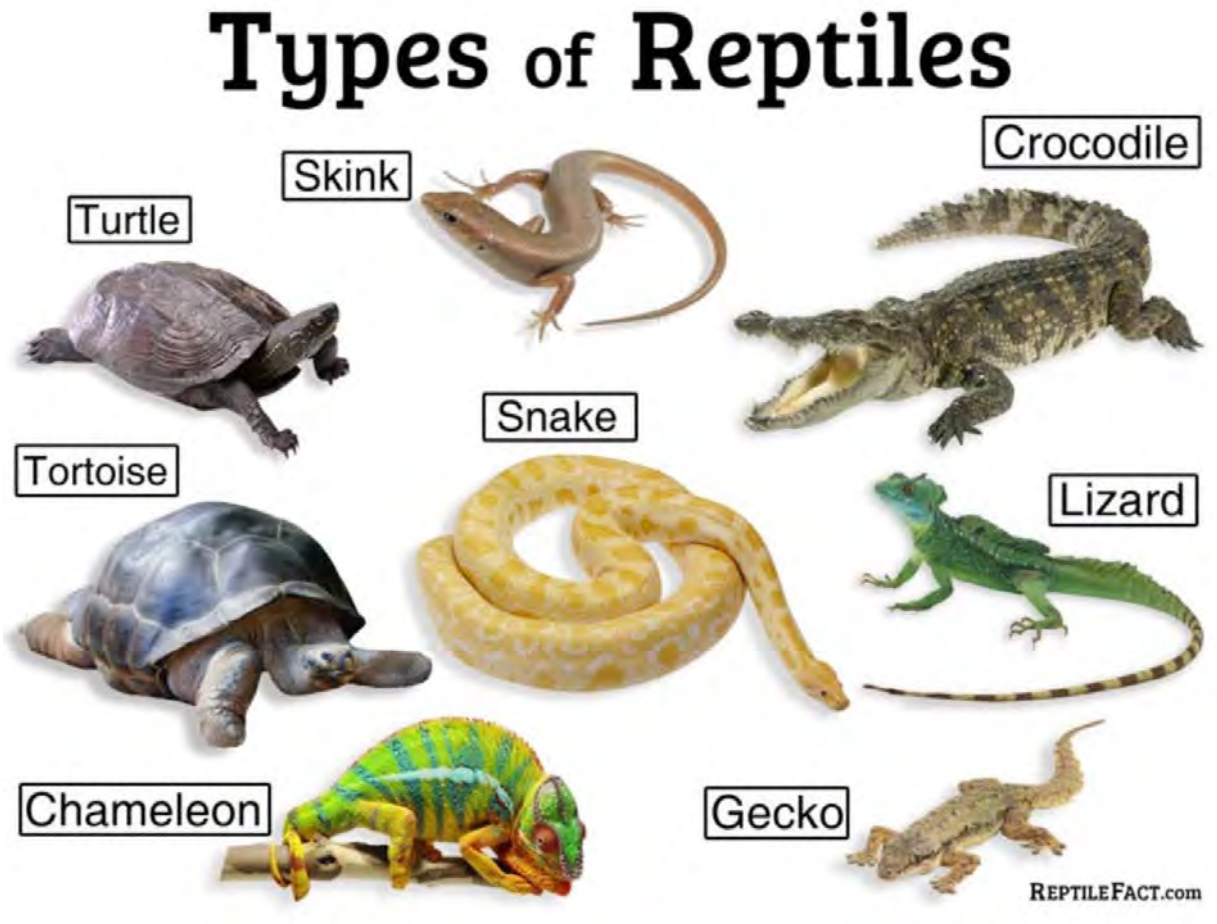
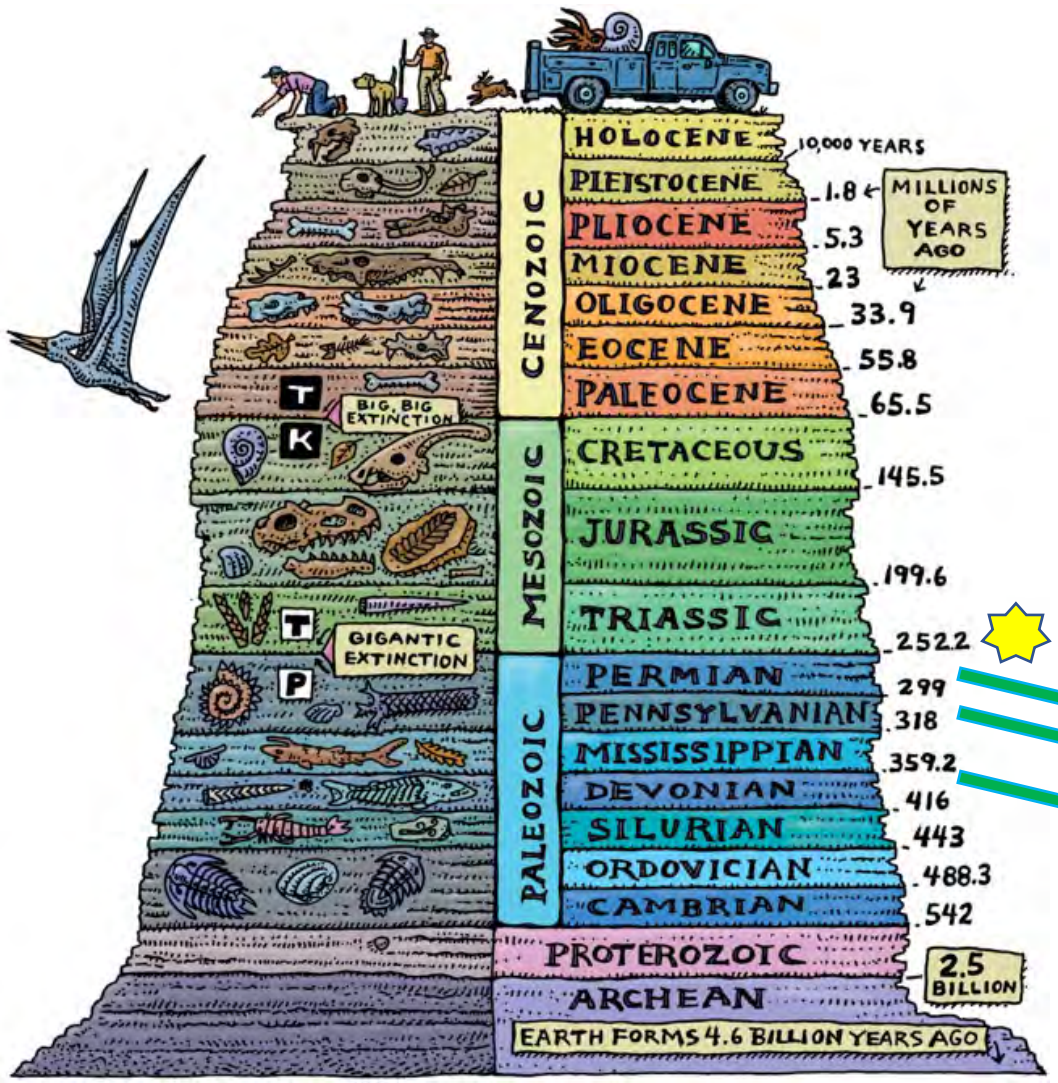
1. The largest marine reptile radiation in Earth's history

Reptiles, including tortoises, turtles, crocodilians, snakes, lizards, and their extinct relatives, are the most diverse modern terrestrial vertebrates.



https://www.reptilefact.com

Evolutionary history of reptiles



End-Permian mass extinction event, the most severe in Earth's history!

Some reptiles moved back to the ocean.

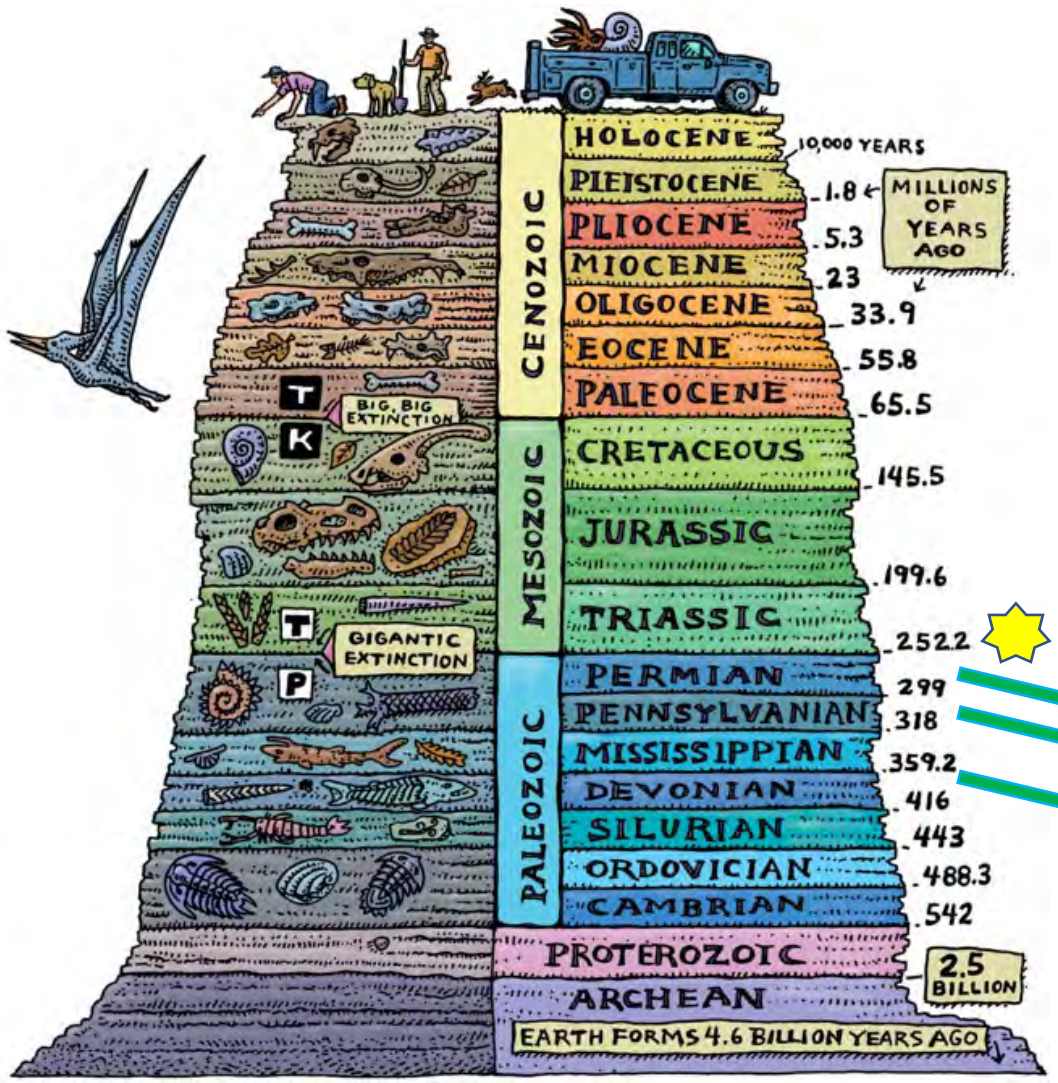
Abundant and diverse reptiles lived dry land.

Proto-reptiles are thought to have evolved from aquatic amphibians in Carboniferous (~359-299 Ma) swamps.

End-Permian Mass Extinction Event

Earth's largest extinction event in history killed **97% of all marine species and an estimated 70% of land species**, including insects. The Permian-Triassic Extinction was so devastating that it was nicknamed the "Great Dying" because of its significance.

Evolutionary history of reptiles



It's difficult to find the underlying cause of the end Permian Mass Extinction because it happened 252 million years ago. Much of the evidence would have been removed. But the general consensus for the cause of the "Great Dying" is severe volcanic activity.

Earth took **at least ten million years** to recover from the end-Permian extinction.

End-Permian mass extinction event, the most severe in Earth's history!

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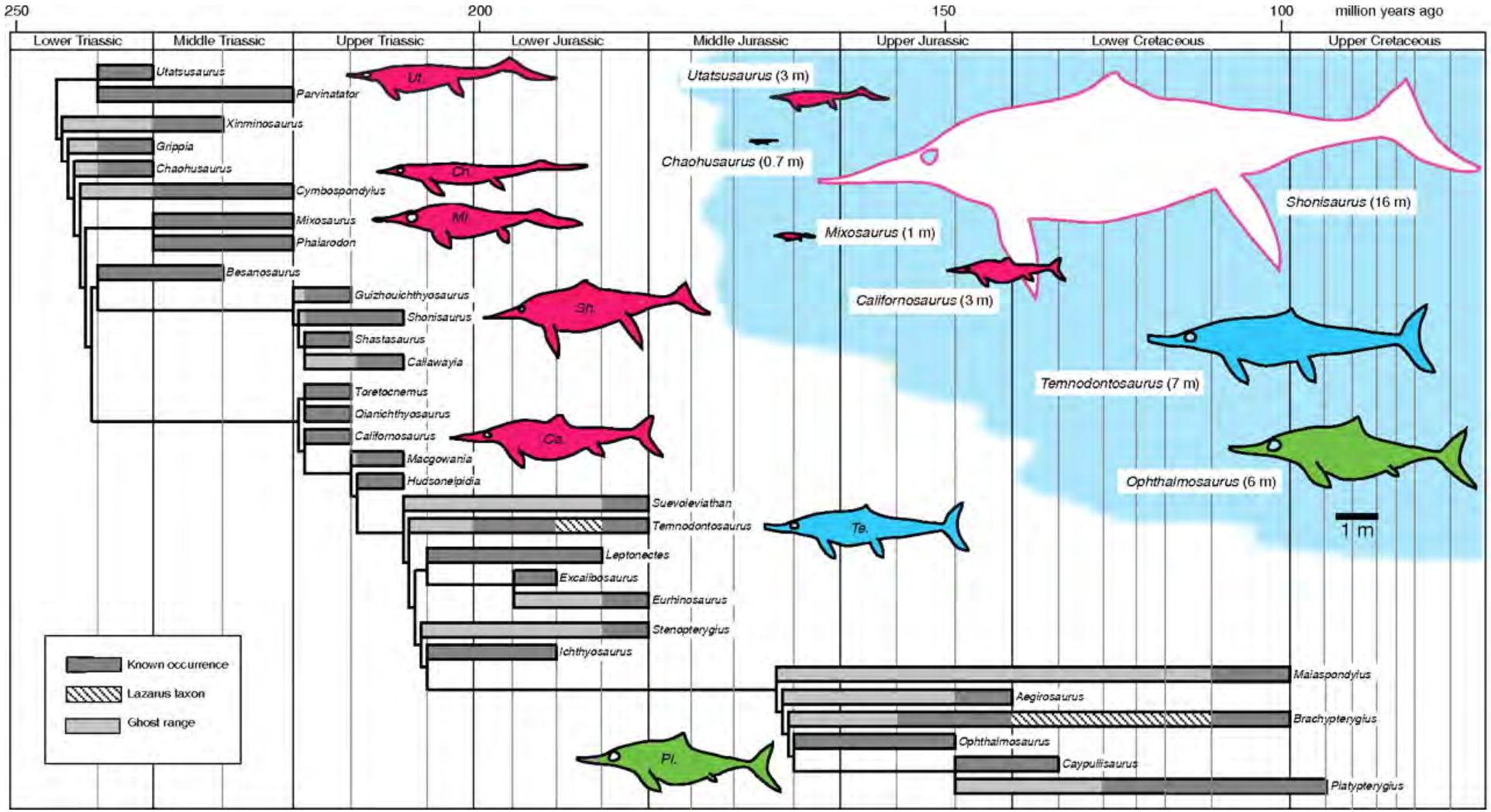
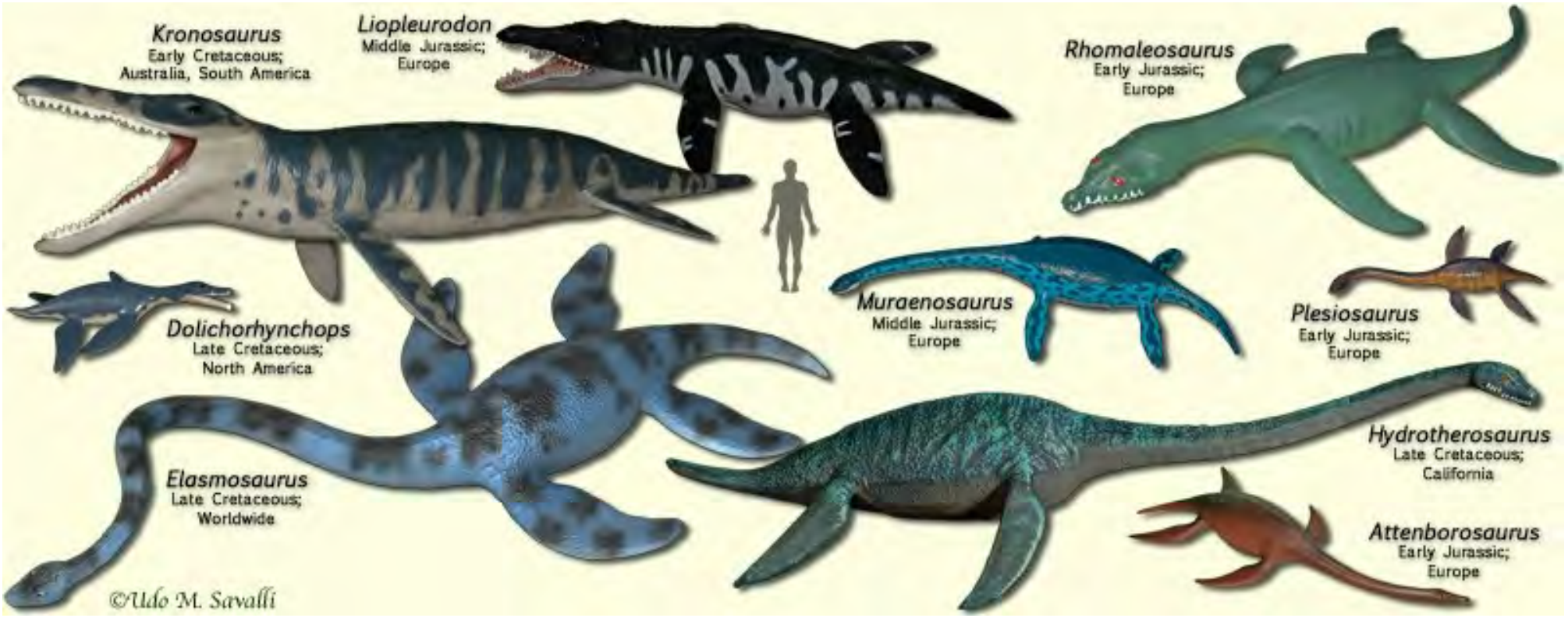
A prevalent hypothesis holds that marine reptiles gradually expanded their diversity throughout the Middle Triassic (~ 240 Ma). This expansion is interpreted to be consistent with the slow tempo of post-Permian-Triassic boundary biostratigraphic patterns, sometimes referred to as “delayed recovery”.

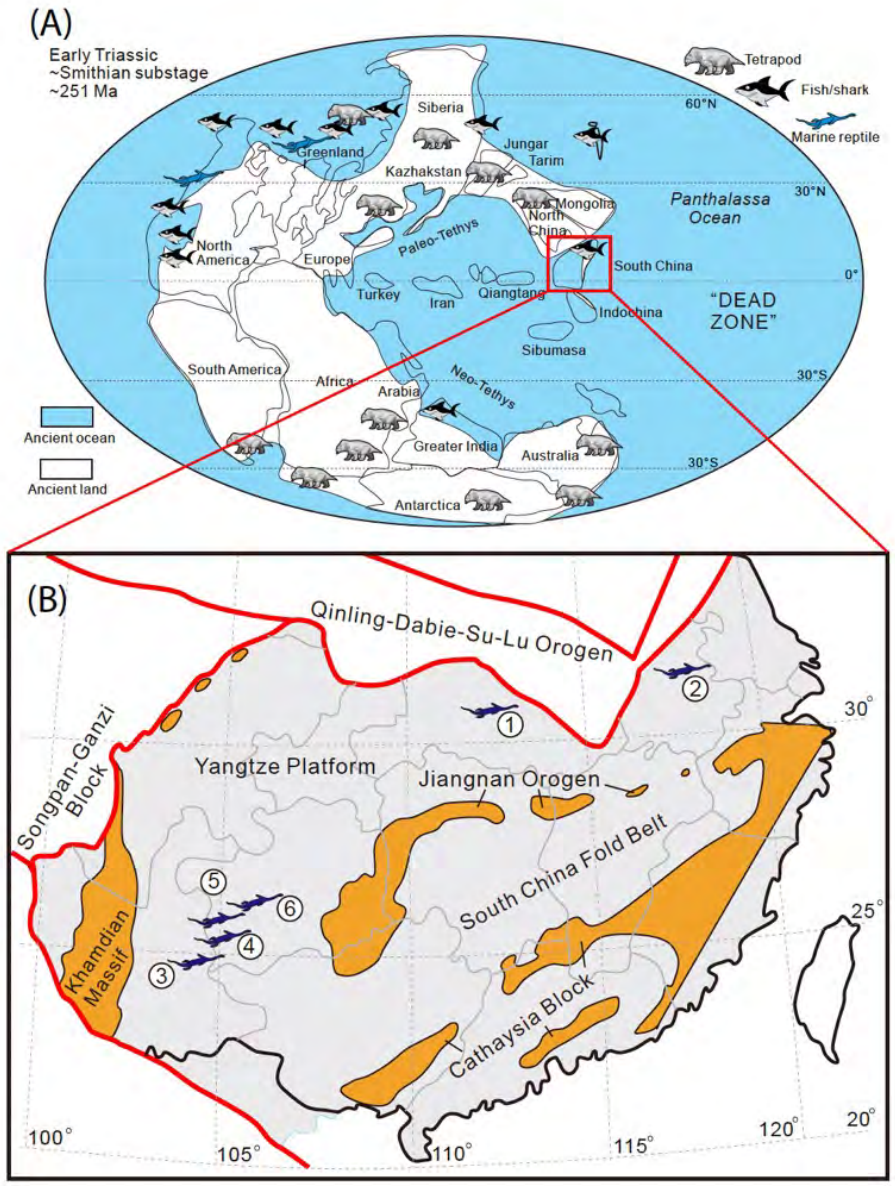


Biotic recovery– marine reptiles



https://biomgroup.wordpress.com

Evidence from South China



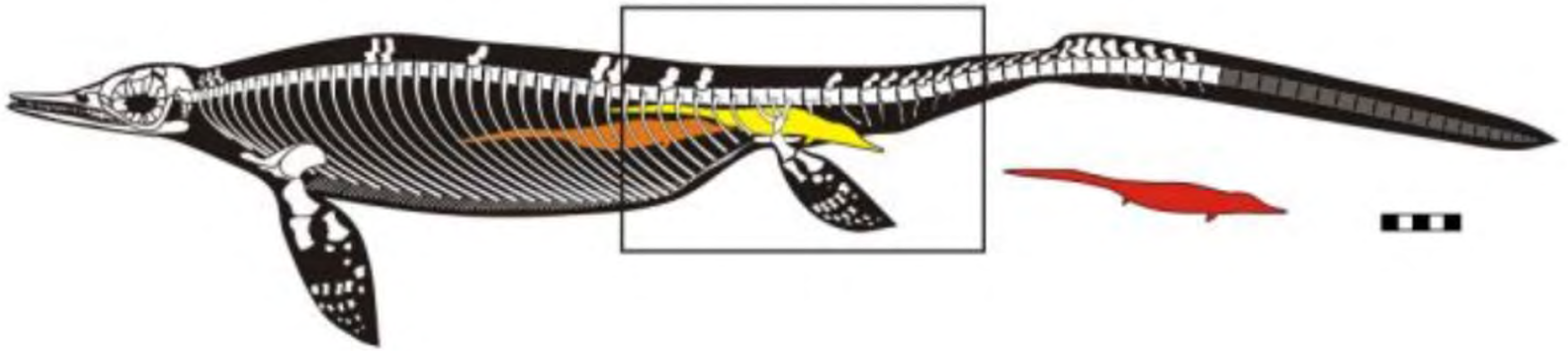
(A) Early Triassic palaeogeographic map showing major global vertebrate distributions and the location of the South China Basin (after Sun et al., 2012). (B) Abundant well-preserved marine reptiles have been discovered from six classic outcrops in South China. 1. Yuanan area of Hubei Province; 2. Chaohu area of Anhui Province; 3. Luoping area of Yunnan Province; 4. Xingyi area of Guizhou Province; 5. Panxian area of Guizhou Province; 6. Guanling are of Guizhou Province (after Benton et al., 2013).

Evidence from South China

Evidence from South China

Oldest Fossil of Reptile Live Birth Found

The maternal specimen with three embryos. Color coding indicates black, maternal vertebral column, including neural and haemal spines; blue, maternal pelvis and hind flipper; green, maternal ribs and gastralia. Embryos 1 and 2 are in orange and yellow, respectively, whereas neonate 1 is in red. Scale bar is 1 cm. (Huang et al., 2019)



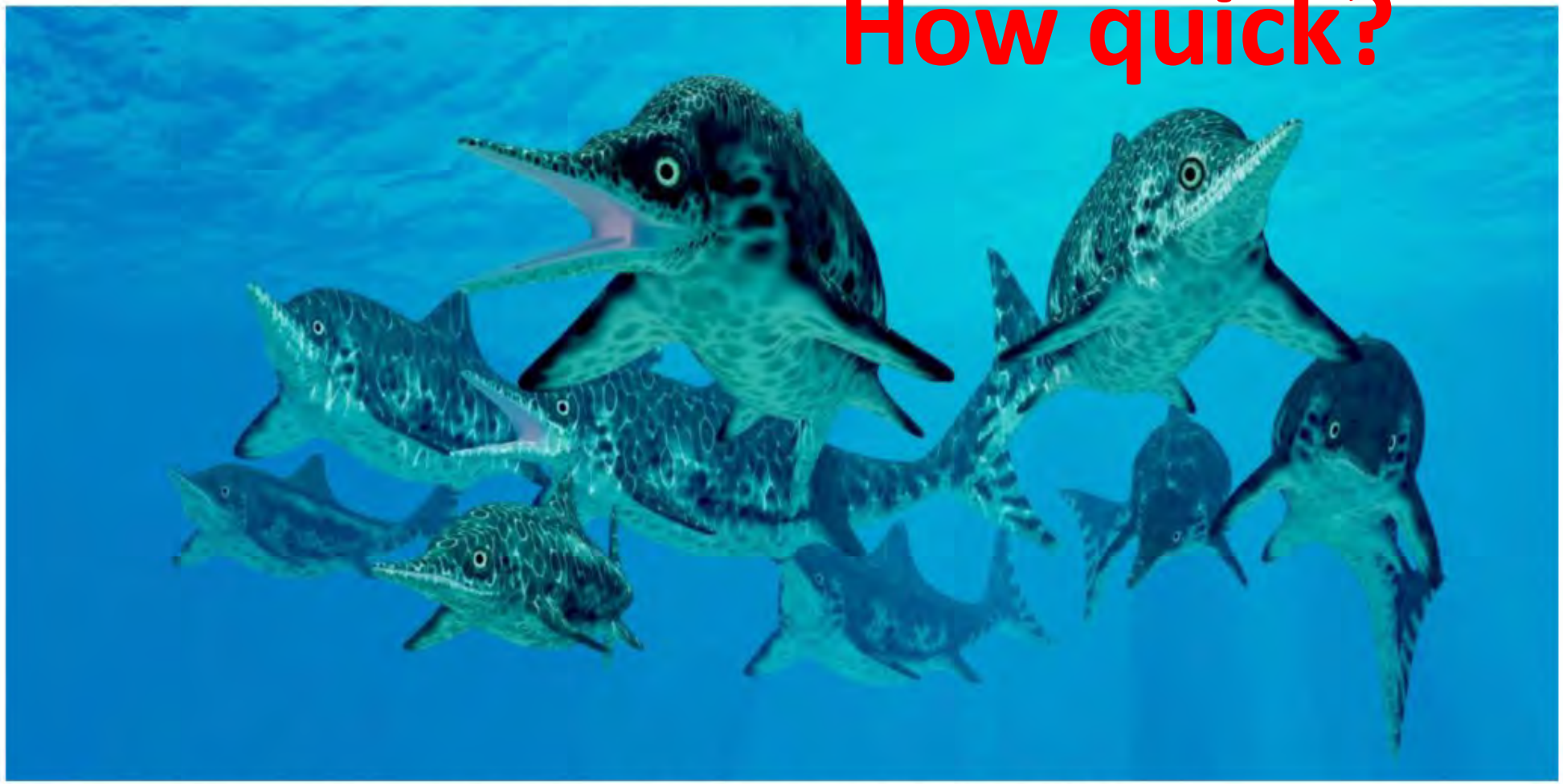
Evidence from South China

The ichthyosaur mother died with three young: one outside the mother, one half-emerged headfirst from her pelvis, and one still inside, waiting to be born. The new ichthyosaur fossil pushes back the known records of live birth to the earliest appearance of marine reptiles during the Triassic. (Huang et al., 2019)

Marine Life Quickly Recovered After Global Mass Extinction

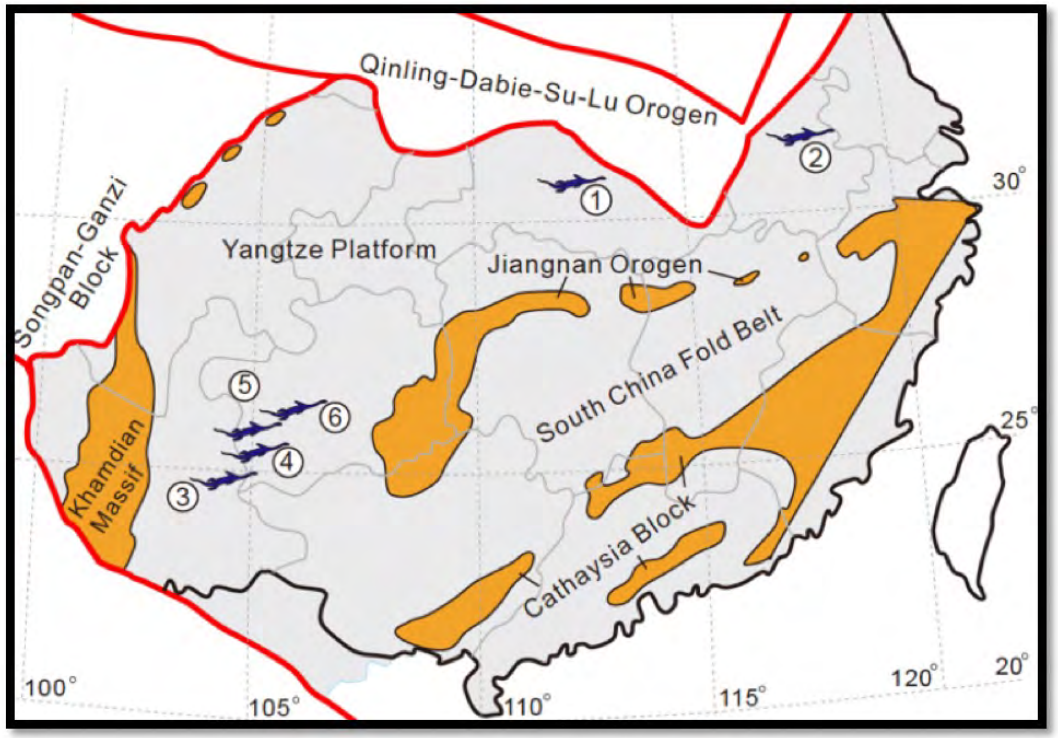
By Becky Oskin on June 13, 2016 in Science & Technology

How quick?



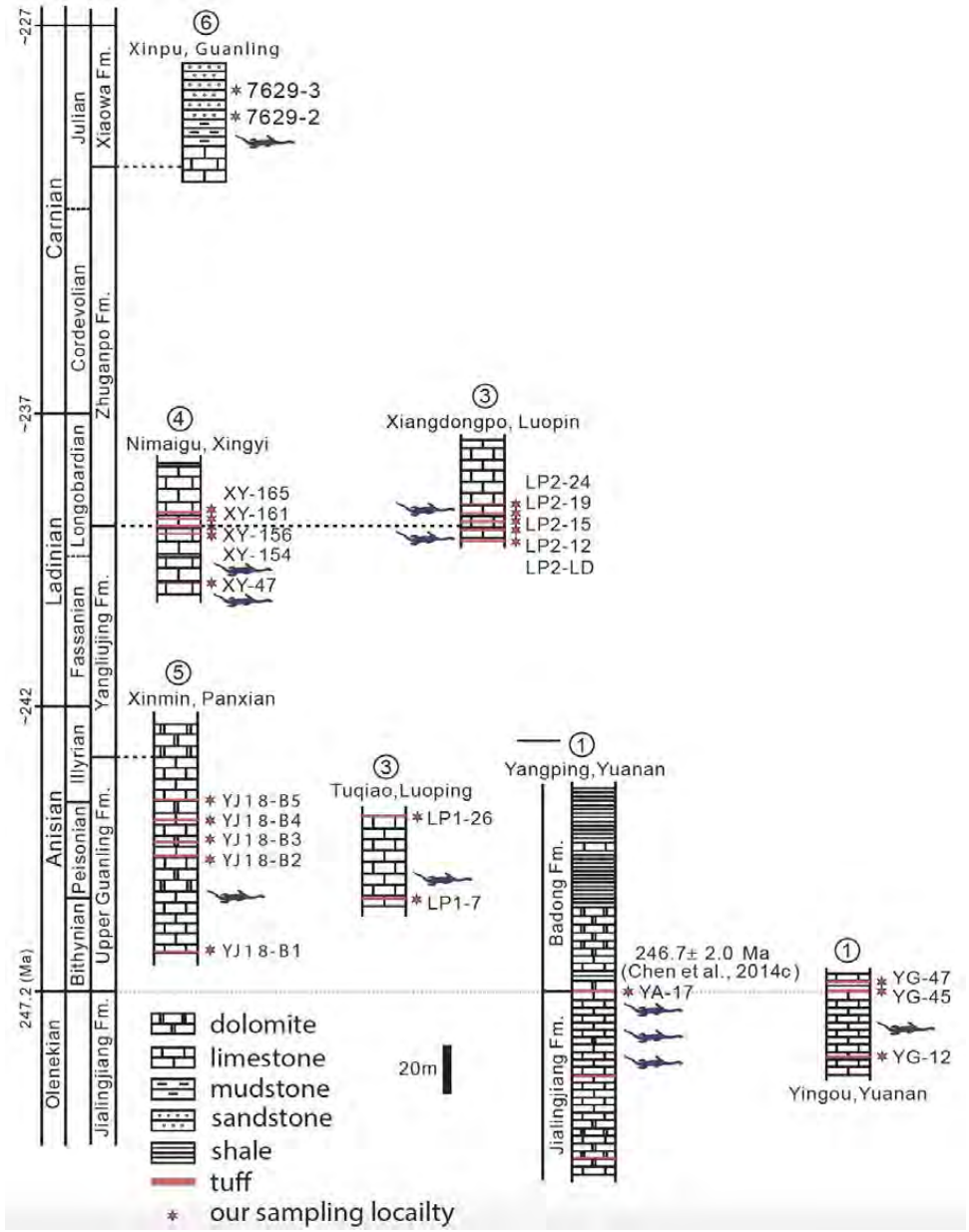
Ichthyosaurs and other marine reptiles invaded the oceans soon after the Permian mass extinction. (Cory Ford/Getty Images)

Our work in South China

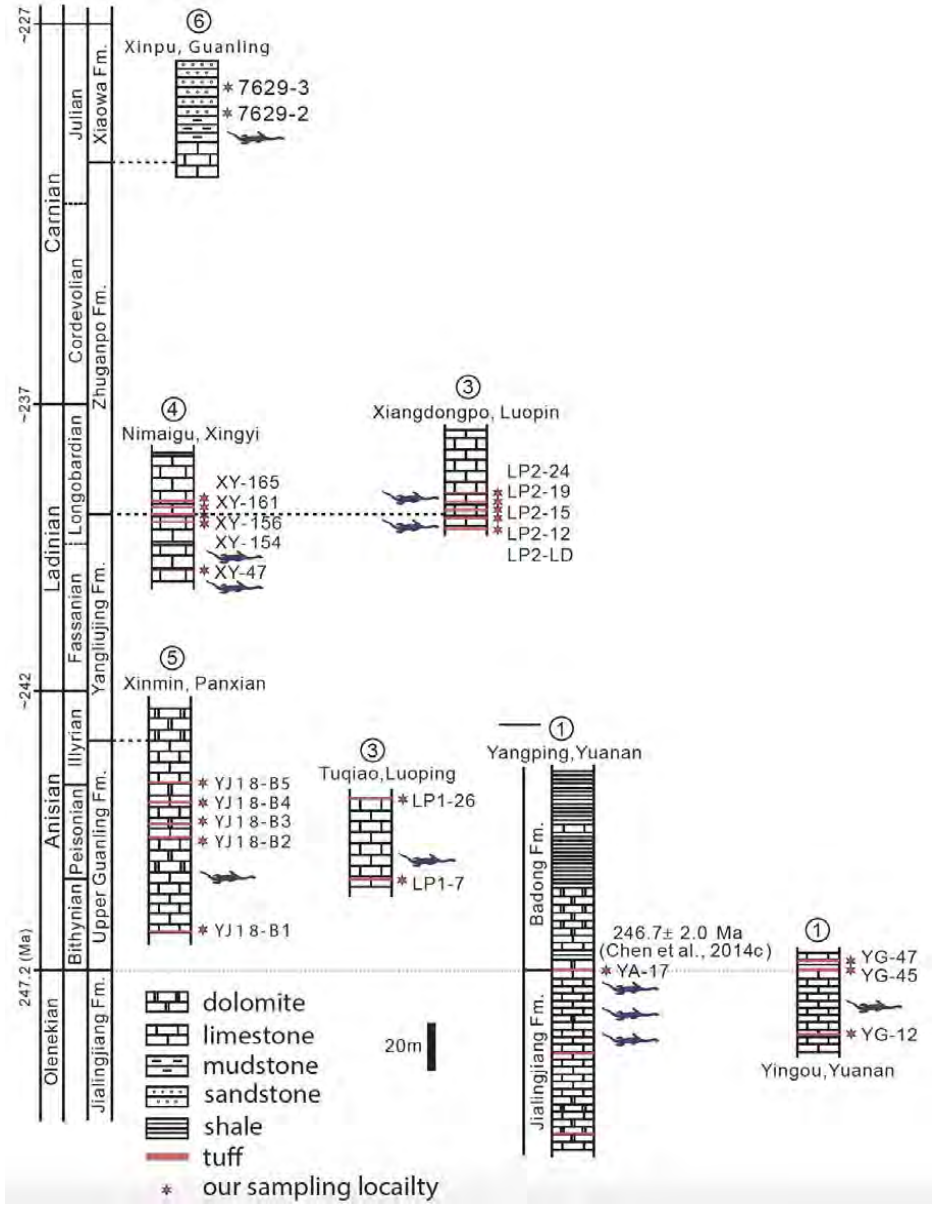


Locality	Province	Age
Yuanan	Hubei	Olenekian- Anisian (Early- Middle Triassic)
Chaohu	Anhui	Olenekian (Early Triassic)
Luoping	Yunnan	Anisian (Middle Triassic)
Xingyi	Guizhou	Ladinian (Middle Triassic)
Panxian	Guizhou	Anisian (Middle Triassic)
Guanling	Guizhou	Carnian (Late Triassic)

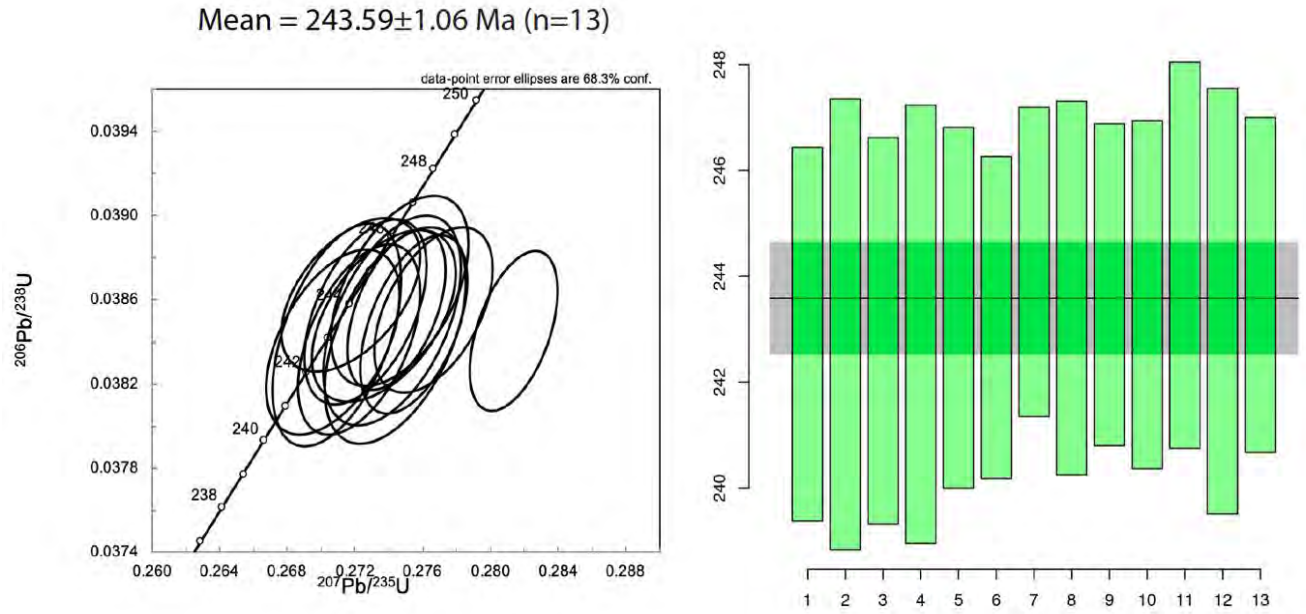
Our work in South China



Our preliminary age date

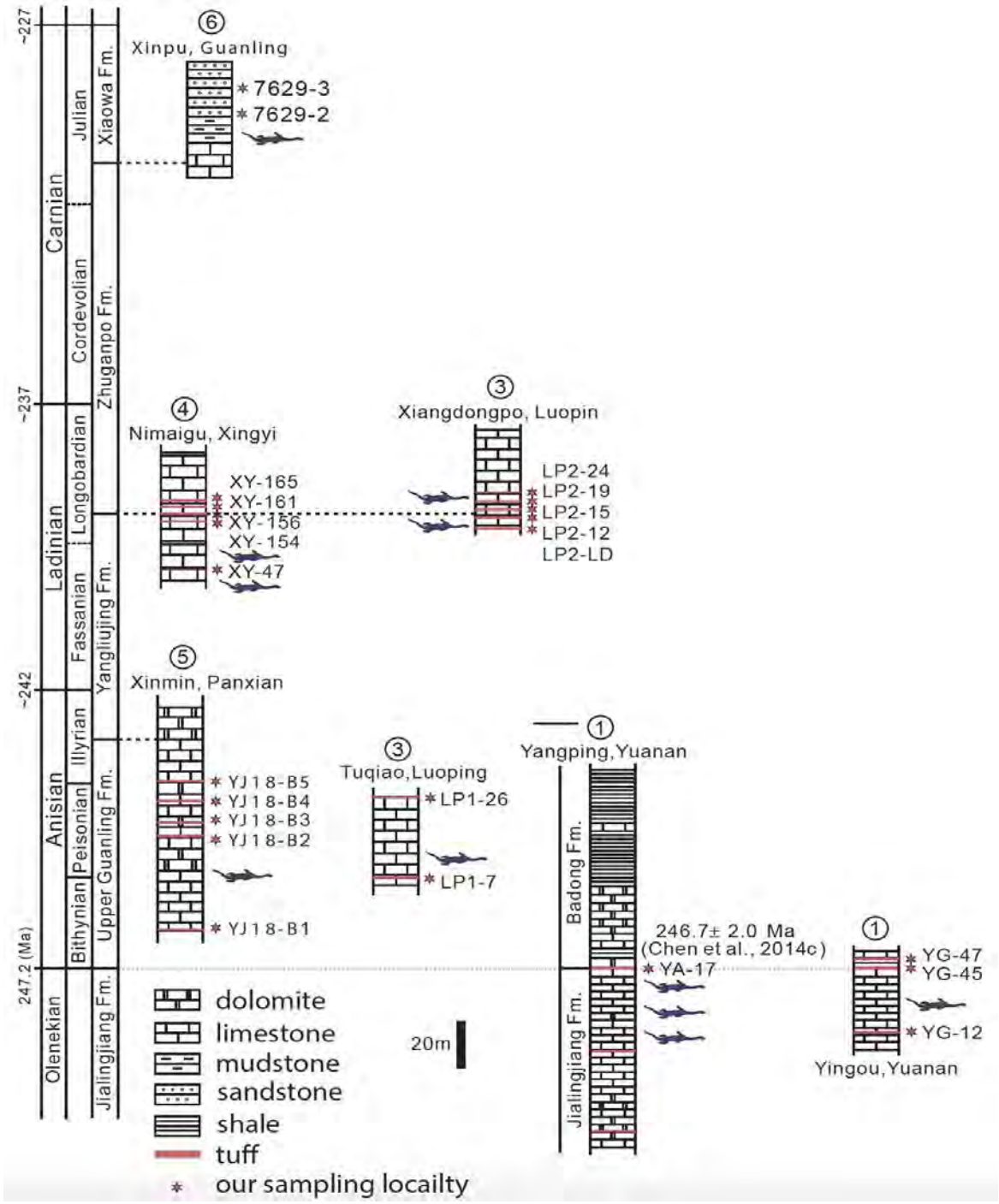


LP2-12



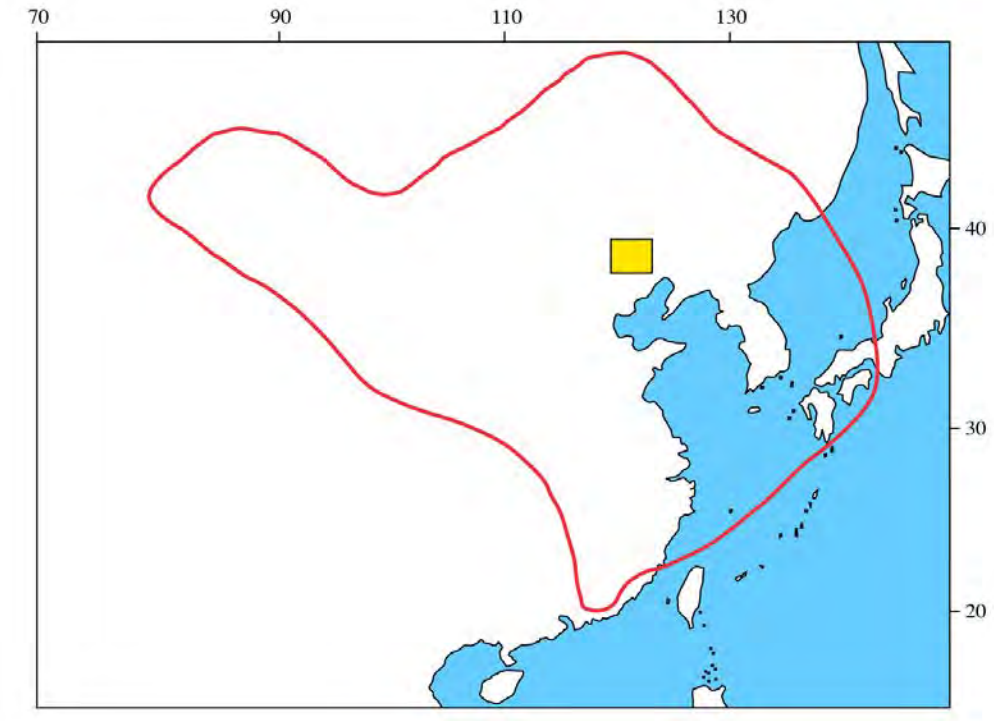
Our goals

- Identify pure volcanic ashes from all classic outcrops.
- Establish high-precision CA-ID TIMS zircon U-Pb ages for the fossil-bearing formations.
- Evaluate models of biological recovery for Triassic marine ecosystems.



2. Age and migrations for the Jehol Bioa

熱河生物群



1. Jehol fauna:

1923- A.W. Grabau

Ephemeropsis

Lycoptera

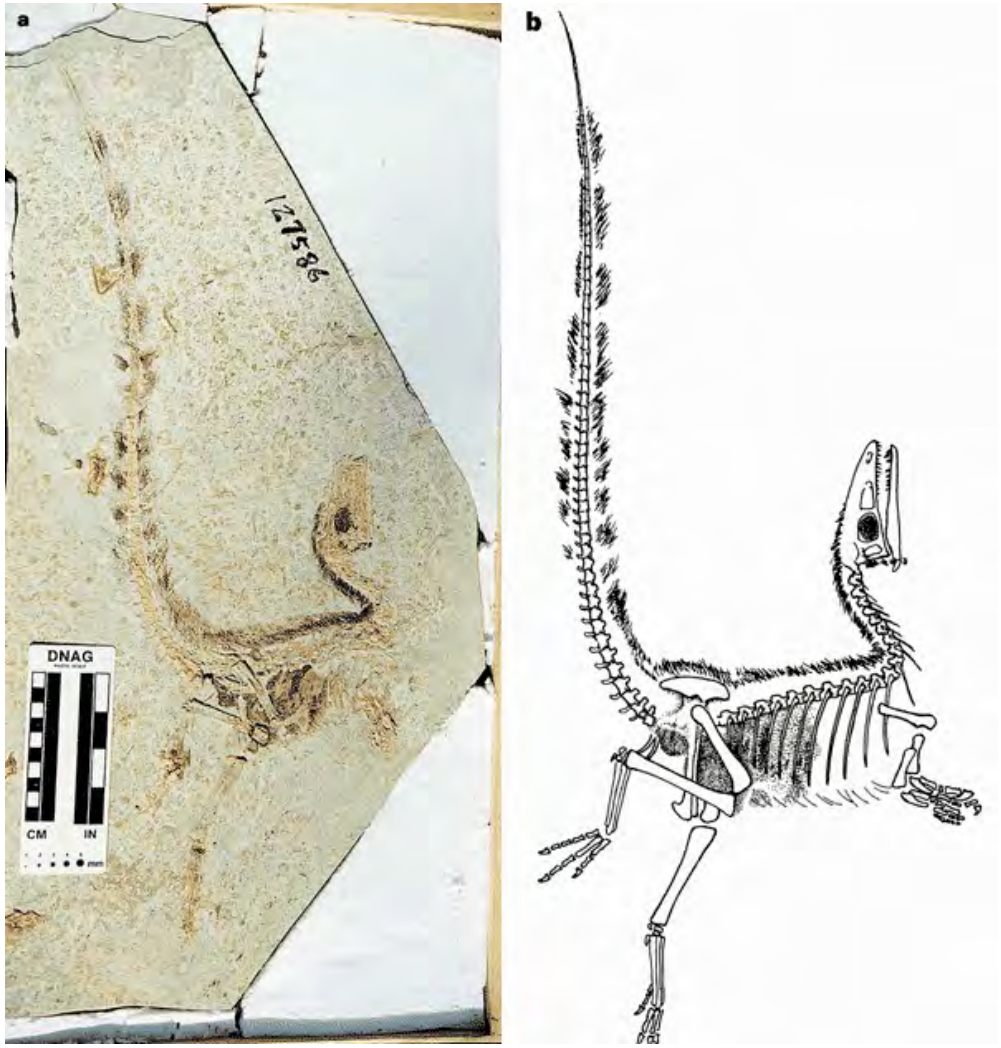
Eosestheria

2. Jehol Group:

1962- J.W. Gu

3. Significant fossils!

Feathered dinosaurs



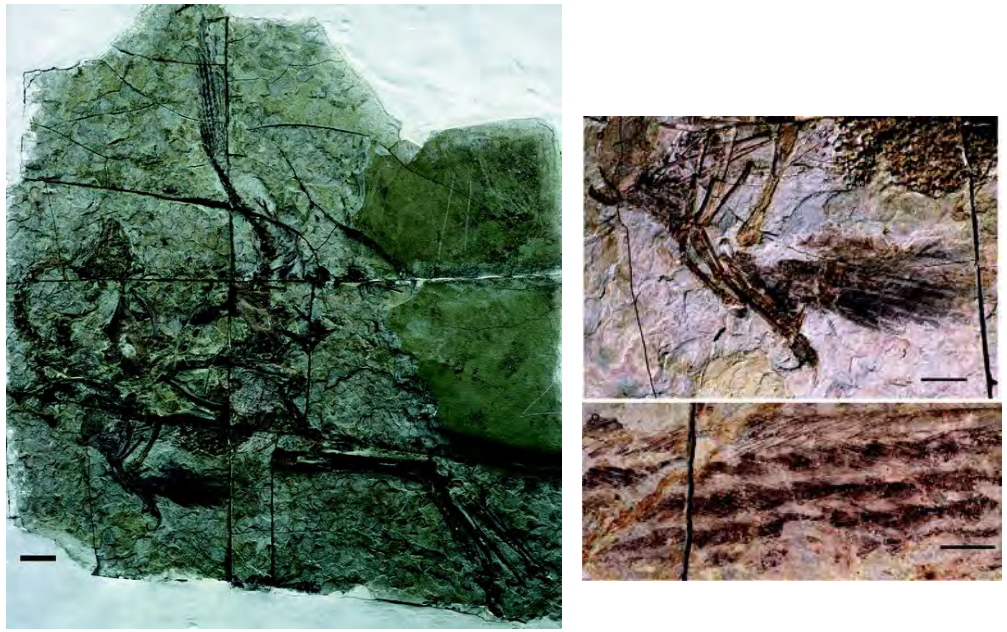
(Chen et al., 1998)

Sinosauropteryx

http://www.amonline.net.au/

Feathered dinosaurs

Caudipteryx



(Ji et al., 1998)

Feathered dinosaurs

(Xu et al., 2003)

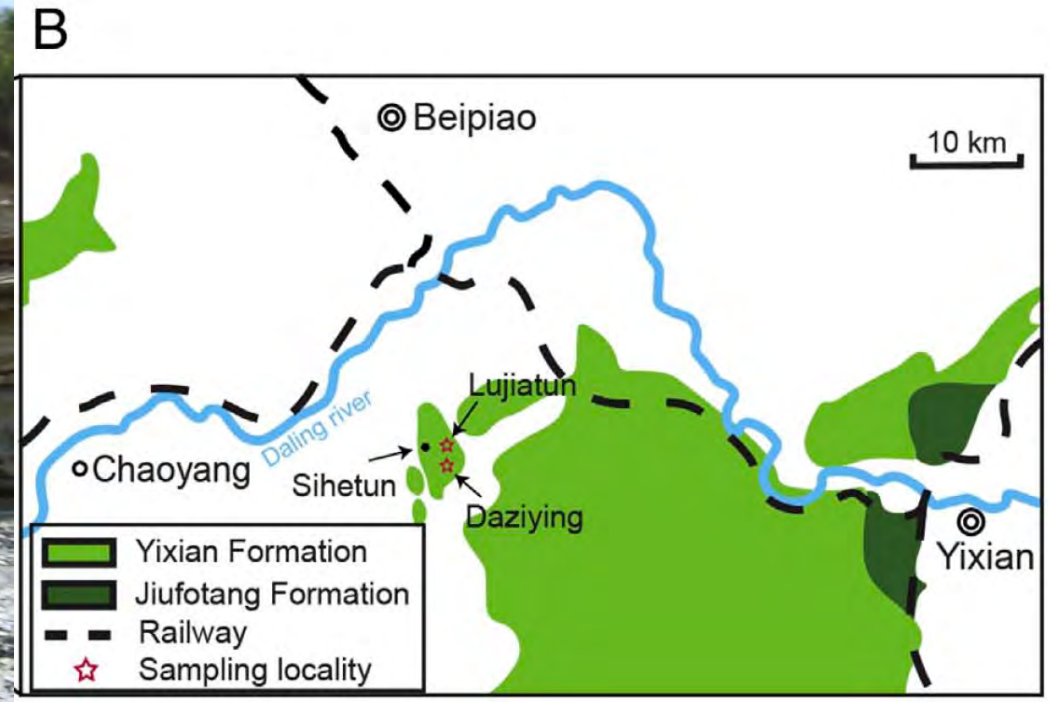
Jehol Biota- importance

(images from pbskids.org)

Jehol Biota- importance

http://www.earthsciences.hku.hk/shmuseum/

The Jehol Biota is particularly noteworthy for the very high diversity of fossils and the many individuals of each species that have been recovered.



Jehol Biota- stratigraphy & age

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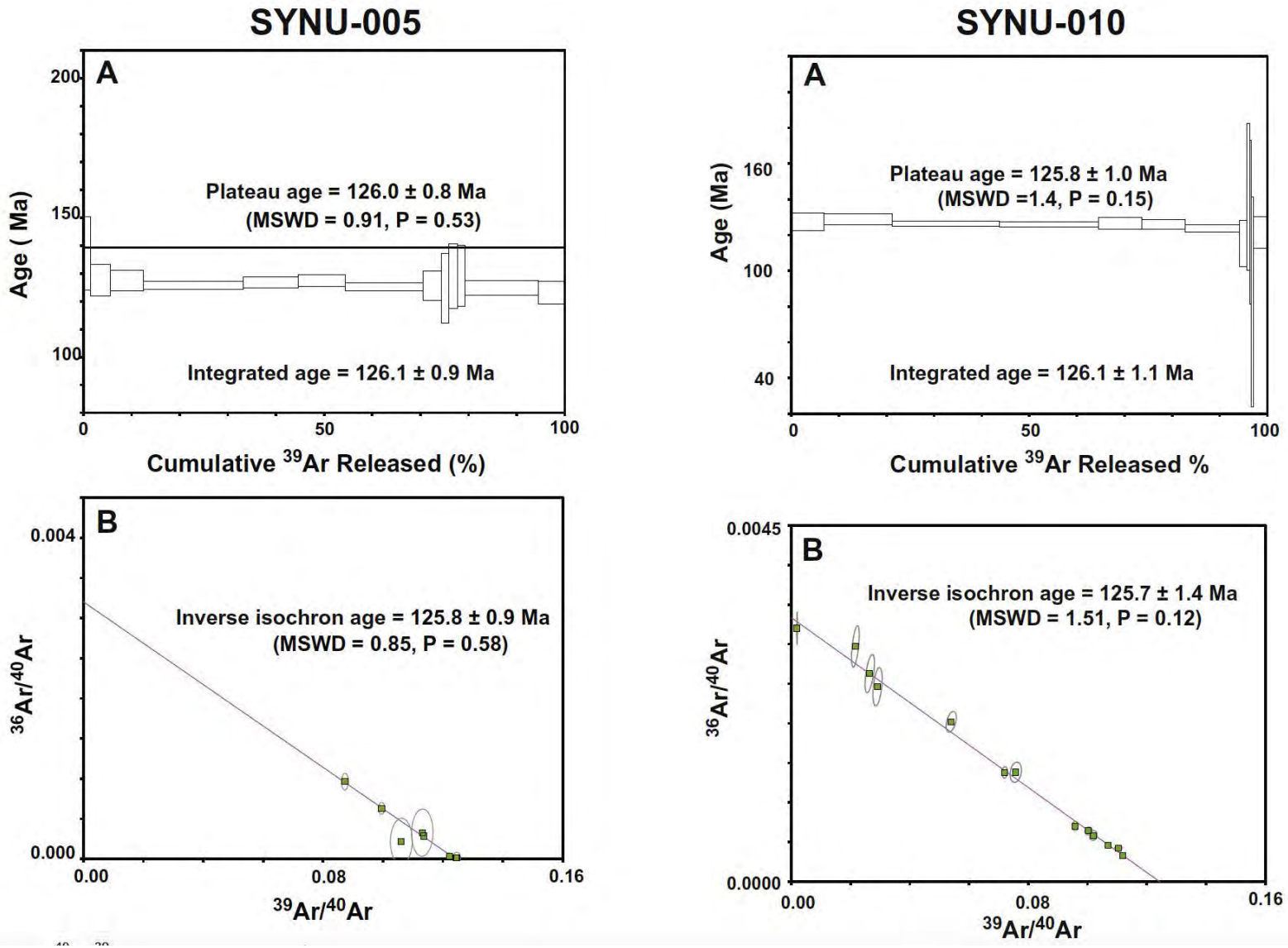
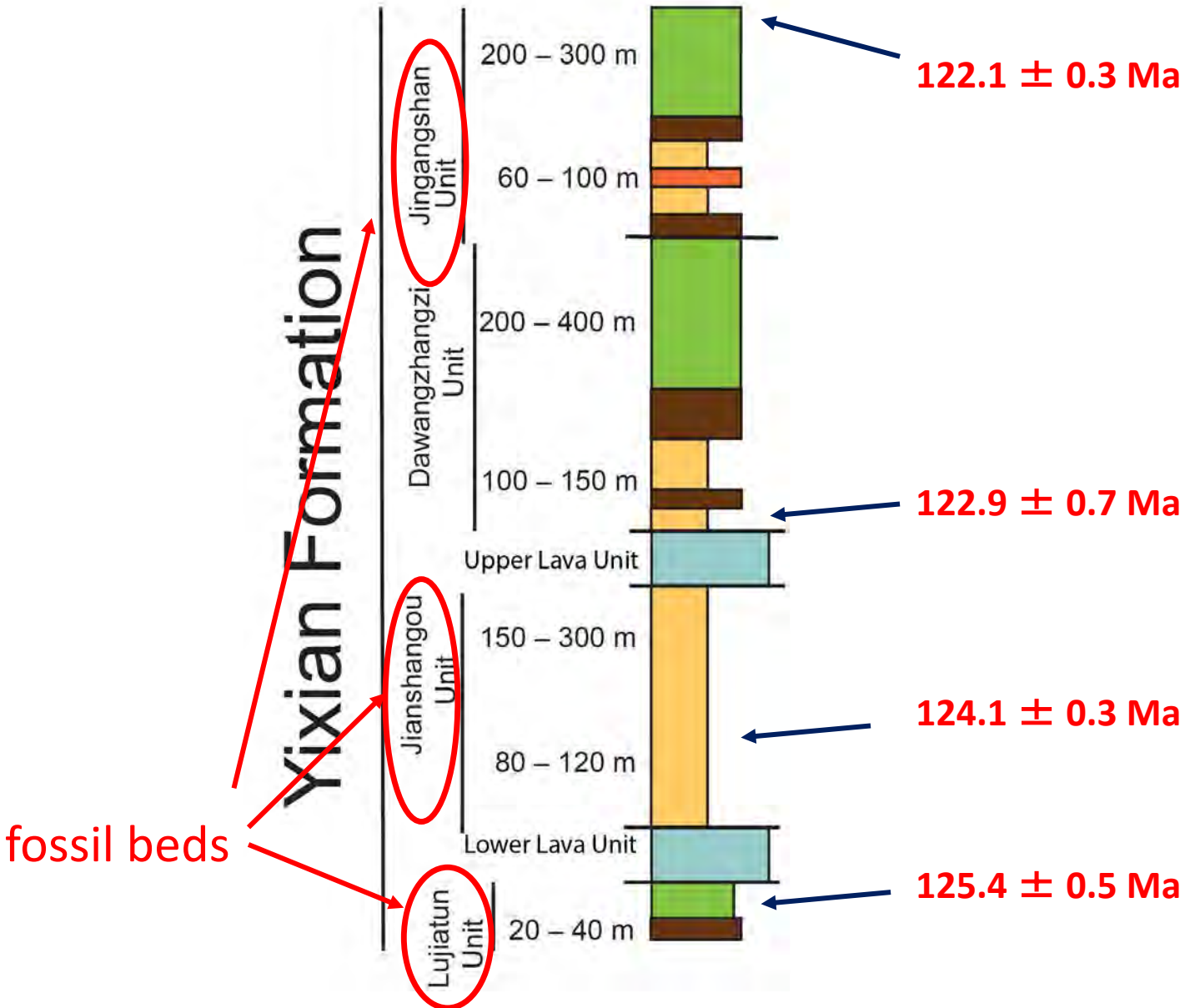
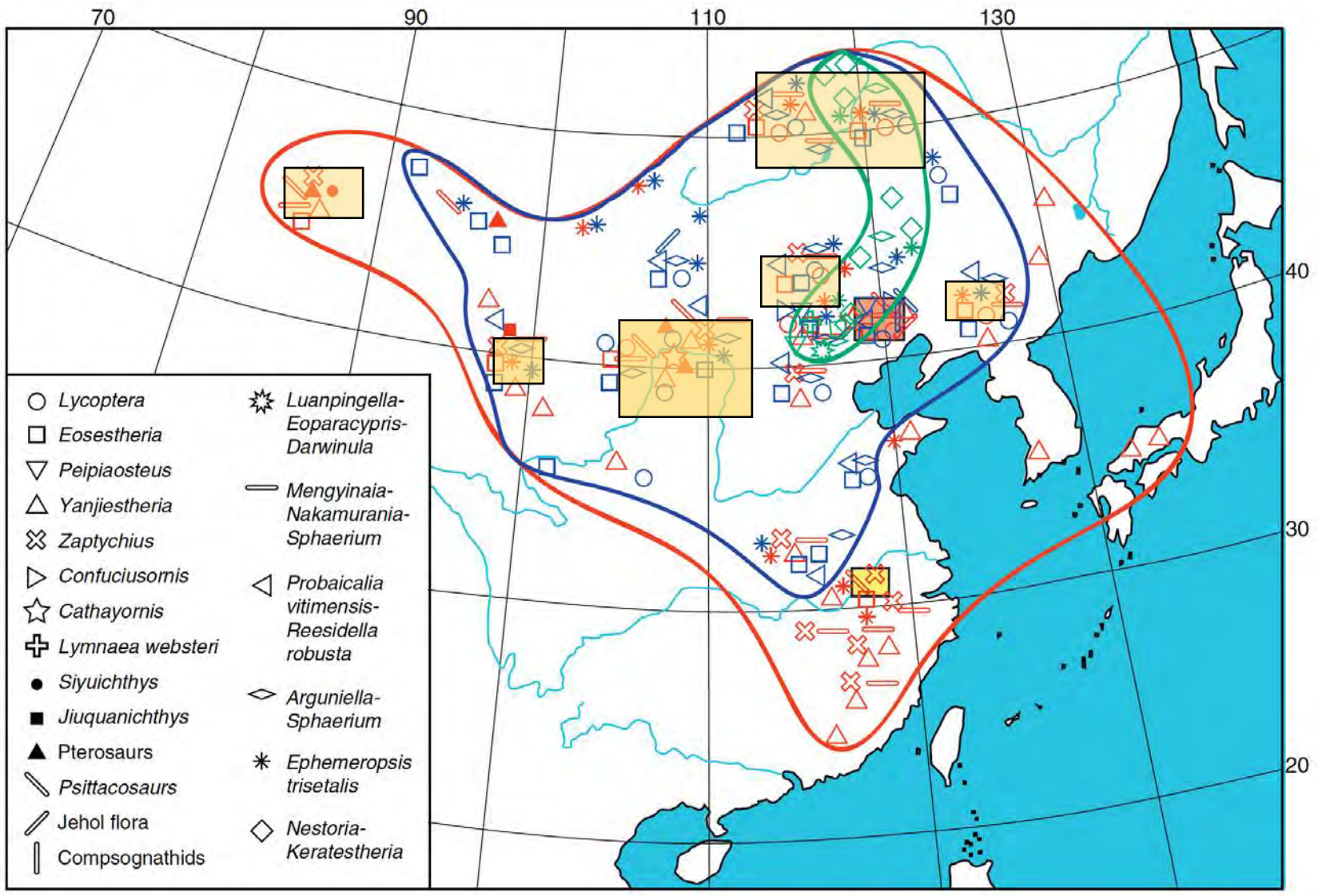


Jehol Biota- stratigraphy & age



(Chang et al., 2009, 2017, Palaeo^3)

Jehol Biota- stratigraphy & age

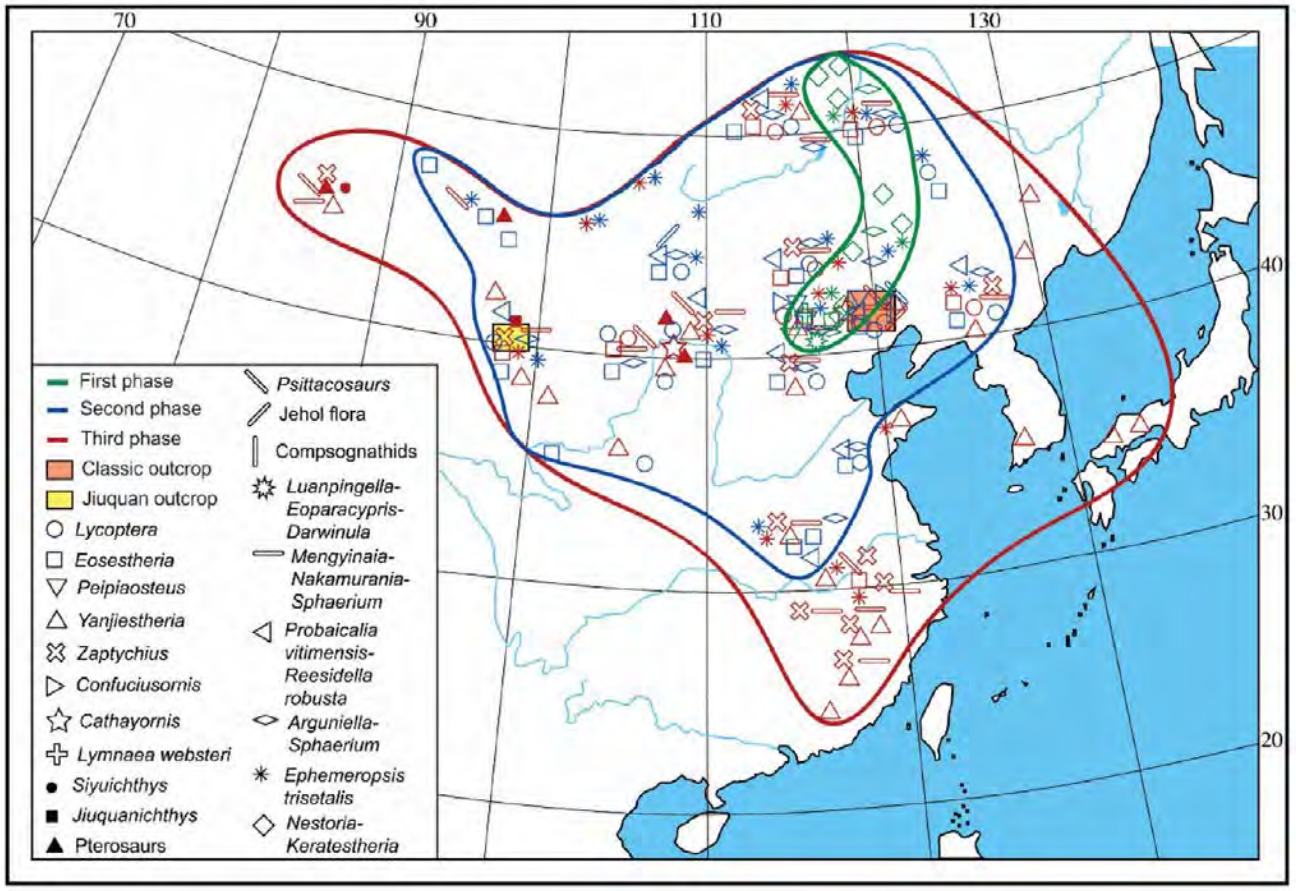


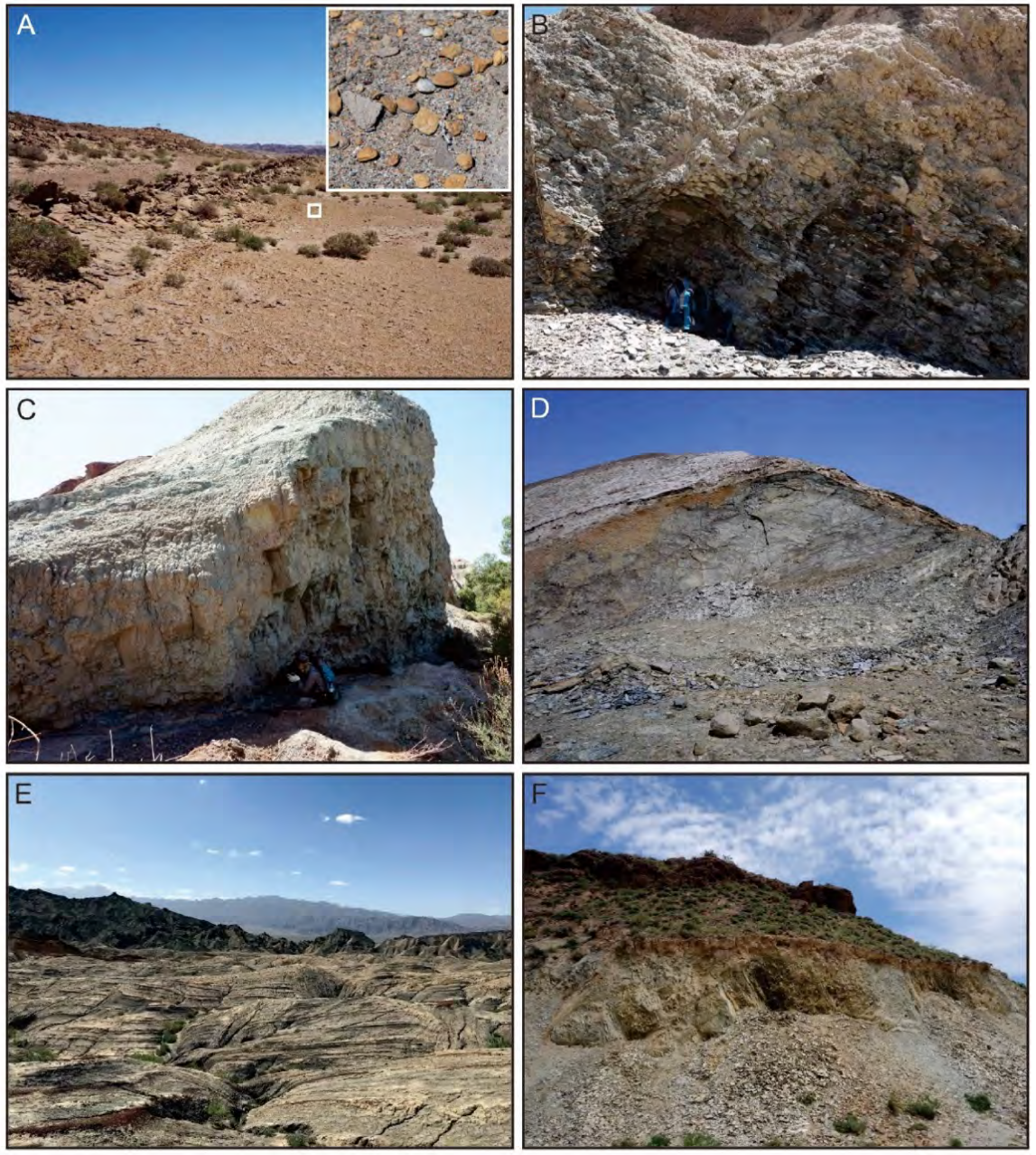
Classic outcrop

Our new field site

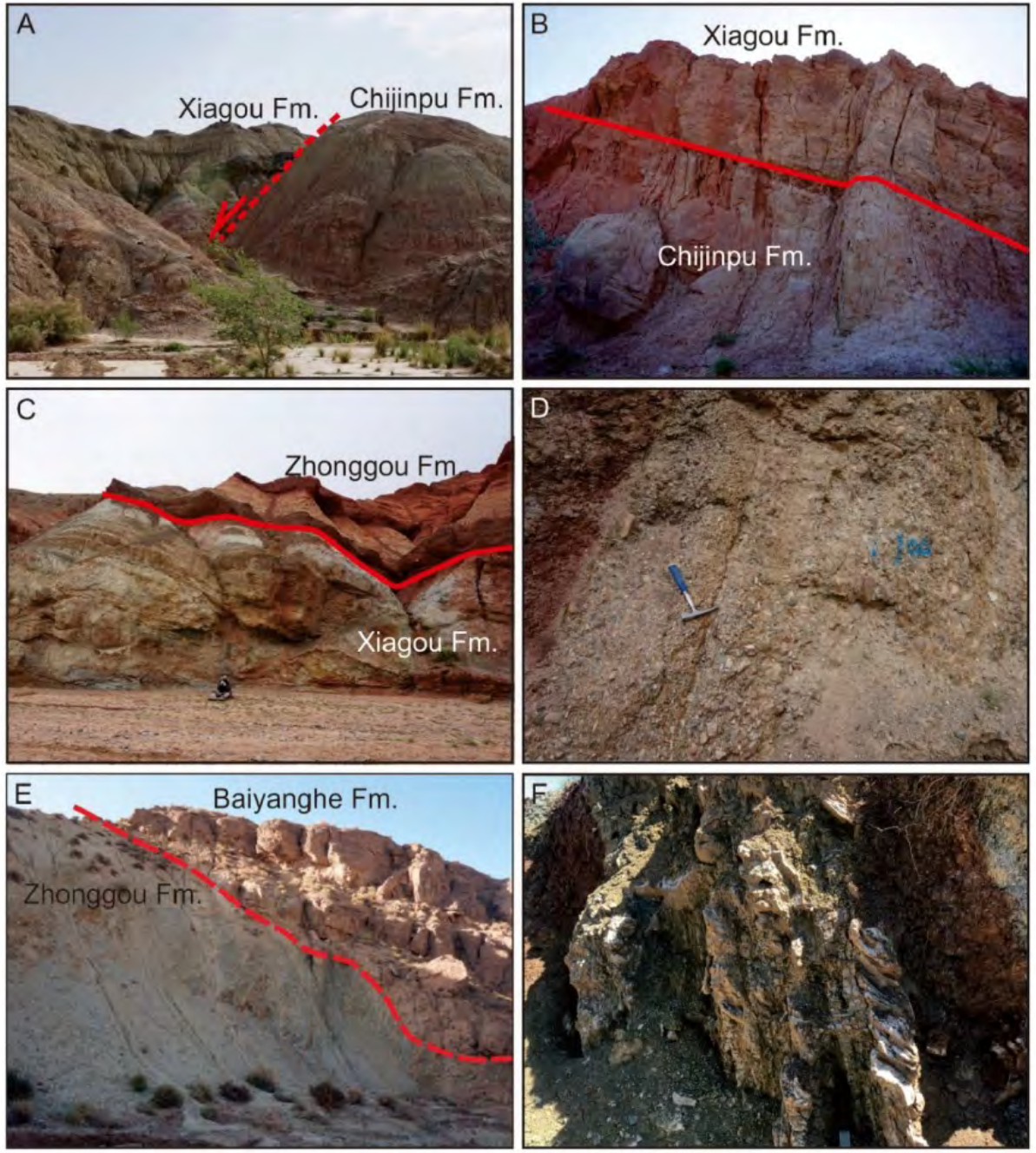
(Chang et al., 2012, 2014, 2017, Palaeo^3; Zheng et al., 2021, ESR; Zhang et al., 2022, Palaeo^3; Zheng et al., 2023, GSAB)

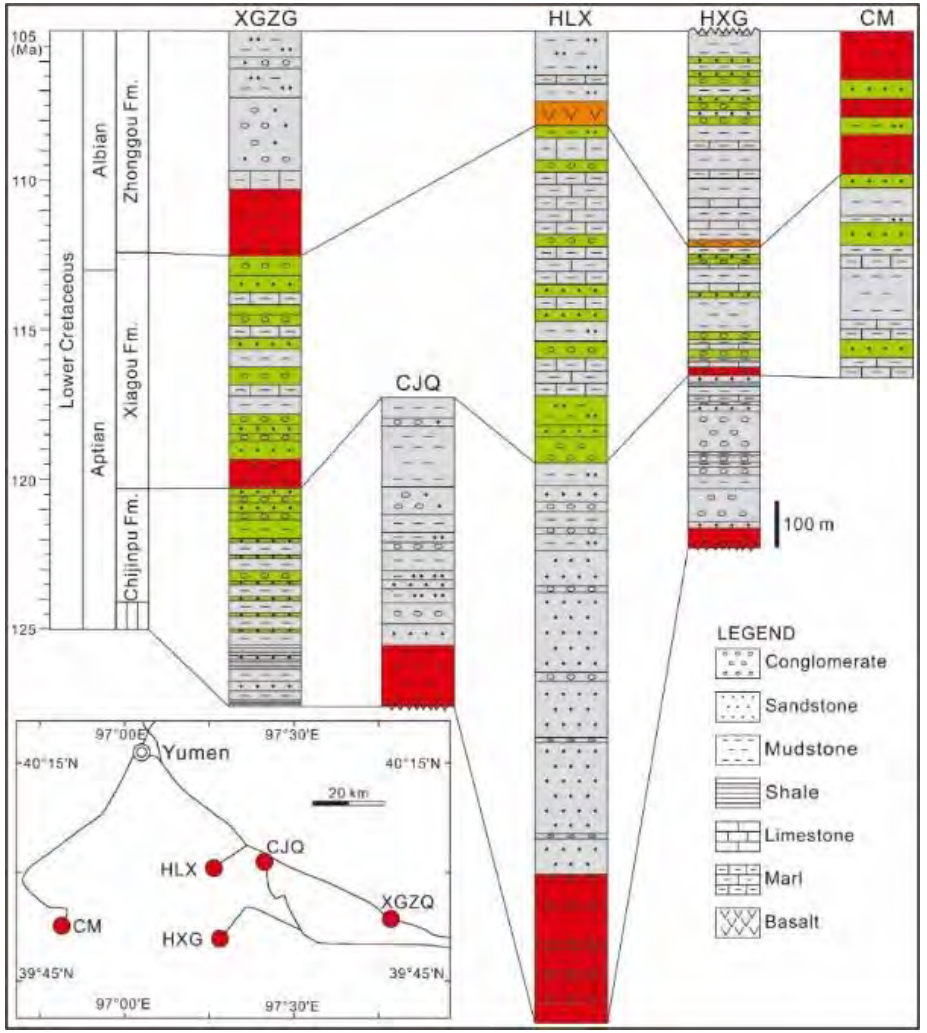
Newly discovered Jehol outcrops in Jiuquan, NW China



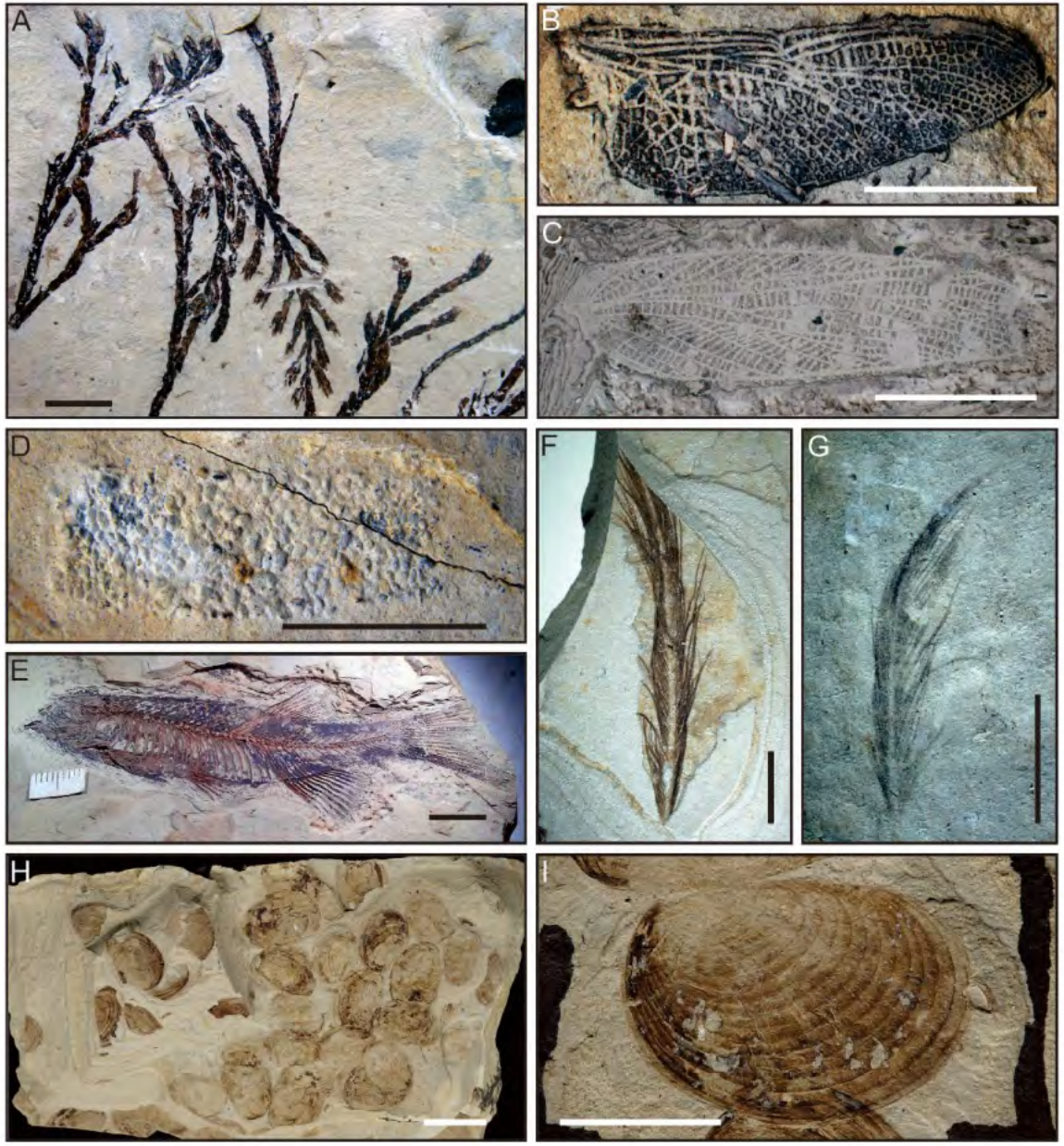


Typical fossil-bearing outcrops in this area



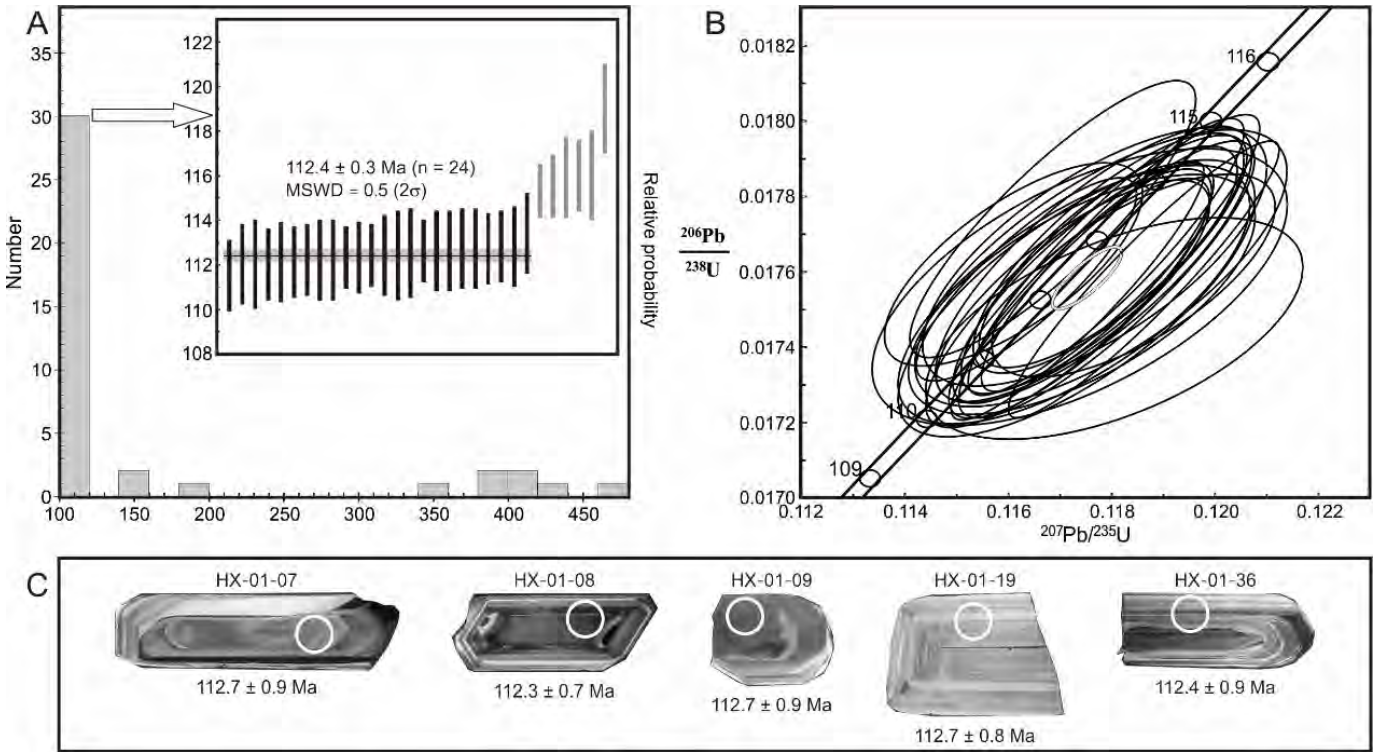


(Zheng et al., 2021, ESR)



Photographs of typical fossils from the upper Zhonggou Formation in the Hanxiagou outcrop of Jiuquan. A. Conifer *Athrotaxites yumenensis*. B. dragonfly *Hemeroscopus baissicus*, hindwings. C. Orthopteran insect *Ashanga jiuquanensis*, forewing. D. Caddisfly case made of sand grains. E. Fish *Qilianichthys hanxiaensis*. F-G. bird feathers. H-I. Clam shrimp *Yanjiestheria yumenensis*. Scale bars, A-C, E and H, 10 mm; D, F-G and I, 5 mm. (Zheng et al., 2021, ESR)

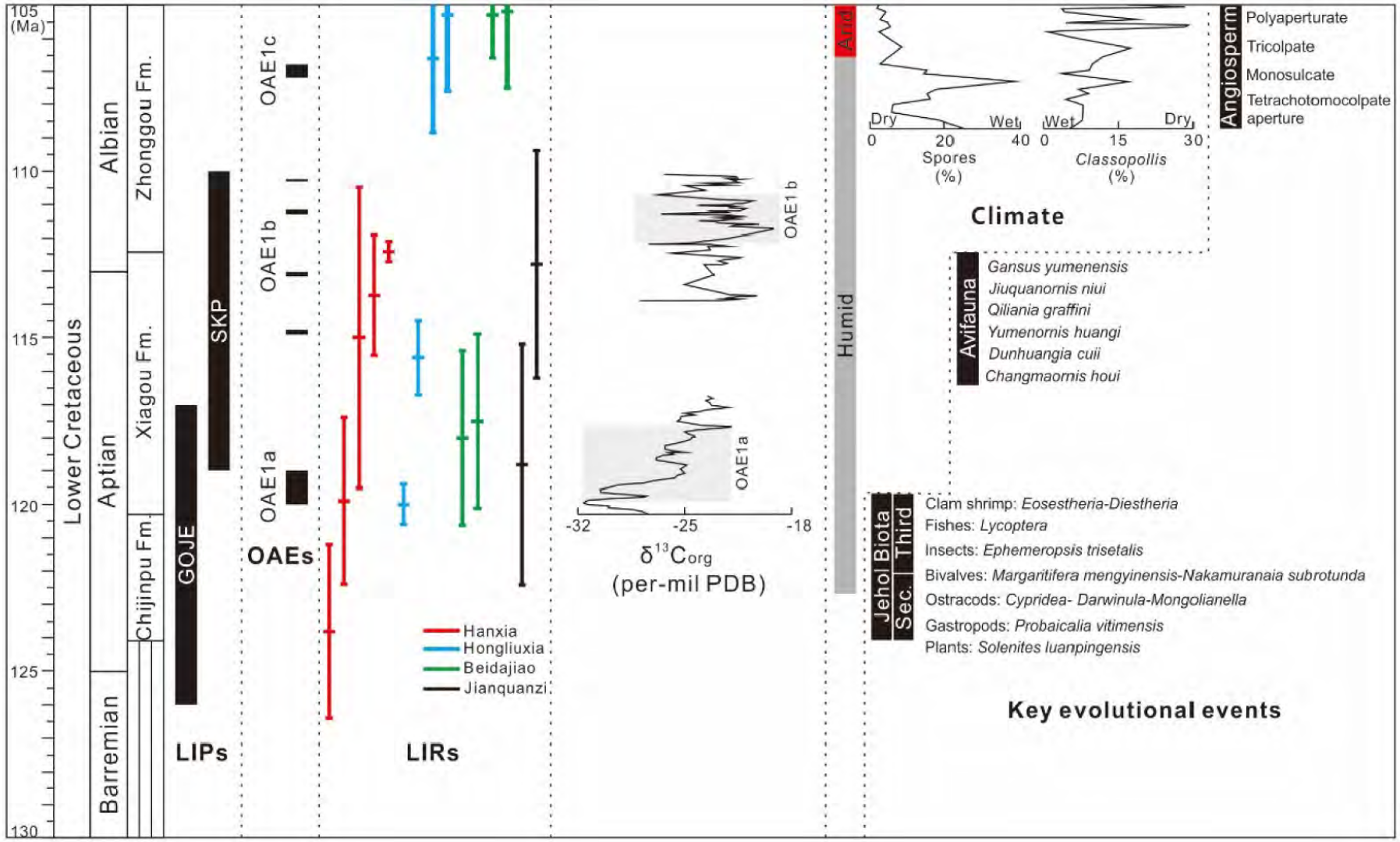
Our U-Pb age results for the Jiuquan outcrop



(Zheng et al., 2021, ESR)

Our study provided a novel age for this newly discovered Jehol outcrop. We provided foundation for the systematic study of the well-preserved Early Cretaceous ecosystem in Jiuquan, allowing to understand correlations between inland and marine environments as recorded in sediments from this critical period.

Link between climate and biological evolution



(Zheng et al., 2021, ESR)

Conclusions

www.sciencephoto.com

1. We established robust age calibrations for fossil beds.

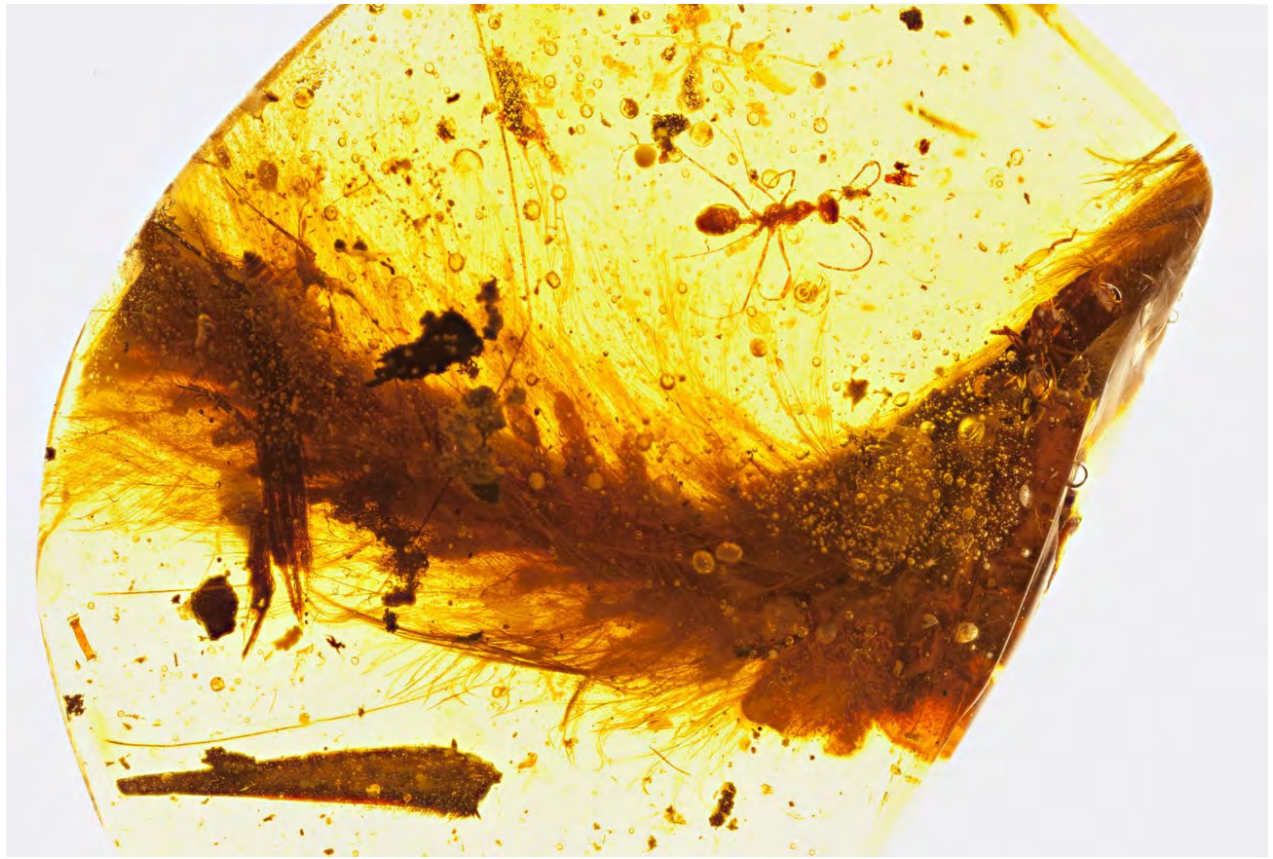
2. Birds, dinosaurs, and feathered dinosaurs co-existed at 125 Ma.

3. We refute the widely accepted hypothesis for the Jehol migration.

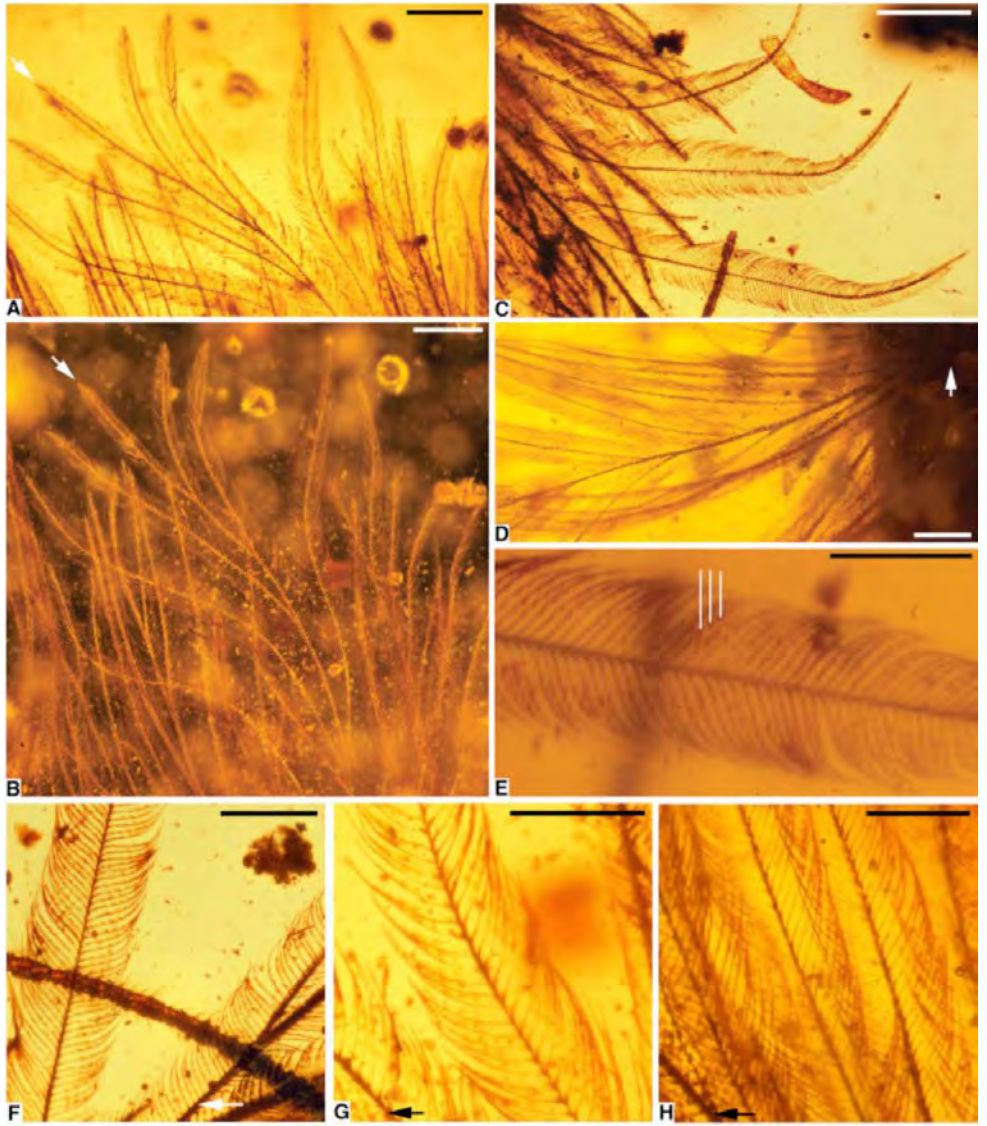
3. Age for fossil-bearing amber from Myanmar

Amber is fossilized plant resin. Burmese amber, sometimes referred to as burmite, is a variety rich in both human and paleontological history.

Well-preserved fossils from Burmese ambers



First dinosaur tail with feathers (Xing et al., 2016, Current Biology)



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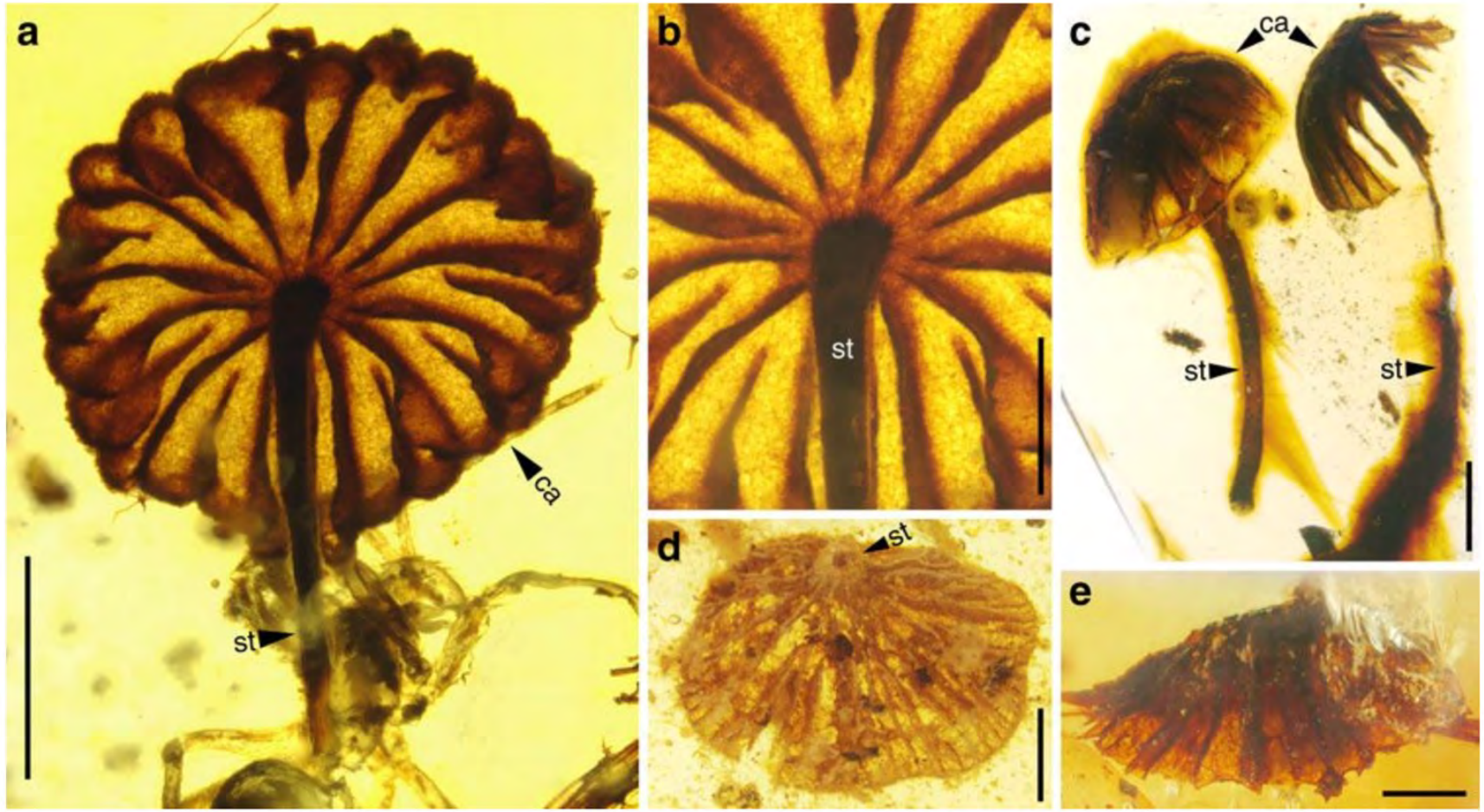
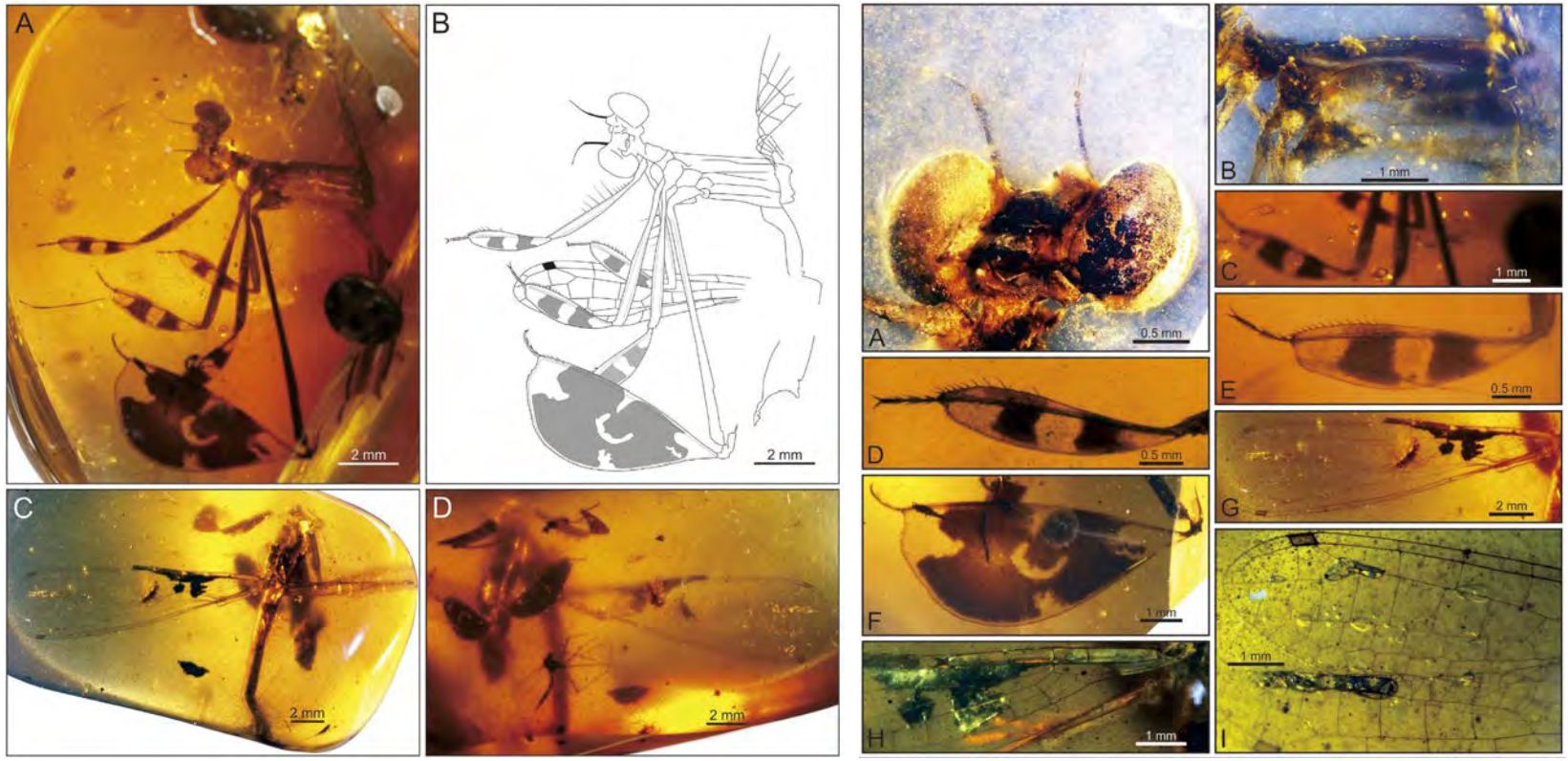


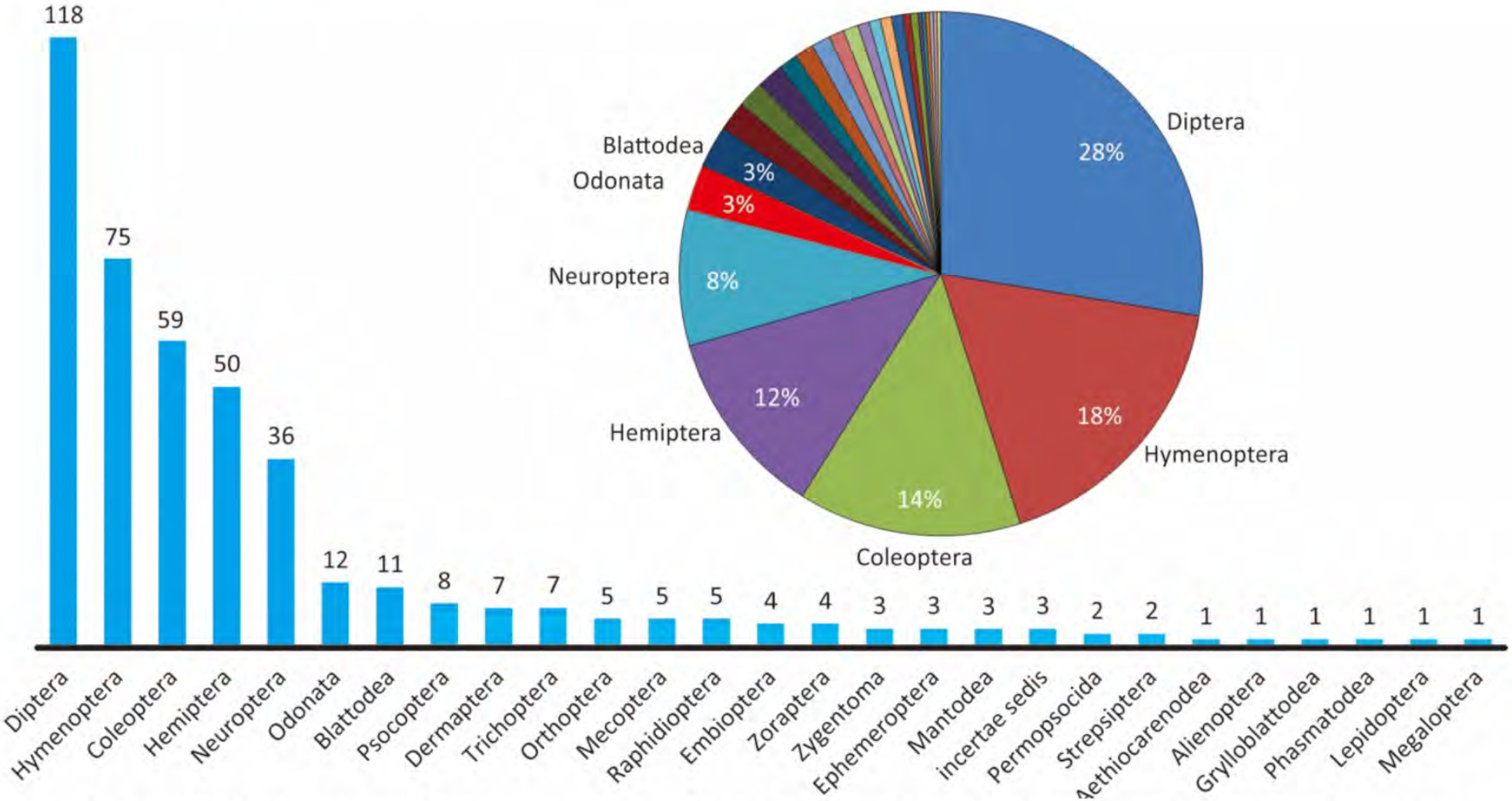
Diverse mushrooms from amber (Cai et al., 2017; Nature Communications)

Well-preserved fossils from Burmese ambers

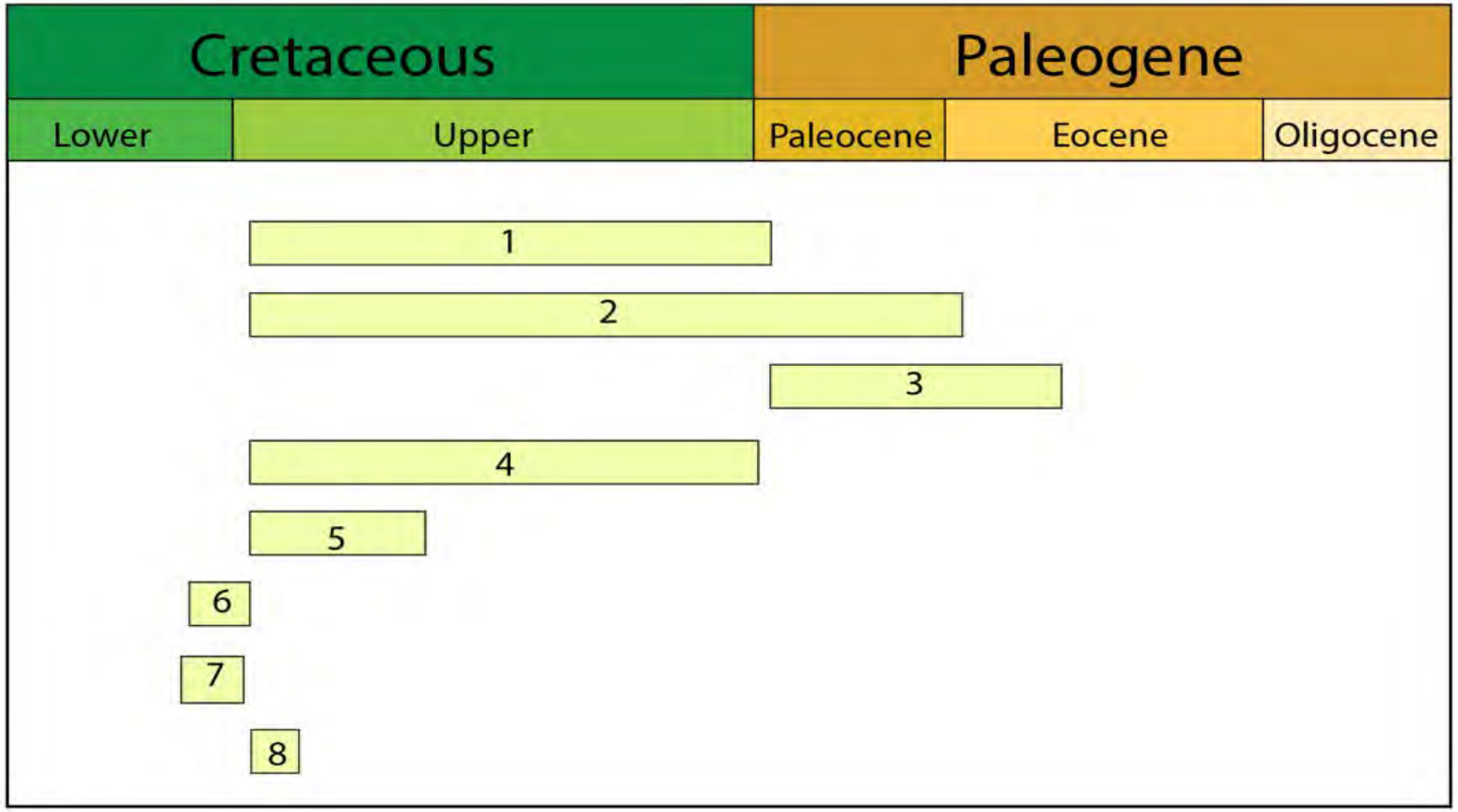


Extreme adaptations for probable visual courtship behavior in a dancing damselfly (Zheng et al., 2016, Scientific Reports)

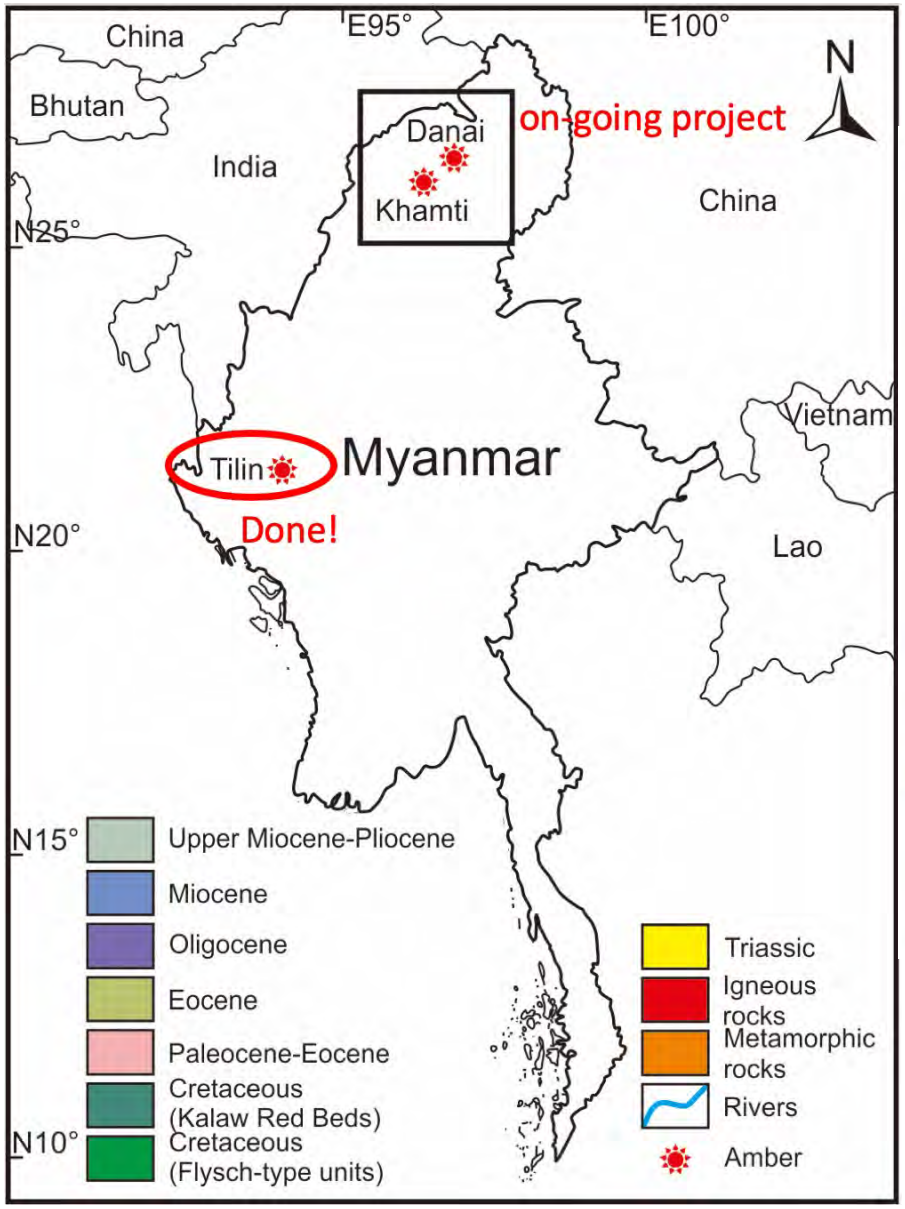
By early 2017, 6 classes, 57 orders, 373 families, 584 genera, and 757 species of anthropods had been discovered from Burmese amber.

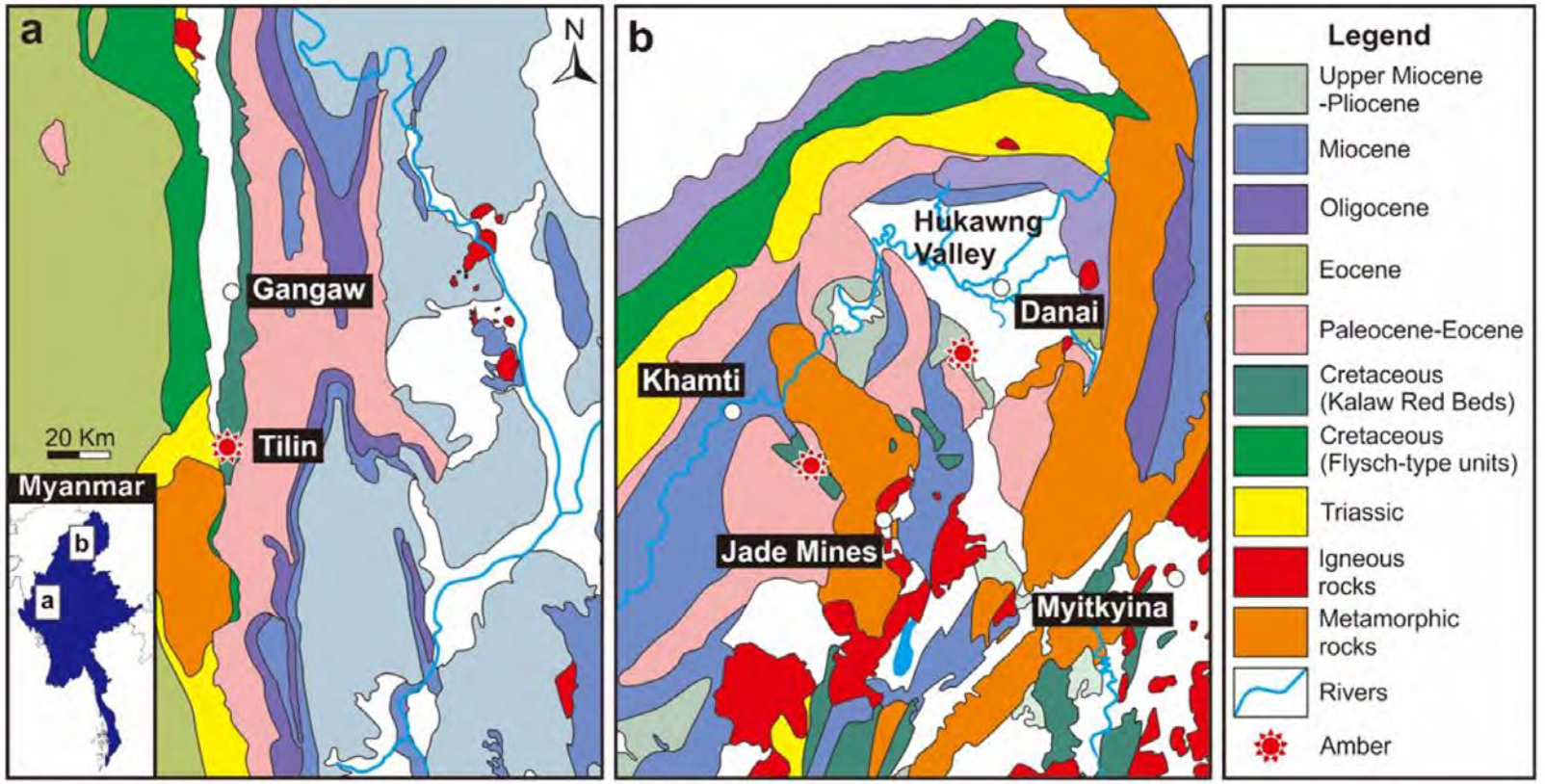


Abundant specimens from numerous insect orders have been reported from Burmese amber (data based on Ross, 2017).



Historical age estimates for Burmese amber. 1. Late Cretaceous (Zherkhin, 1978), 2. Late Cretaceous-Early Tertiary (Rasnitsyn, 1996), 3. Paleocene or early Eocene (Grimaldi et al., 1997), 4. Late Cretaceous (Zherkhin and Ross, 2000), 5. Turonian-Cenomanian (Grimaldi et al., 2002), 6. Upper Albian (Cruicksank and Ko, 2003), 7. Upper Albian (Ross et al., 2010), 8. Cenomanian (Shi et al., 2012).

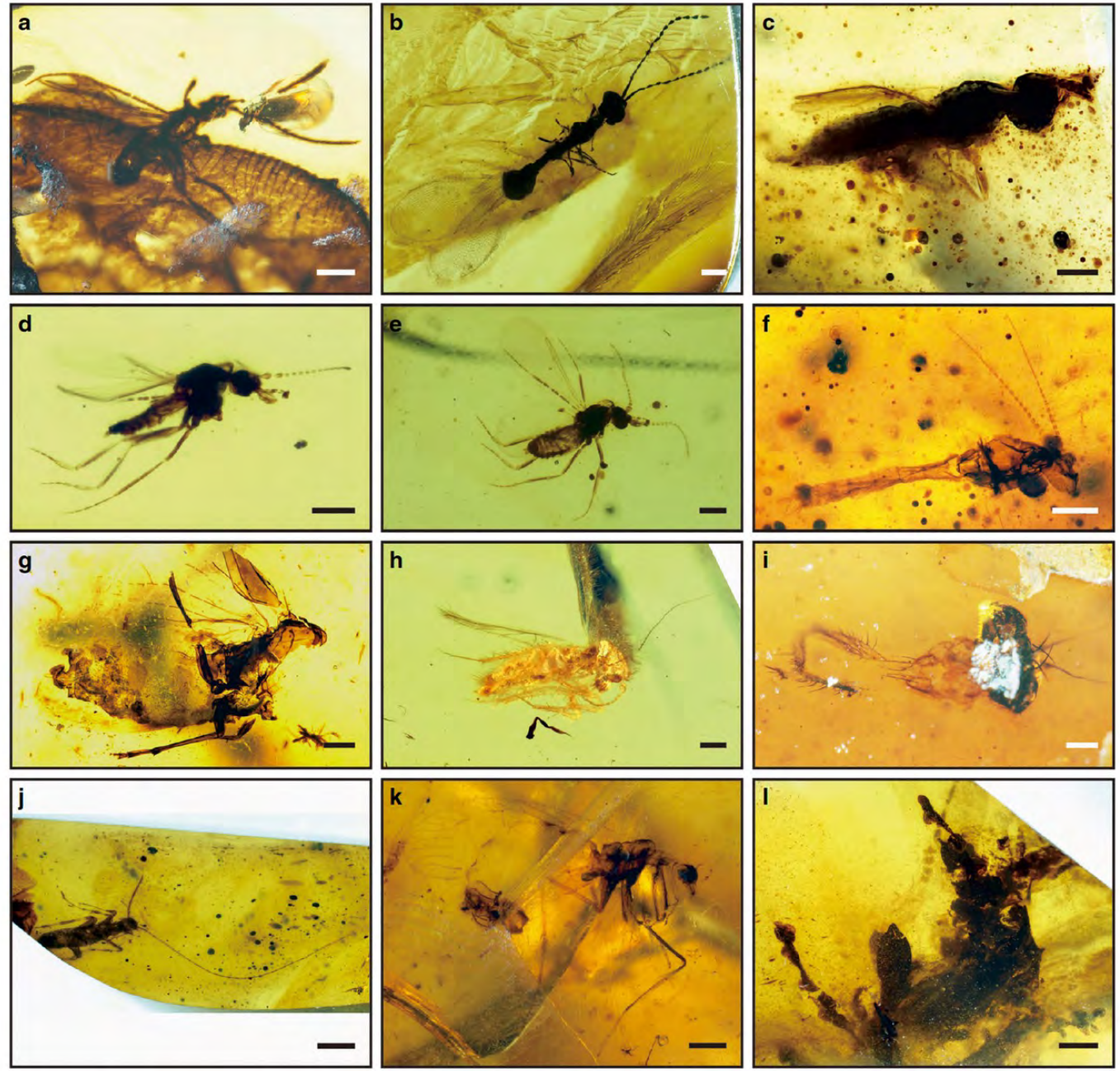




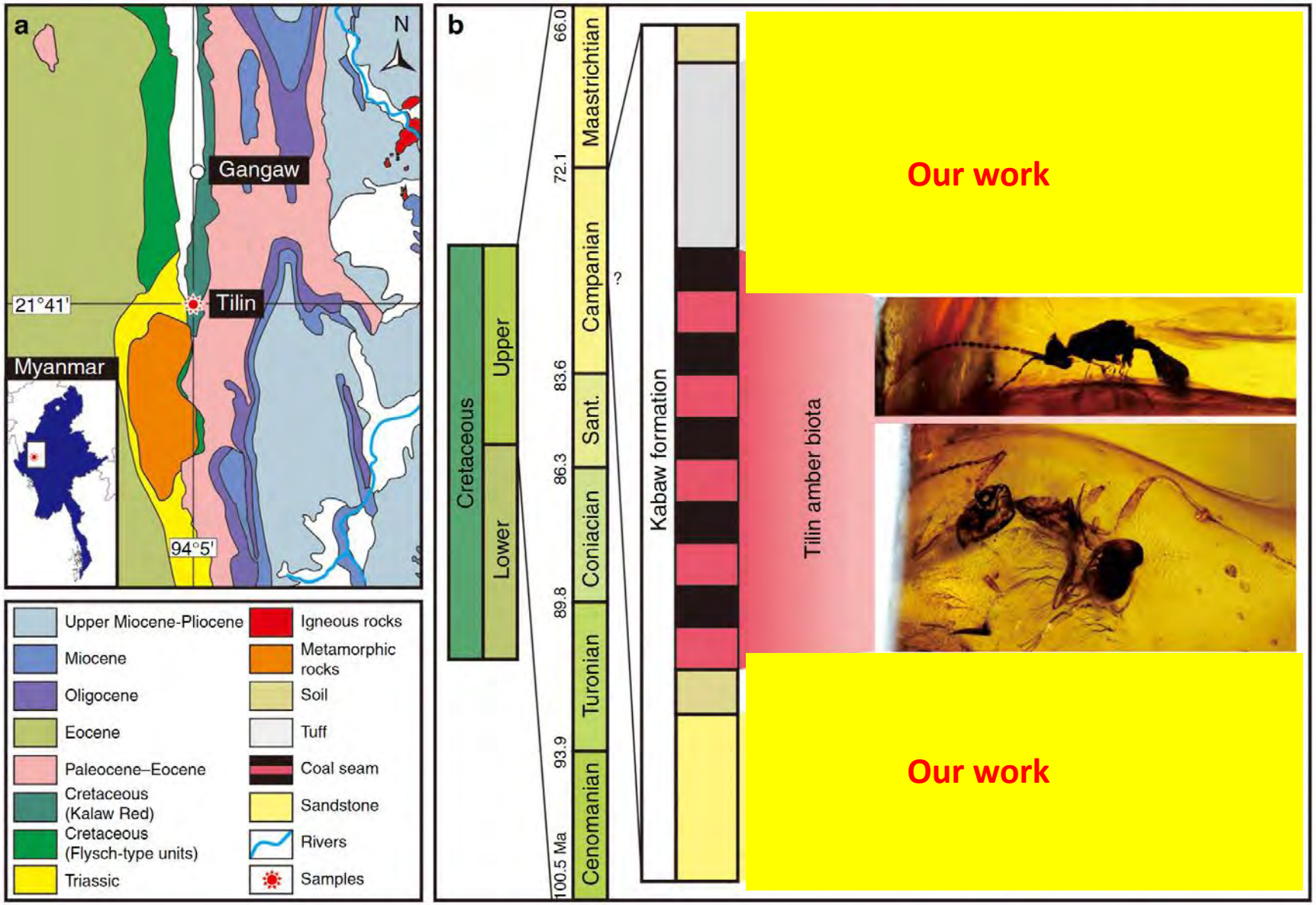
Geological map showing the locations of classic amber outcrops in Central and Northern Myanmar (Zheng et al., 2017, Nature Communications)

Amber outcrops in Tilin, Central Myanmar (Zheng et al., 2017, Nature Communications)

Unpolished amber pieces (photo by D. Zheng)



Typical inclusions in Burmese amber (Zheng et al., 2017, Nature Communications)



Geological and stratigraphic background of Tilin amber (Zheng et al., 2017)

Conclusions

Images provided by Bo Wang from NIGPAS

- We report a unique amber biota from the Upper Cretaceous (~ 72.1 Ma) of Tilin, Central Myanmar.
- The tropical forests were the cradle for diversification of crown-group ants.
- This study has allowed to understand late Cretaceous forest ecosystem in South Asia.