Food and Agriculture Organization of the United Nations

BLACK SOILS INTERNATIONAL NETWORK

Understanding the formation of black soils

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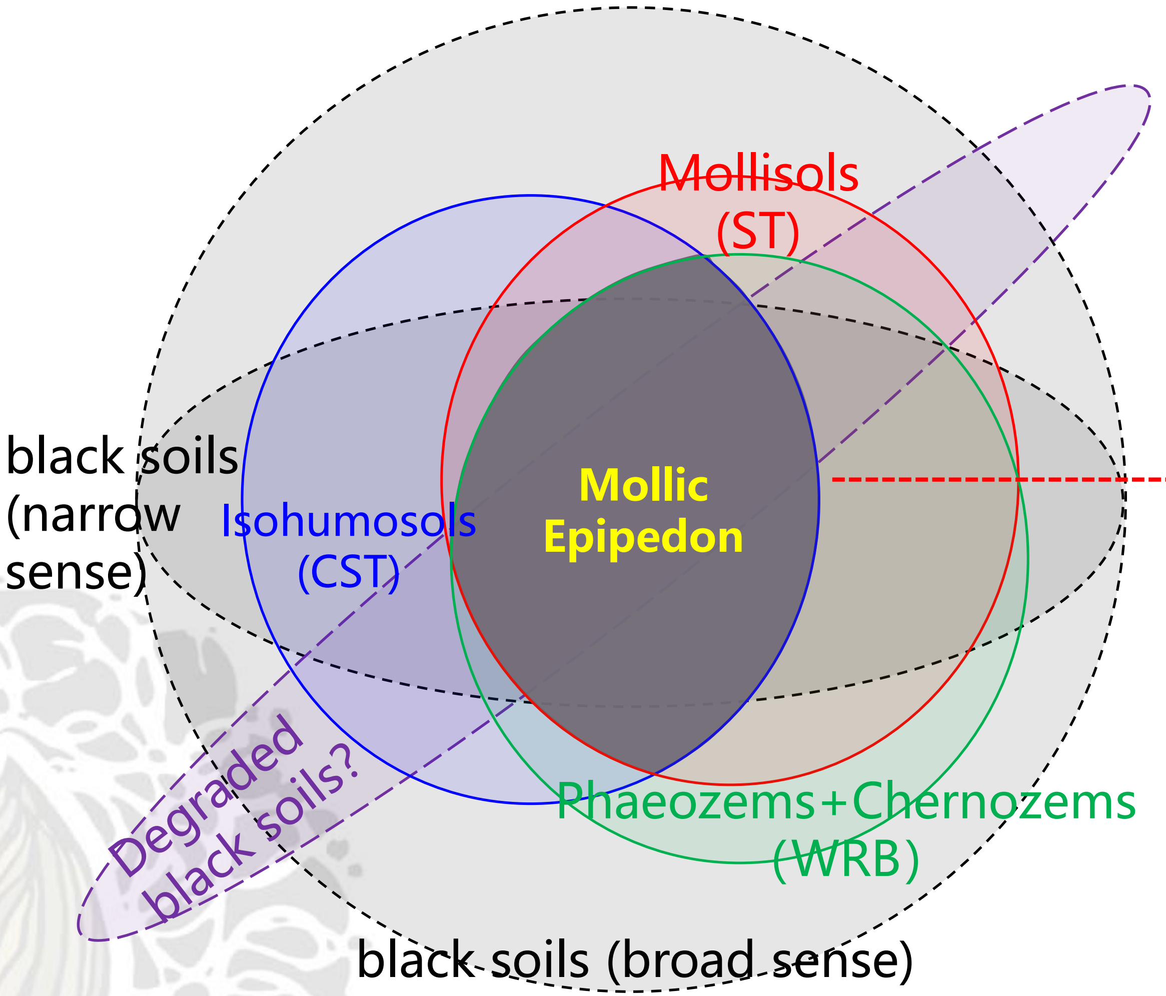
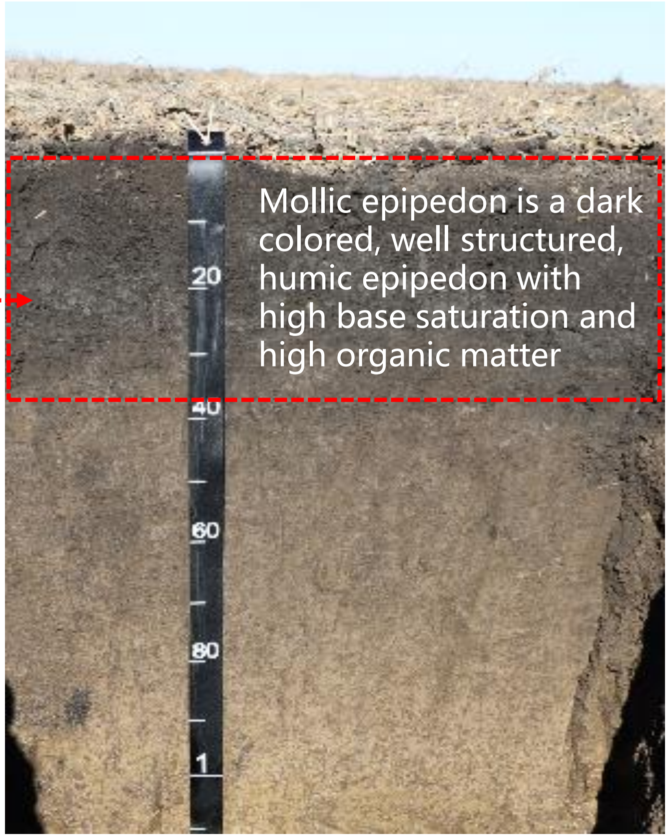
Webinar series
SUSTAINABLE MANAGEMENT OF BLACK SOILS

GLOBAL SOIL PARTNERSHIP

Blacks soils in different classification systems

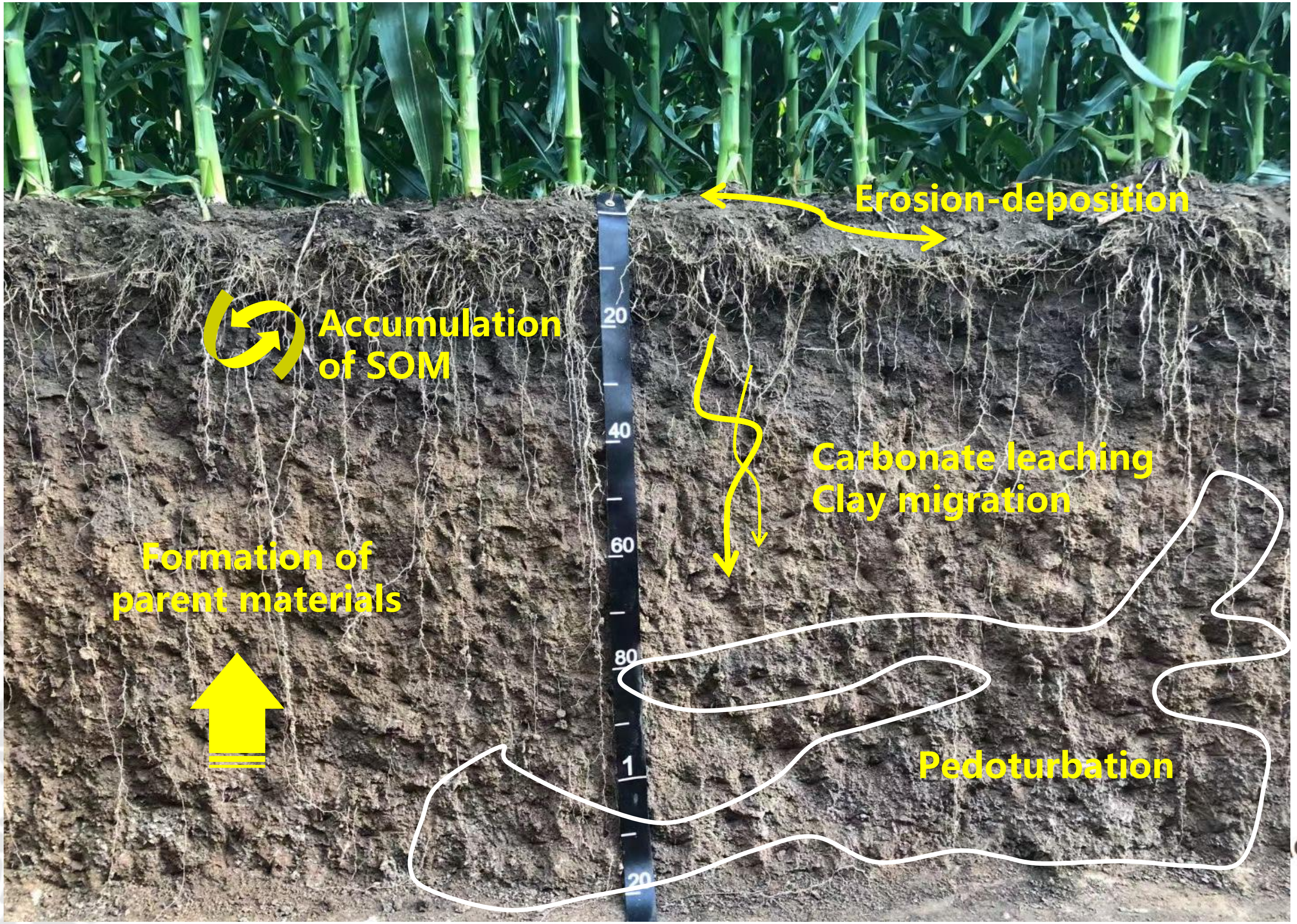


Mollic epipedon is the core of black soils, and the basis for its high fertility



Blacks soils in different classification systems

Key processes in the formation of black soils

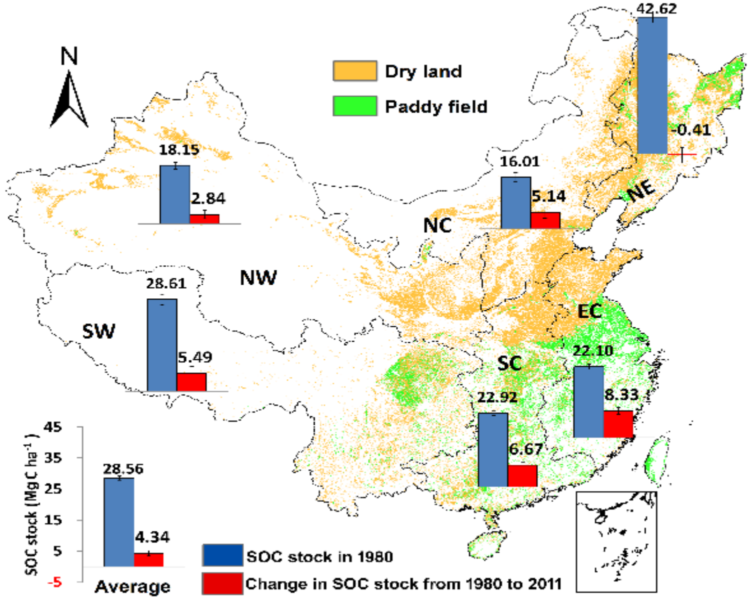


Black soils are under threats

Soil erosion

Two major threats of black soils

Loss of SOM



(Zhao et al., 2018, PNAS)

Other threats

soil compaction

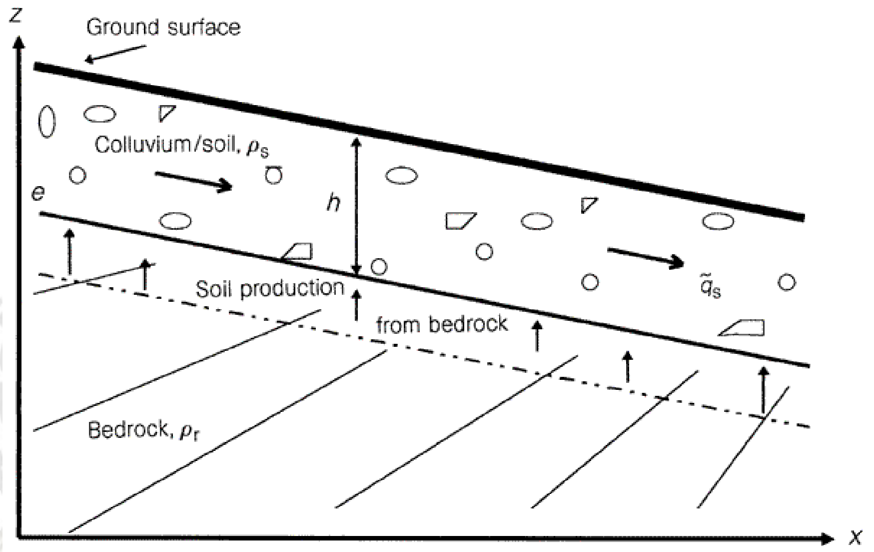
water logging

biodiversity loss

Soil pollution

Sustainability of black soils

The sustainability of black soils depends on the balance between the rates of soil loss and the rates of soil formation.



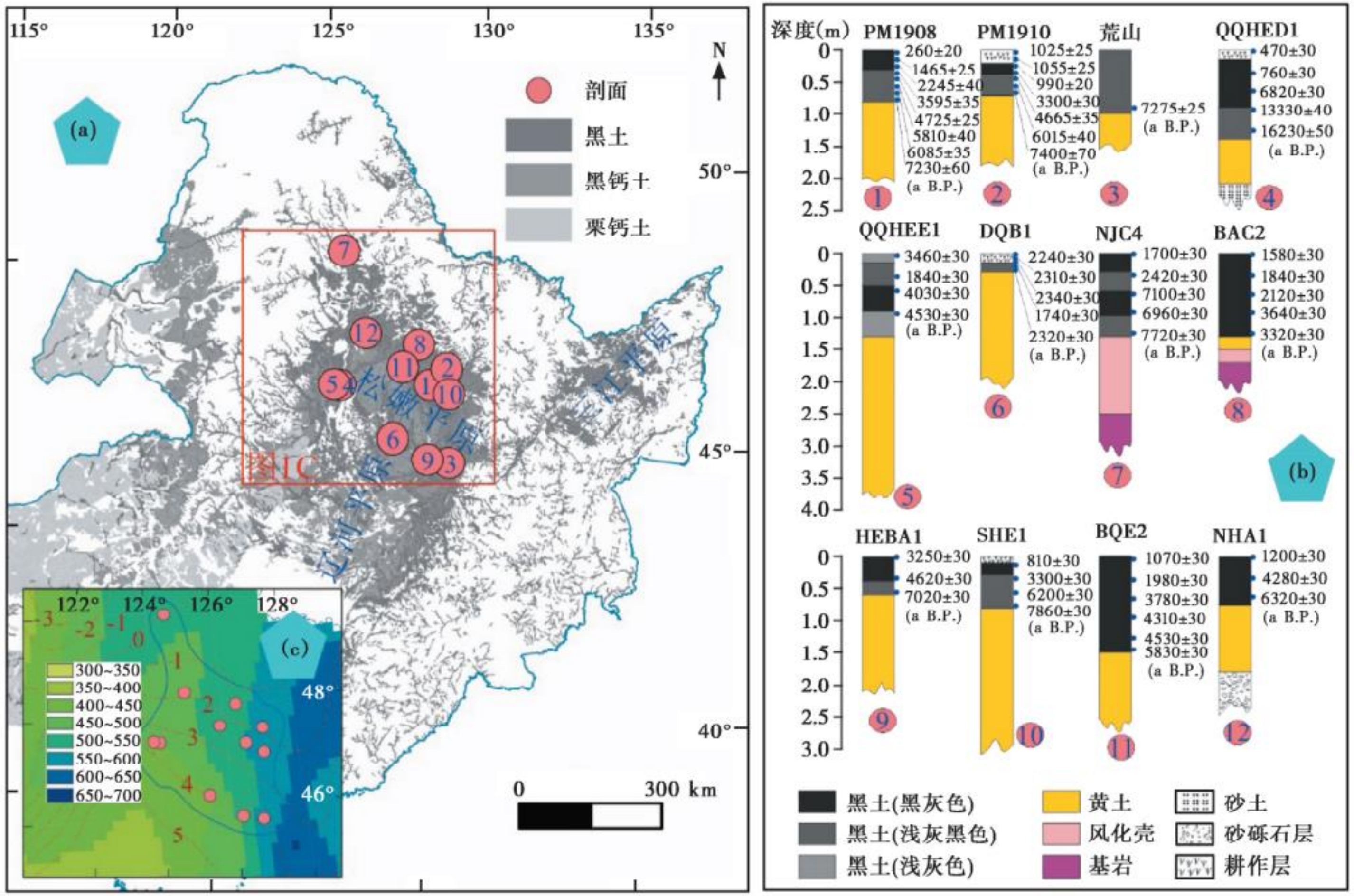
(Heimsath et al., 1997, Nature)

Soil thickness = soil formation (e.g., rock weathering, exogenous input) – soil loss (e.g., erosion, denudation)

- **Black soils loss at average rates 0.2-0.3cm yr^{-1}**
  (Zhang & Liu, 2020)
- **How long does it take to form 1cm black soils?**
  - 20-40 yrs (Lin et al., 1999)
  - ~100 yrs (Song et. al., 2020)
  - 120-400 yrs (Yan & Tang, 2005)
  - 300-400 yrs (Liu et al., 2003)

Knowledge on the rates of black soil formation is limited by the lack of precise soil chronology!

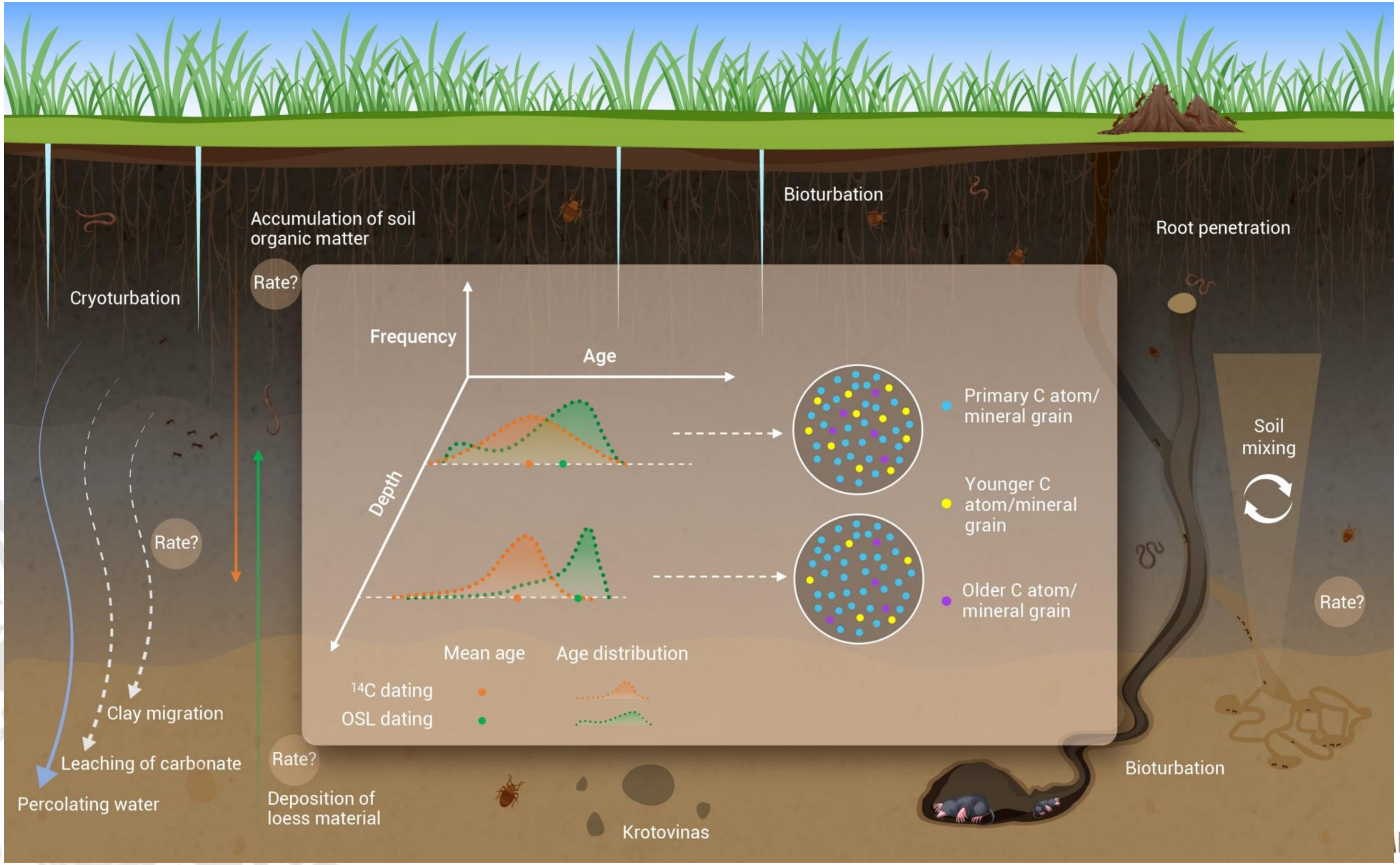
Previous knowledge on black soil ages



(Cui et al., 2021)

- Black soils in Northeast China formed during **early-mid Holocene**, based on ^{14}C dating of SOM (Cui et al., 2021)
- Results from other regions of the world (e.g., Mid-USA, Europe, Argentina) also point to a **Holocene age** of black soils. Only in rare cases with an older age.

An open and complex system – dating soil is a challenge



Source of younger C:
① continuum nature
② rooting
③ leaching of DOC
④ pedoturbation

Source of older C:
① inherent
② erosion-deposition

Source of younger grain:
① pedoturbation
② clay migration

Source of older grain:
① erosion-deposition
② bioturbation
③ insufficient bleaching

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Zhang GL, Long H, Yang F. Understanding the formation time of black soils. The Innovation Geoscience. 2023

Two protocols to determine black soil ages

Protocol 1

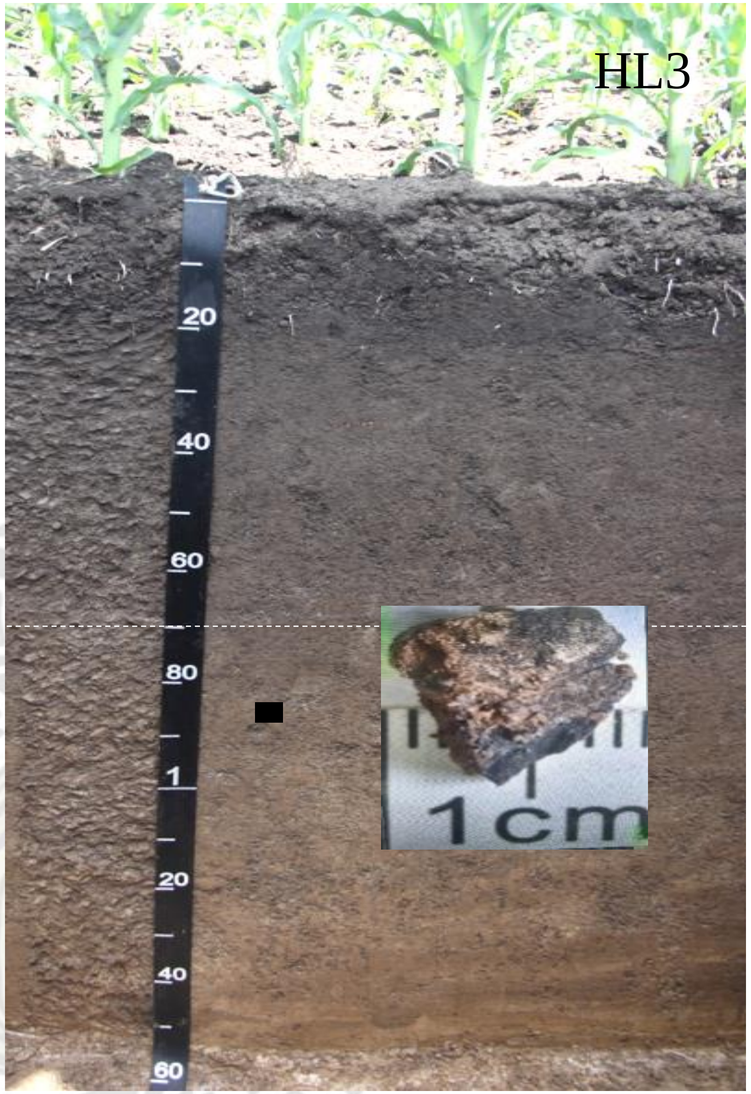
To find closed/ semi-closed systems,
such as charcoal, or buried soils

Protocol 2

To identify signals of primary age and pedoturbation,
fine-grained soil dating, such as single-grain OSL dating and ^{14}C dating of SOM at molecular level

Study 1

Upper age limit for black soils – charcoal



- A piece of woody charcoal beneath the Mollic layer aged 16.9 ka. a BP, setting the upper age limit of black soils in northeast China.
- It could be forest landscape prior to the presence of black soils

		^{14}C age
	charcoal	16897±161 a BP
85cm	SOM	12742±19 a BP
	Humin	12992±100 a BP
	Humic acid	15870±150 a BP

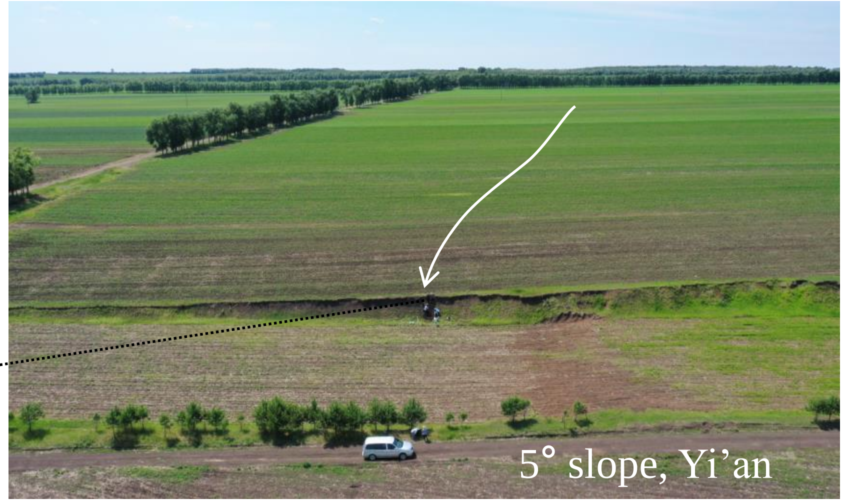
Mollisols did not form at the time (16.9 ka BP) of the formation of the charcoal

Study 1

Lower age limit for black soils – buried mollic layer

Buried mollic layer

- Buried Mollic layer, fast erosion – deposition protect SOM from deposition
- ^{14}C age of the buried layer = C age prior to burial + time elapse since the burial



^{14}C age

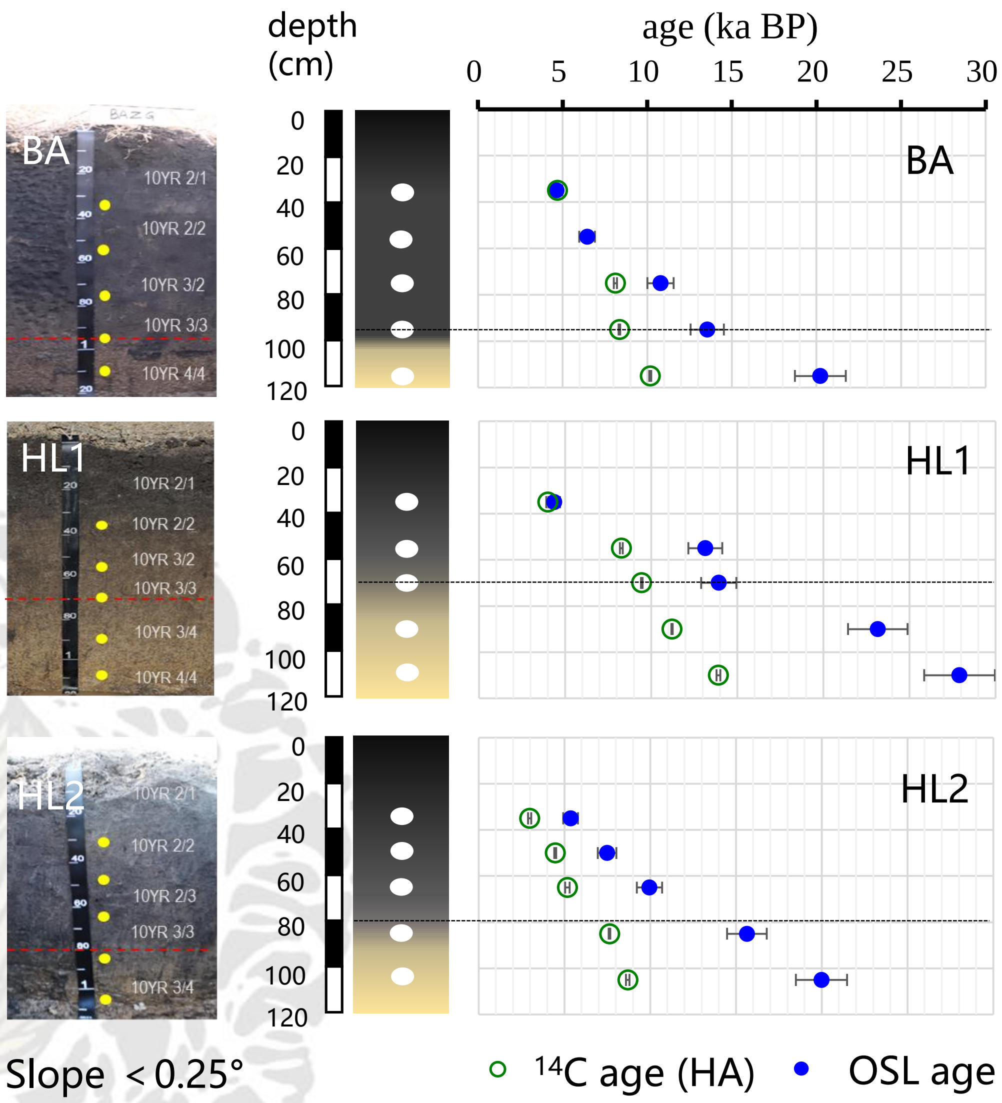
	SOM	11873±129 a BP
215cm	Humin	12287± a BP
	Humic acid	12548± a BP
	SOM	11835± a BP
275cm	Humin	12571± a BP
	Humic acid	12071± a BP

Well-developed black soils existed prior to 12.6 ka BP

Thus, black soils in northeast China started to form between 16.9-12.6 ka BP.

Ages discrepancies between ^{14}C and OSL dating

^{14}C and OSL dating of three soils from flat terrain



Lower boundary of mollic layers

^{14}C ages
~ 7-9 ka BP

OSL ages
~ 13.5-14 ka BP

- OSL ages are much older than ^{14}C ages, especially in deeper soils.
- The OSL ages at the bottom of the mollic layer 13.5-14 ka BP, agree well with aforementioned results.

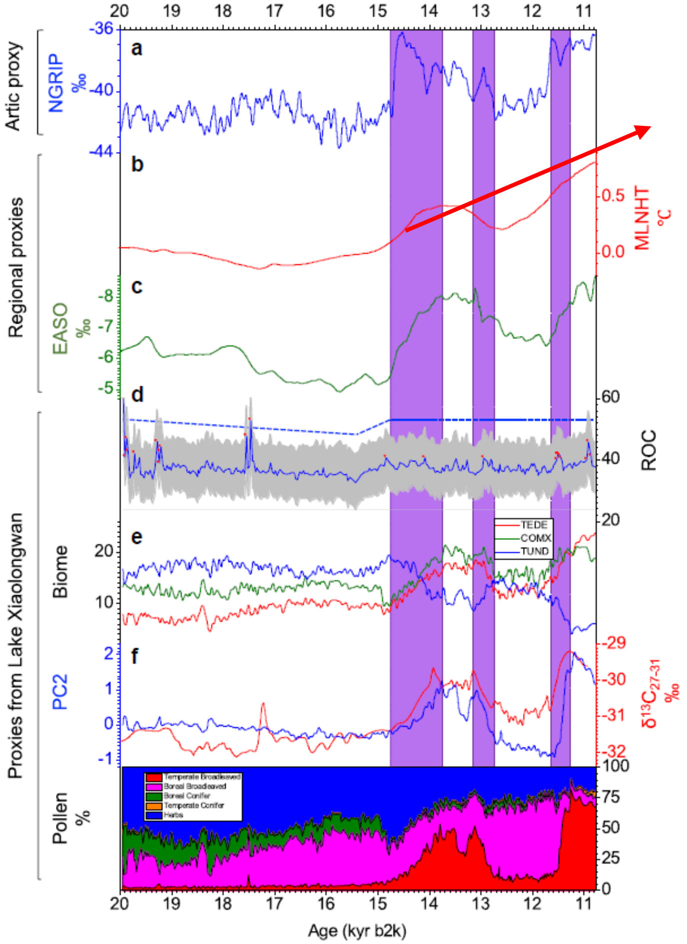
Bølling-Allerød warm period (14.7~12.7 ka BP)

Previous ^{14}C dating of SOM may have underestimated the age of black soils.

- Contamination by younger C from roots exudates, DOC leaching, pedoturbation…

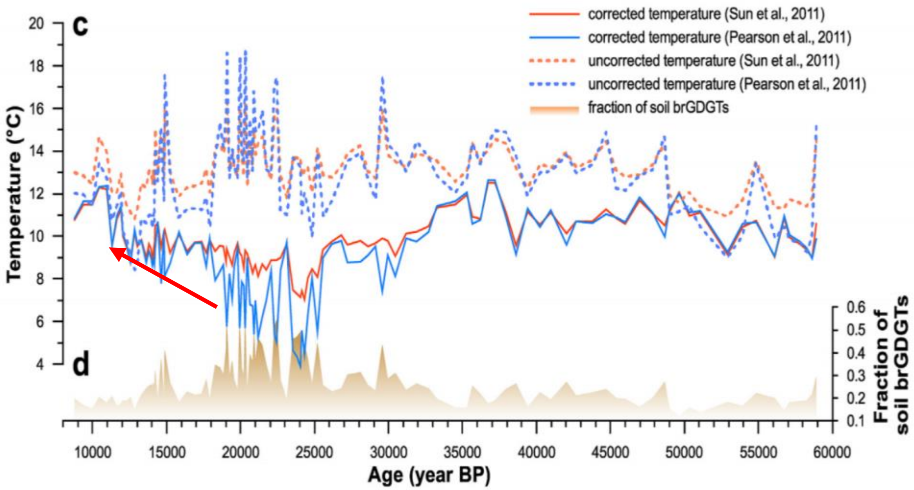
Study 1

Favorable environment for black soils formation



Vegetation expand in response to abrupt warming during the last deglaciation *(Xu et al., 2023)*

Temperature raised since 20 ka indicated by GDGT *(Zhu et al., 2021)*



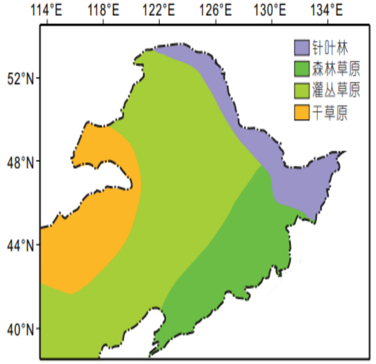


图 15 末次盛冰期东北地区植被格局

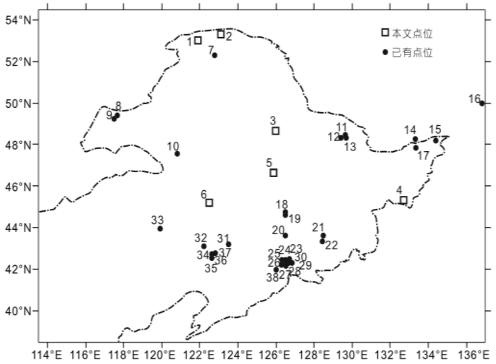


图 14 东北地区末次盛冰期以来花粉资料点分布

Intensive grassland expansion ~18 ka B.P. *(Zhu et al., 2019)*

- Climate is favorable for black soil formation prior to the Holocene

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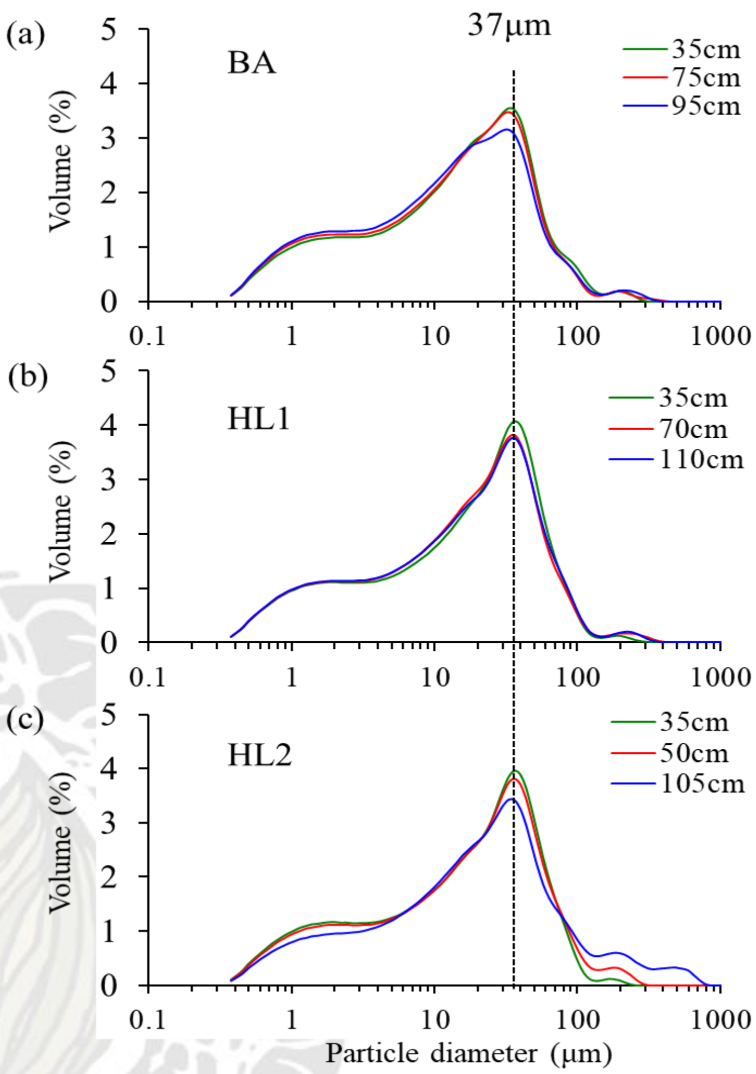
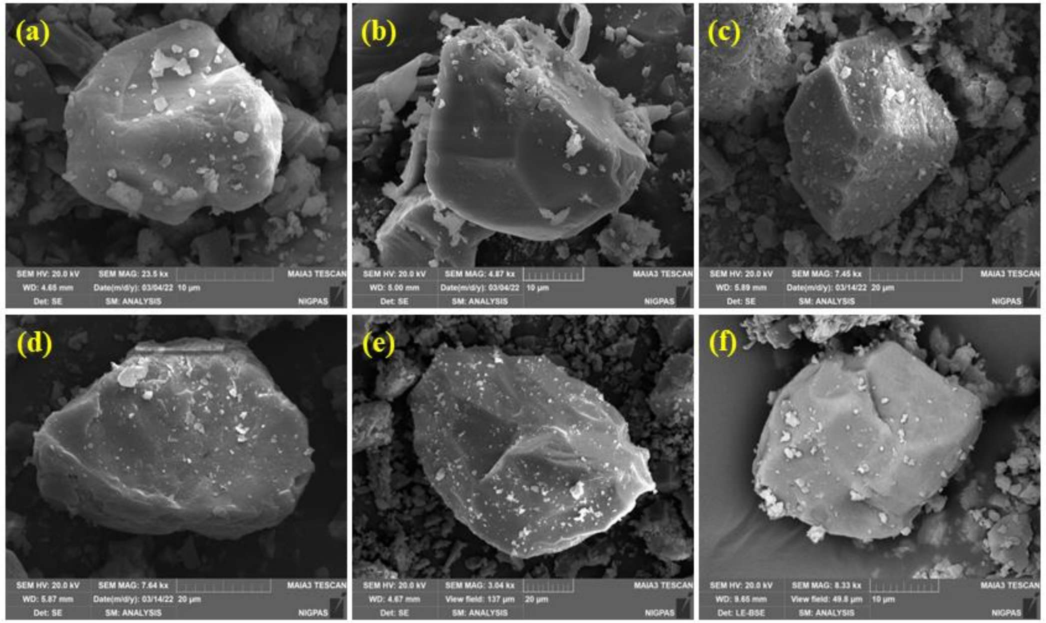
Dust as a major source for parent material of black soils



Particle-size distribution of quartz

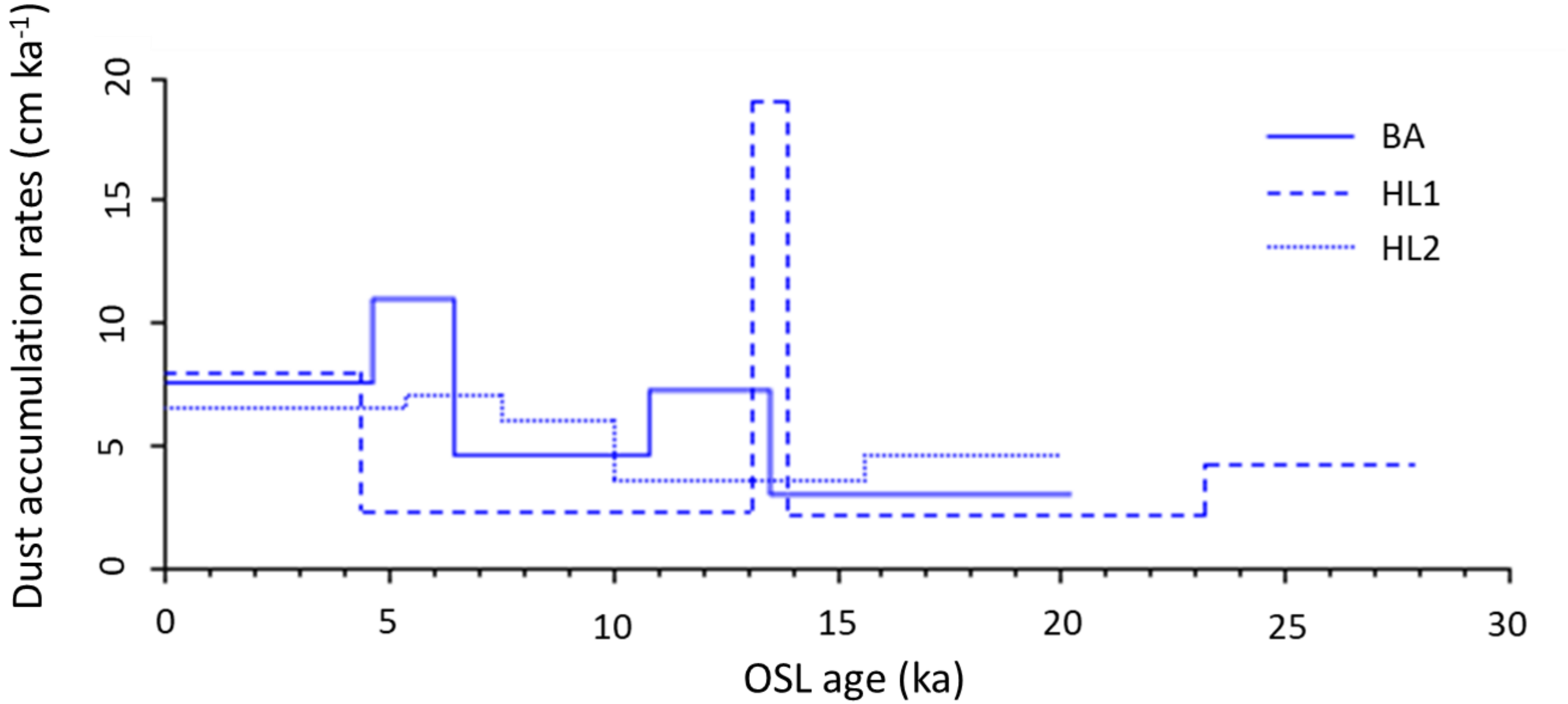


- The surface of the quartz particles shows the mechanical impact characteristics typically generated during the wind transport

- The primary peak at ~37μm was identical with typical loess, suggesting their aolian origin.

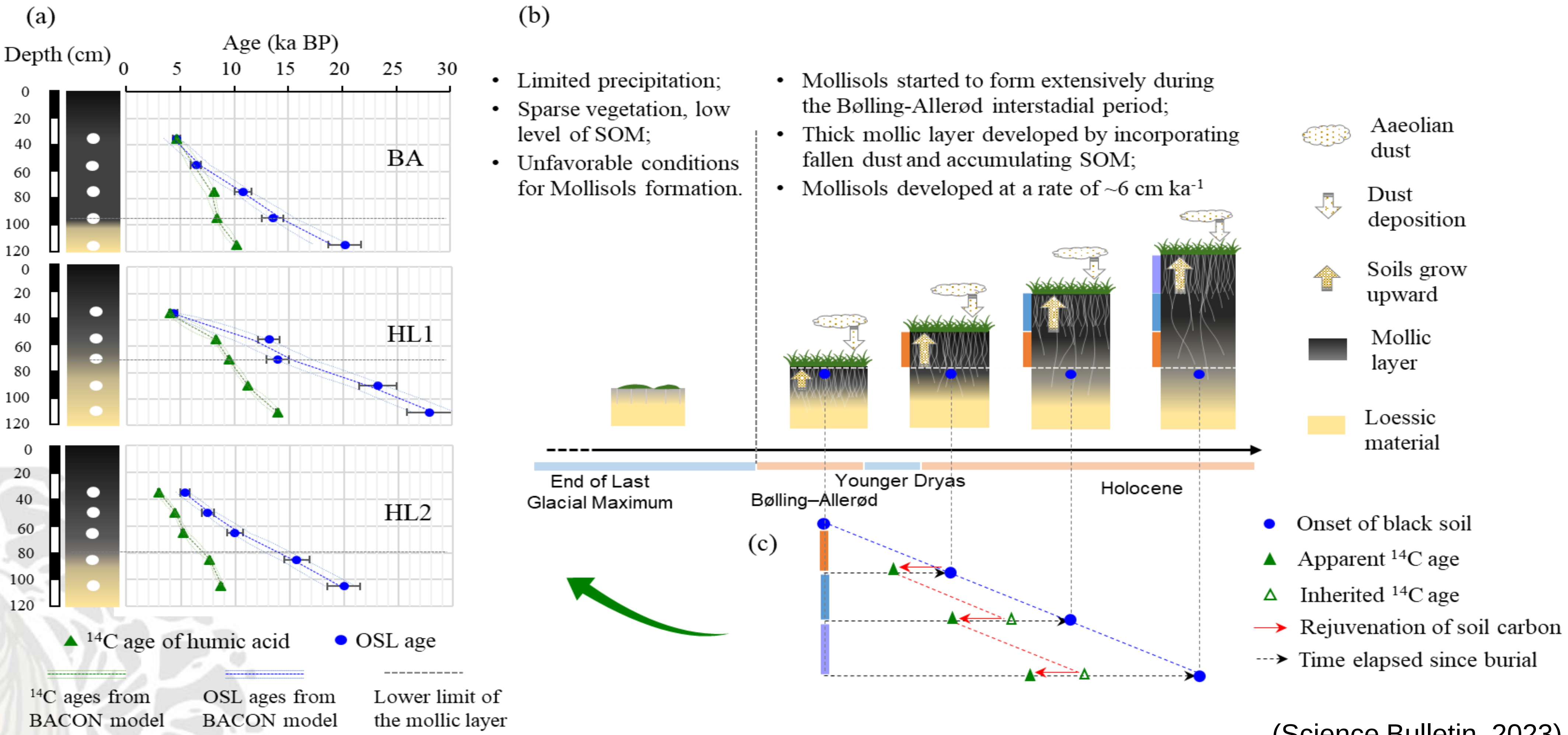
Study 1

Variations in rates for dust accumulation



- Based on the depth-OSL ages, dust accumulates continuously since glacial period
- Black soils formed (dust accumulated since B-A period) at a rate of ~6 cm ka^{-1}

An accretionary pedogenic model for black soil formation



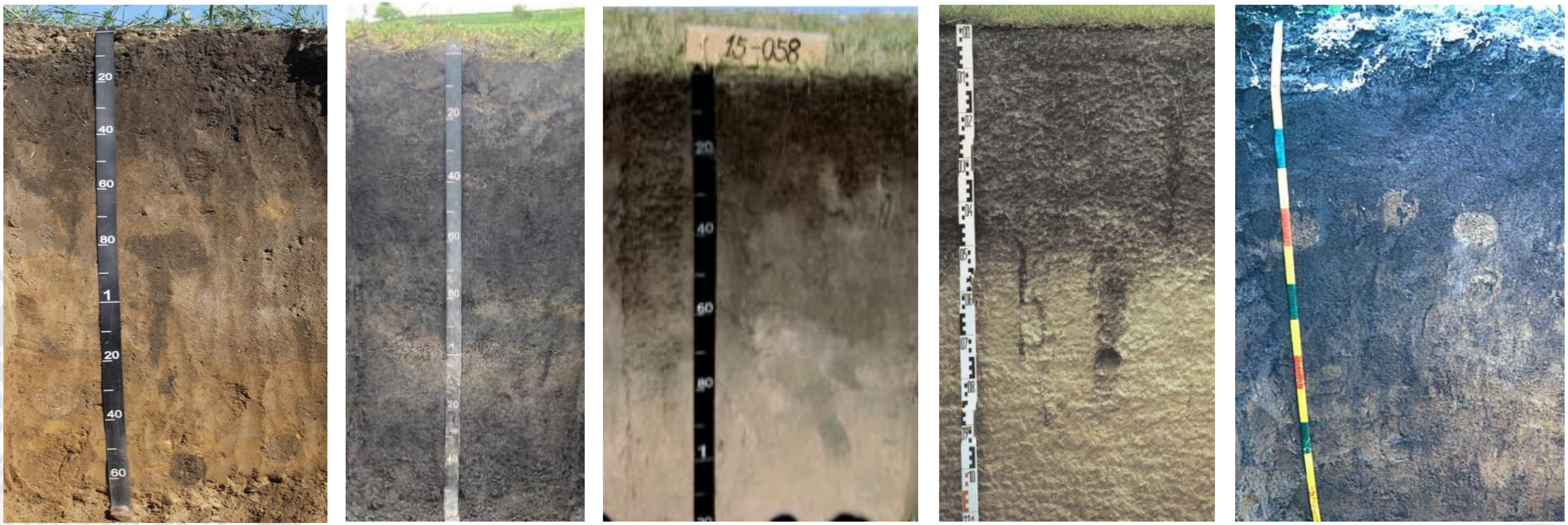
(Science Bulletin, 2023)

- Black soils grow upwards by incorporating the continuous dust inputs and the accumulation of SOM.
- The model explains that the ^{14}C ages are progressively younger than OSL ages with increasing depth.

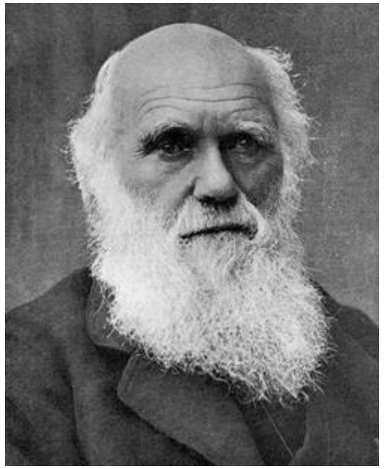
Study 2

Pedoturbation and black soils formation

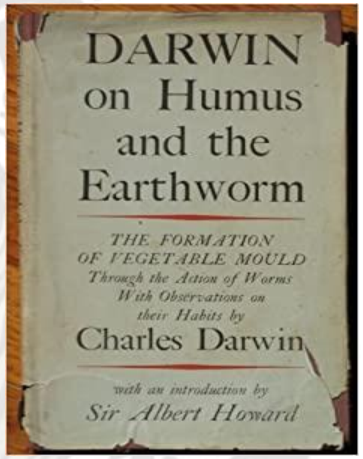
The widespread Krotovinas (rodents burrow) indicate the intense bioturbation in black soils

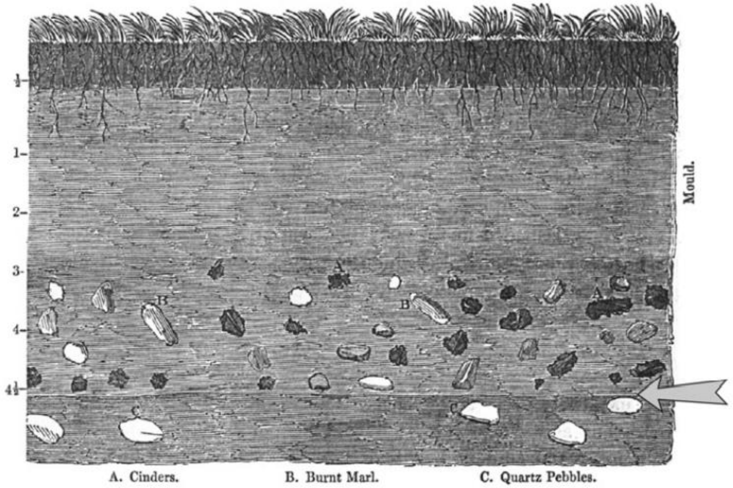


Pedoturbation and black soils formation



Charles Darwin





Sketch of black soils by Darwin (1840s)

Based on observations, Darwin proposed that bioturbation is an important factor in forming soils

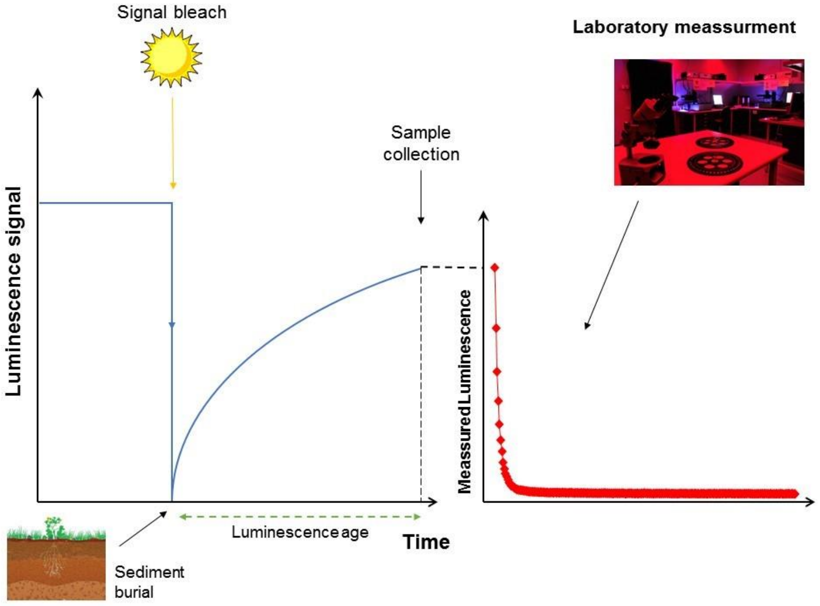
How deep can bioturbation reach?
Relations between intensity and depth?

Krotovinas in black soils

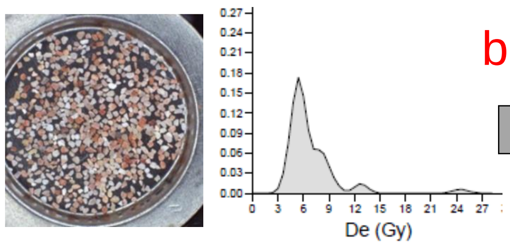
How to quantify pedoturbation/ soil mixing?

Single-grain luminescence as a bioturbation tracer

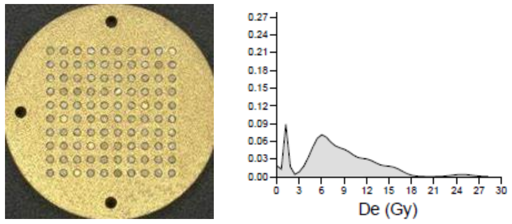
Optically Stimulated Luminescence (OSL) dating records the time elapsed since the last exposure to sunlight of soils (quartz or feldspar)



$$\text{Age (ka)} = \frac{\text{Measured amount of } \textit{luminescence} \text{ in a grain}}{\text{The radiation received by the grain from the surroundings}}$$



Technical breakthrough

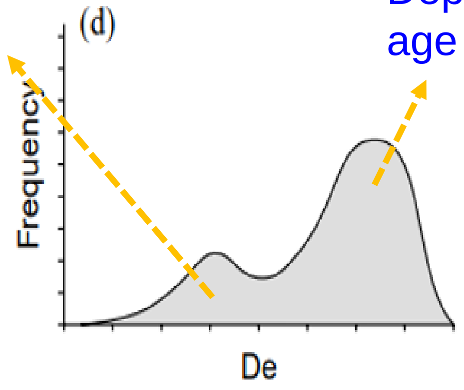


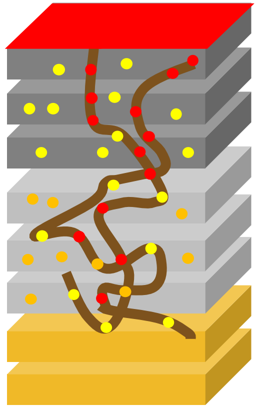
Traditional Multiple-grain dating

Single-grain technique

Pedoturbational signal

Depositional age

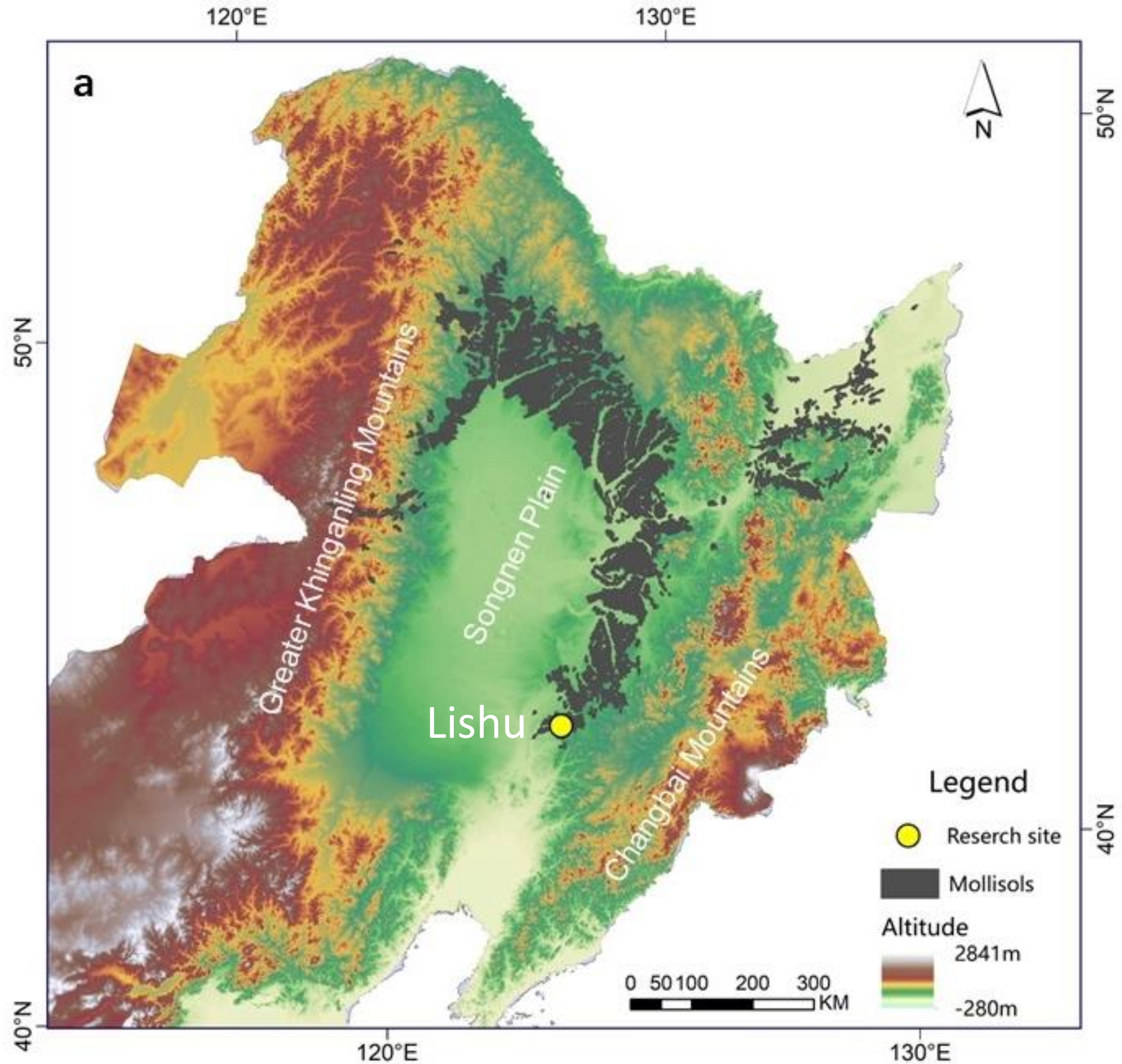




0-age particle

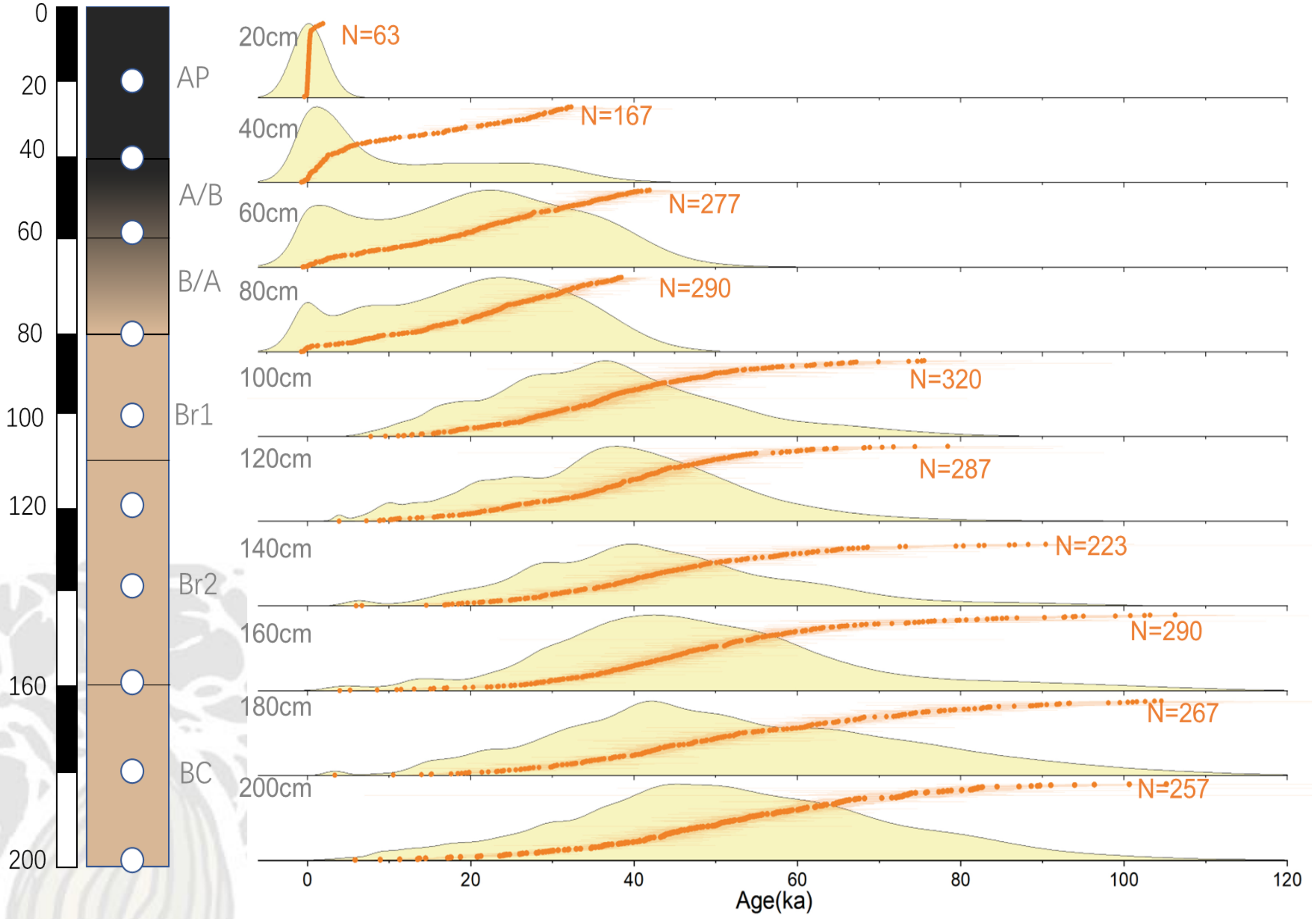
Study 2

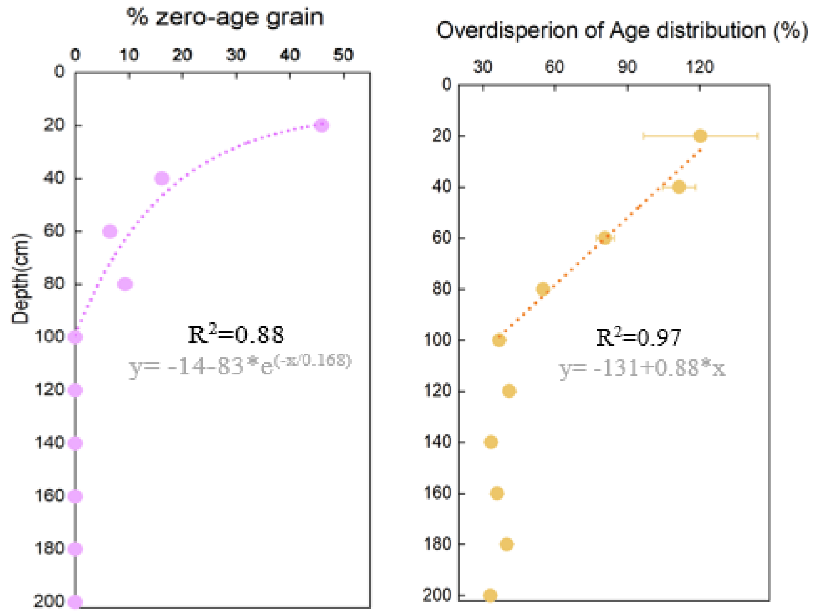
Research site and soil



Study 2

Bioturbation quantified by single-grain luminescence





P_0: quantification of recent downward mixing

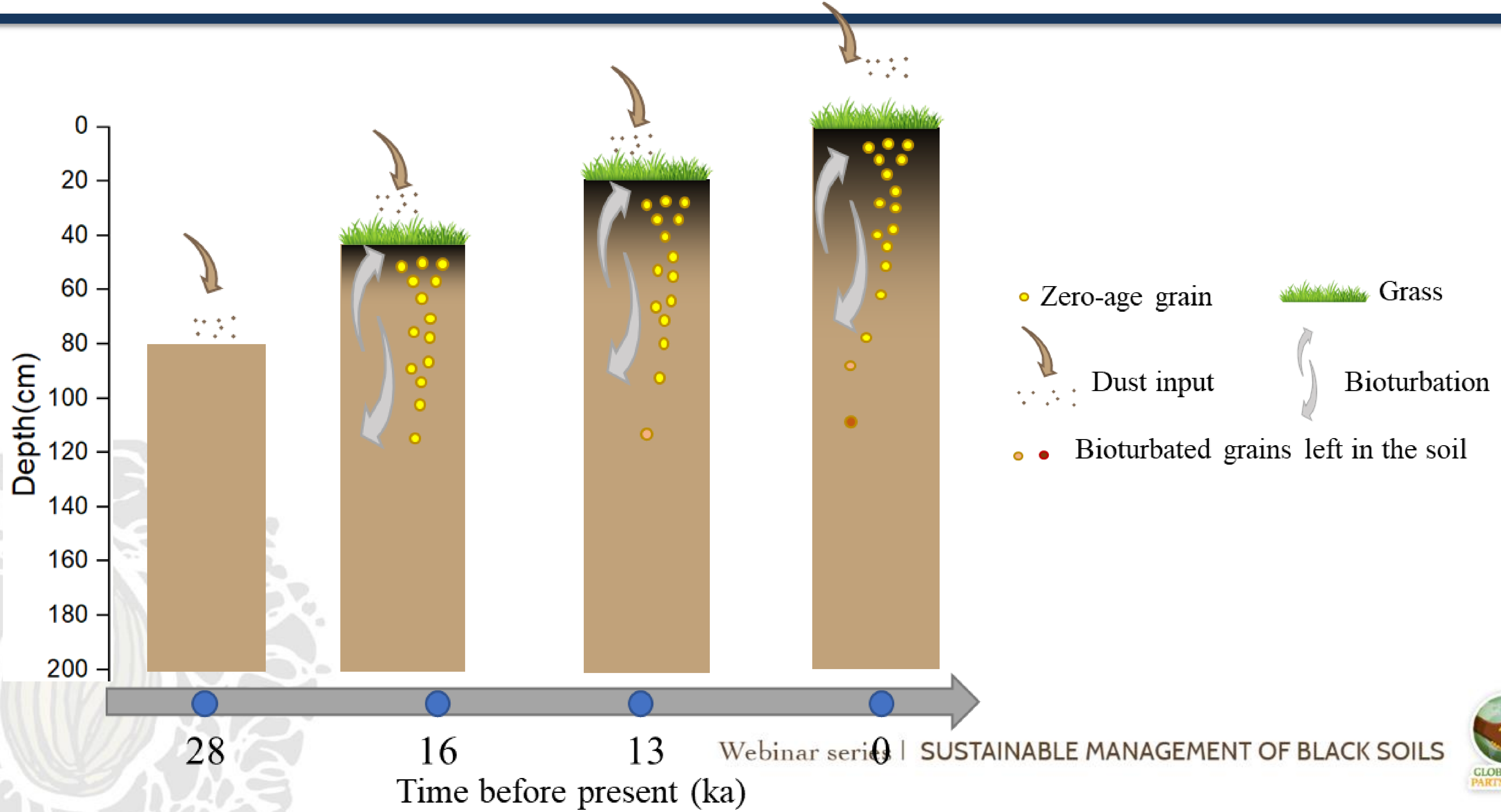
(e.g., Bateman et al., 2007; Gliganic et al., 2016; Reimann et al., 2017)

OD: quantification of overall mixing intensity

(e.g., Bateman et al., 2007; Gliganic et al., 2016)

Study 2

Deciphering black soils formation through bioturbation



Conclusions

- The onset time for black soils was 16.9-12.5ka BP, most probably during the Bølling-Allerød period. This is much earlier than previously reported.
- Black soils formed at a rate ~6 cm ka^{-1}. Black soils grew upwards by incorporating the continuous dust inputs and the accumulation of SOM.
- Modern bioturbation can reach 80cm, its intensity decrease exponentially. Bioturbation intensified since 16.4 ka, which can be viewed as a starting point for black soil formation.

Related publications

- Zhang, G., Long, H., Yang, F., 2023. Understanding the formation time of black soils. The Innovation Geoscience 1(1): 100010.
- Yang, F., Long, H., Gong, K., Shi, Y., Zhang, J., Zhang, A., Yang, N., Cheng, P., Pan, X., Zhang, G., 2023. Onset time and accretionary formation of Mollisols in Northeast China. Science Bulletin 68, 1999-2002.
- Gong Keyang, Yang Fei, Long Hao, Gu Jun, Zhang Ganlin, 2023. Thermostability of soil organic matter under different soil formation patterns. Acta Pedologica Sinica, DOI: 10.11766/trxb202211180627.
- Aimin Zhang, Hao Long, Fei Yang, Jingran Zhang, Jun Peng, Yonghui Shi and Ganlin Zhang, Single-grain luminescence deciphers pedoturbation along the formation of Mollisols, submitted

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Thank you for your attention!

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