Data-Driven Earth Science Frontiers and Development of Geological Sciences in Asia

IUGS

unesco
Chair
on Deep-time Digital Earth
and Mineral Resources

Deep-time Digital Earth
IUGS Big Science Program

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UNESCO Chair on DDEMR

Initiator of IUGS DDE

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The 37th IGC D-1 event, Busan, Aug. 28-29, 2023

Outline

- Data-AI Driven Earth Science Innovation
- Learning and Discovery of Geological X-Events
- Development of Geological Sciences in Asia

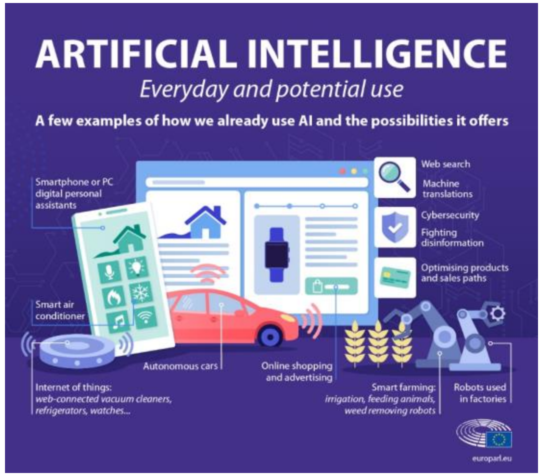
Data-AI Driven Earth Science Innovation

➢ What is artificial intelligence (AI)?

AI is the ability of a machine to display human-like capabilities such as reasoning, learning, planning and creativity.

➢ Why is AI important?

Artificial intelligence is seen as central to the digital transformation of society and it has become an EU priority.

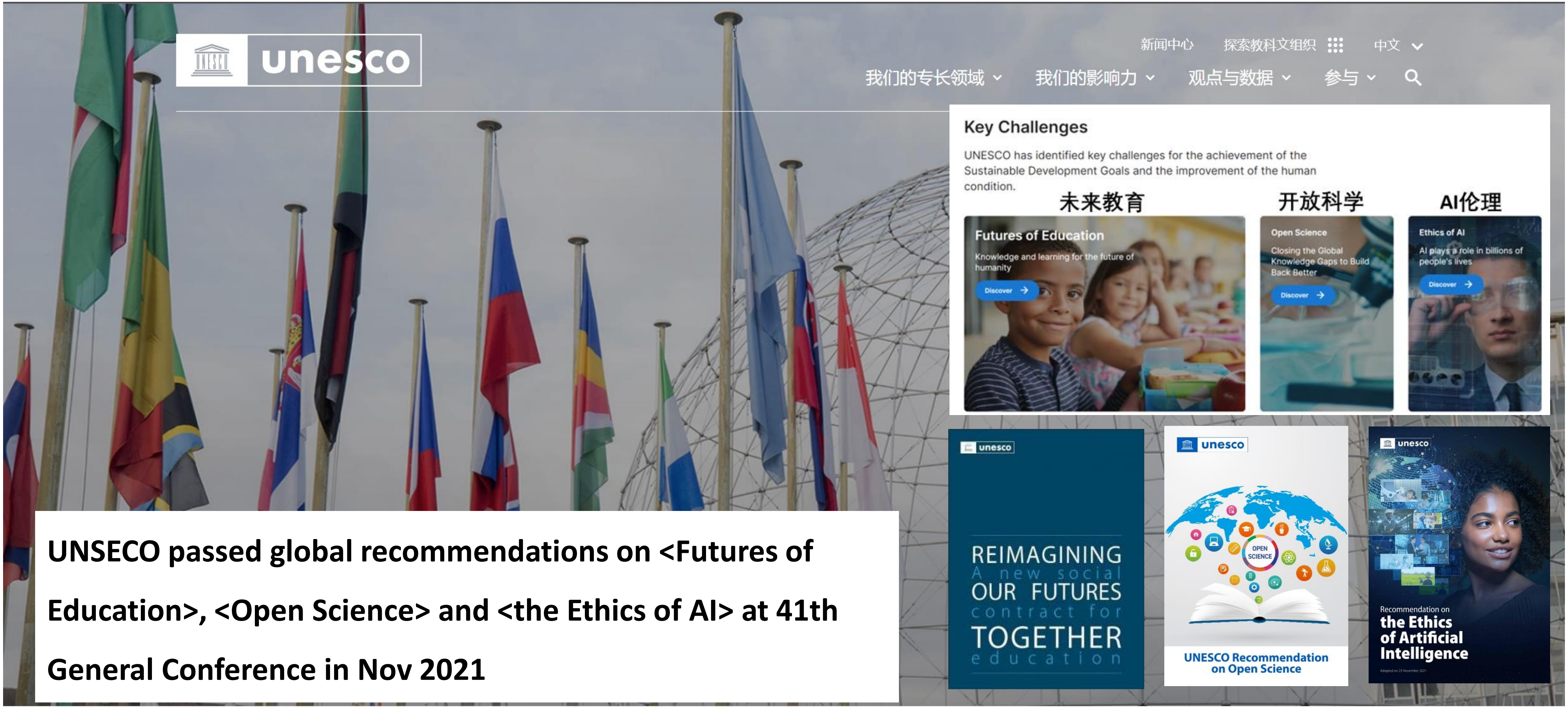


AI is set to transform practically all aspects of life and the economy © AdobeStock/zapp2photo

EU AI Act: first regulation on artificial intelligence

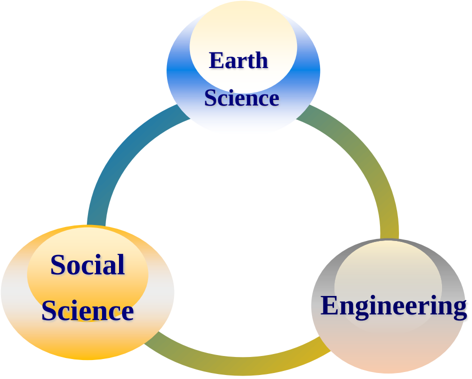
https://www.europarl.europa.eu/news/en/headlines/society/20230601STO93804/eu-ai-act-first-regulation-on-artificial-intelligence

UNESCO – Key Challenges for the Achievement of SDGs



UNSECO passed global recommendations on <Futures of Education>, <Open Science> and <the Ethics of AI> at 41th General Conference in Nov 2021

Global Strategic Challenge Domains



Solutions-Oriented Science Technology

International Science Council

Vision: science as a global public good

2022-2024 Challenge Domains

- Global Sustainability
- Converging Science and Technology in a Digital Era
- Science in Policy and Public Discourse
- Changing Practices in Science and Science Systems
- Freedom and Responsibility in Science

EU AI Act: First Regulation on artificial intelligence

News
European Parliament

Headlines | Press room | Agenda | FAQ | Election Press Kit

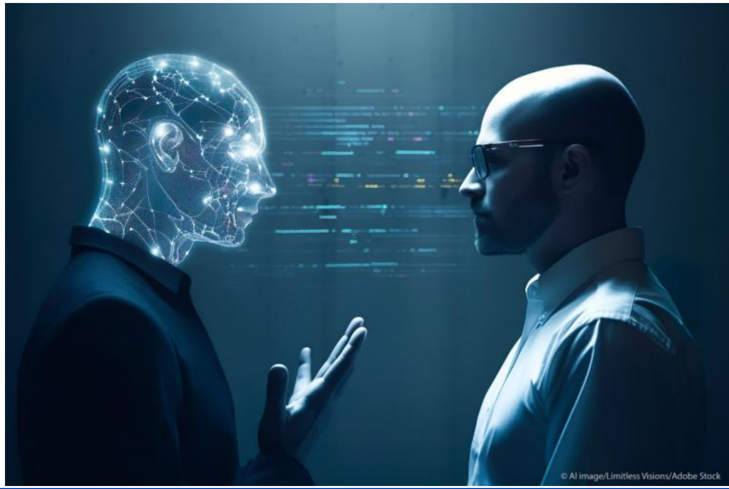
Headlines / Society / EU AI Act: first regulation on artificial intelligence

EU AI Act: first regulation on artificial intelligence

Society Updated: 14-06-2023 - 14:06
Created: 08-06-2023 - 11:40

Generative AI like **ChatGPT**, would have to comply with transparency requirements:

- **Disclosing that the content was generated by AI**
- **Designing the model to prevent it from generating illegal content**
- **Publishing summaries of copyrighted data used for training**



IUGS in leading global geoscience

Geoscience Contribution

Resources
Urban space
Environment
Geo-energy
Geo-hazards
Geo-health
Earth life
Atmosphere

UN 2030 SDGs

Slides from President Candadite address to Council 2016, Qiuming Cheng

IUGS New Big Science Programs

Data-driven earth science

Big data and AI etc. facilitating changes:

- Question-driven to data-driven research
- Human intelligence/learning to AI/Machine learning
- Known questions to unknown questions

Criteria for setting up big science program

1 Global and major issues
2 International collaboration
3 Transdisciplinary
4 Global – Free – Open – Sharing - Service
5 Collaboration with ISC, UNESCO etc.
6 Promotion in underrepresented nations

IUGS President's Report for 72th IUGS EC

January 21-27, 2018 Potsdam

Qiuming Cheng

This annual report (February 2017 – January 2018) provides a summary of the main activities of President Cheng in two sections: 1. Business meetings and activities and 2. New Initiatives and suggestions. The first part mainly

Qiuming Cheng, Roland Oberhänsli and Molei Zhao, 2020, A new international initiative for facilitating data-driven Earth science transformation, Geological Society, London, Special Publications,499: Pages 225 - 240

DDE – IUGS Big Science Program

Kicked off: Deep-time Digital Earth (DDE) – IUGS Big Science Program

DDE Accord being signed

Opening Ceremony of the DDE Forum

IUGS President Qiuming Cheng announced the DDE program

Science

Earth scientists plan a 'geological Google'

Dennis Normile

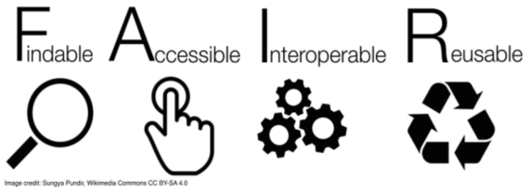
Primary Goals Deep-time Digital Earth

- ❑ **Mission: harmonize global earth evolution data, and share geoscience knowledge**
- ❑ **Vision: transform Earth science**

➢ DDE - an international consortium

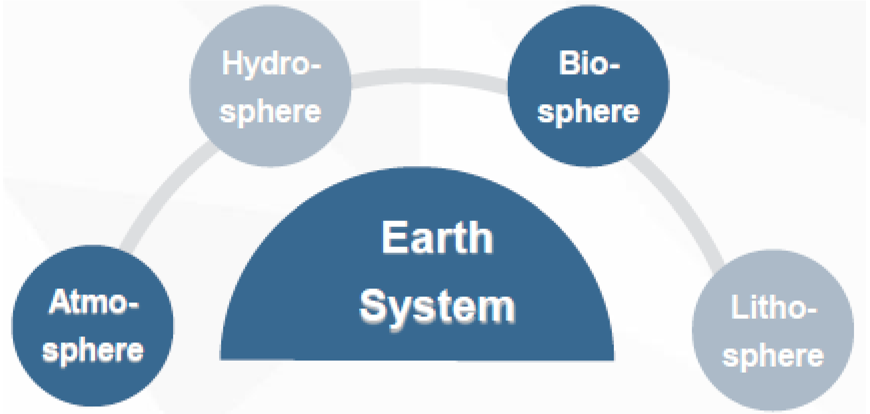
➢ Open platforms of deep time digital earth

➢ FAIR data (Findable, Accessible, Interoperable, and Re-usable)



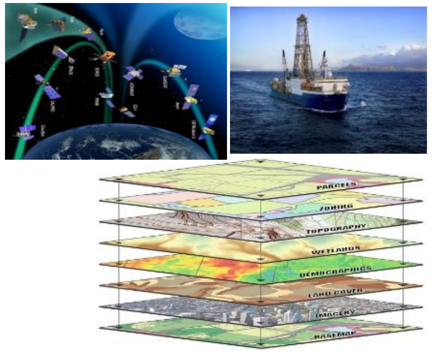
➢ Linking various Earth’ s spheres (hydrosphere, geosphere, atmosphere, biosphere)

➢ New ways of conducting open science for Co-Evolutions of life, materials and environments.

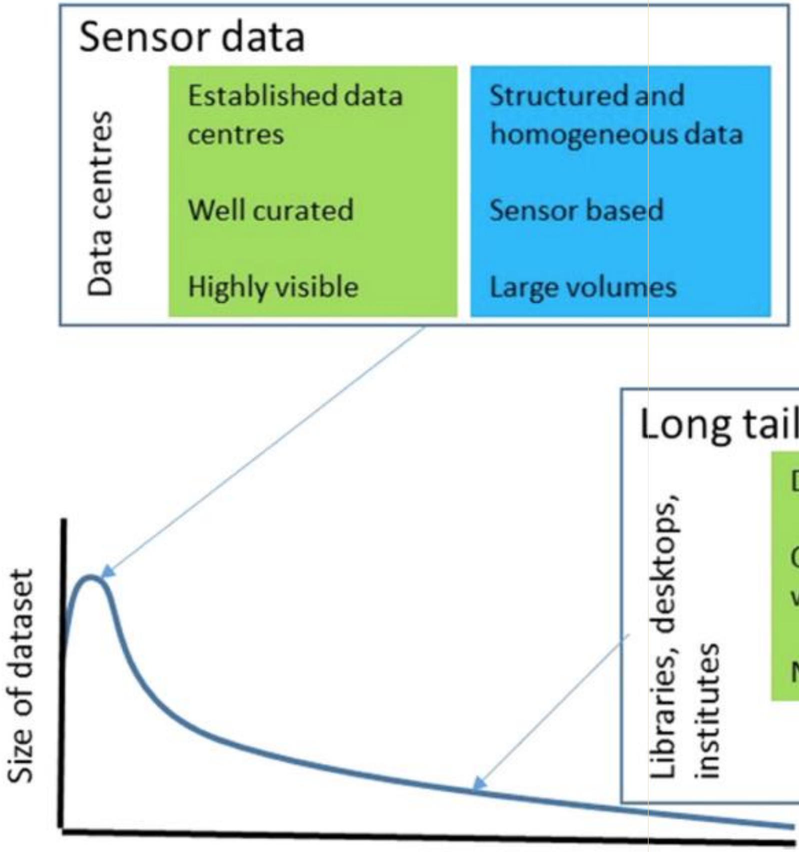


Challenges: Extracting and Integrating Big Data and Long-tail Data

GIS database:
Survey and Mapping



Report



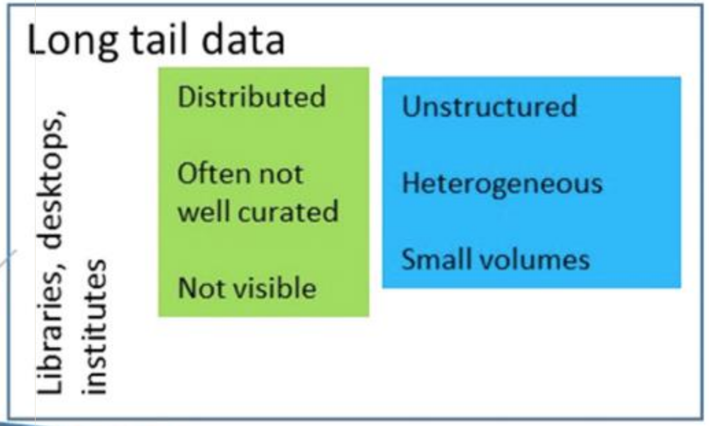
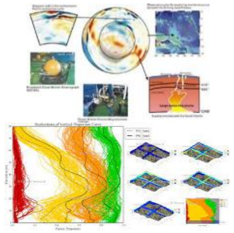
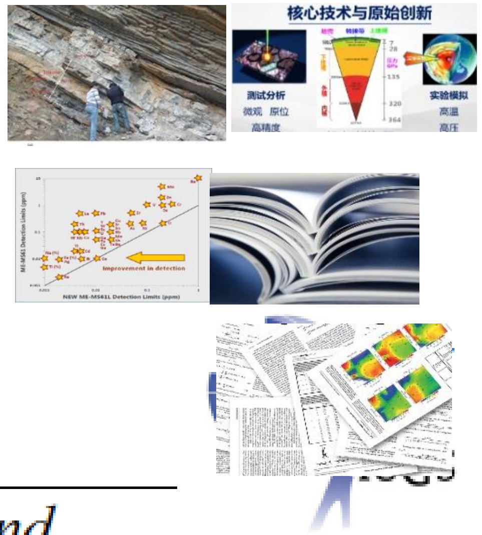


Figure 1. Two types of geoscience data.

Simulator: Physical and numerical Simulation

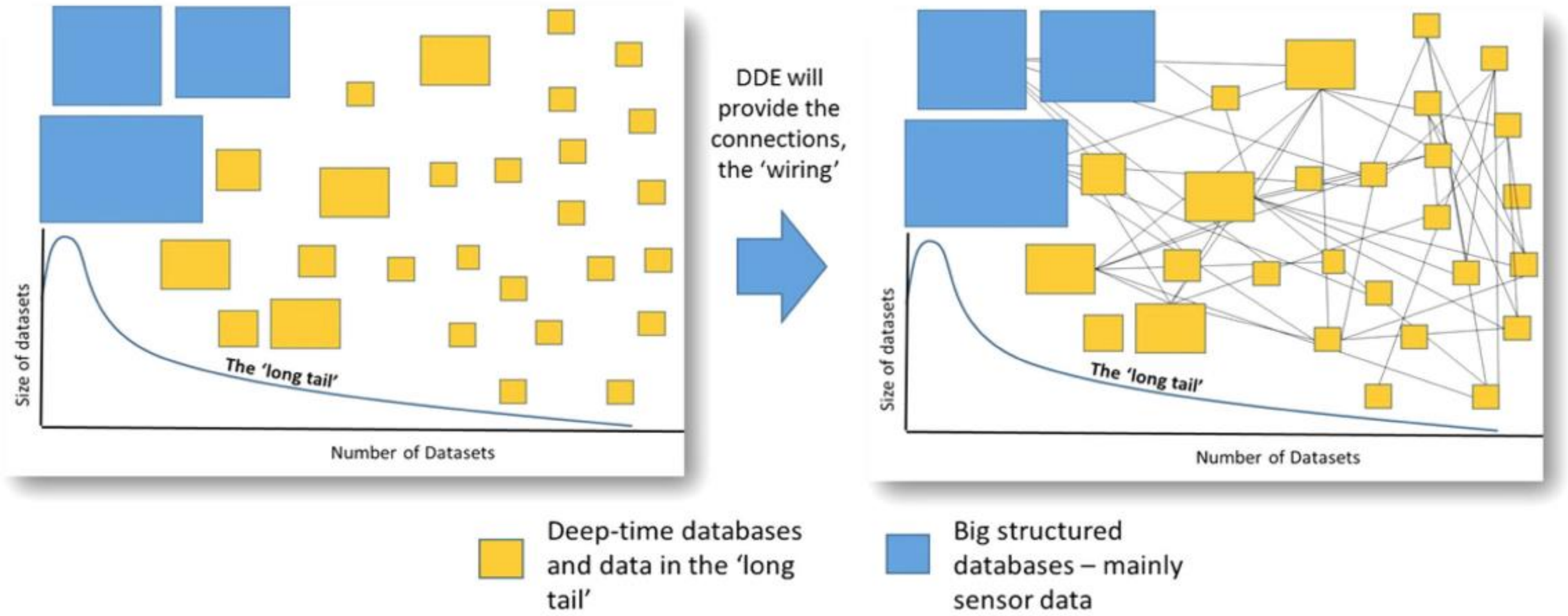


Observation, description, sampling and analytical detection



by Michael H. Stephenson[1], Qiuming Cheng[2], Chengshan Wang[3], Junxuan Fan[4], and Roland Oberhänsli[5]*

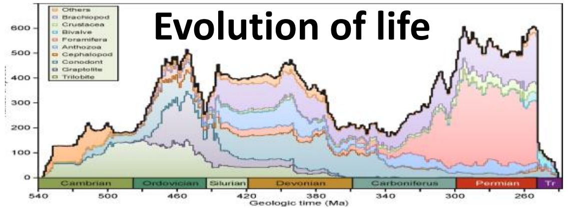
Challenges: Extracting and Integrating Big Data and Long-tail Data



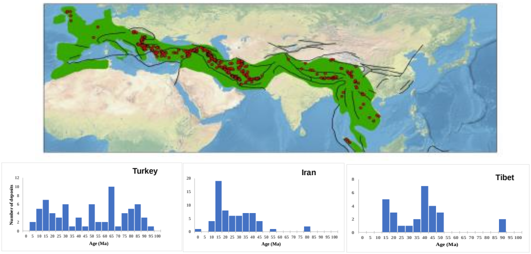
by Michael H. Stephenson[1], Qiuming Cheng[2], Chengshan Wang[3], Junxuan Fan[4], and Roland Oberhänsli[5]* *Progress towards the establishment of the IUGS Deep-time Digital Earth (DDE) programme, 2020, Episodes 43(4)*

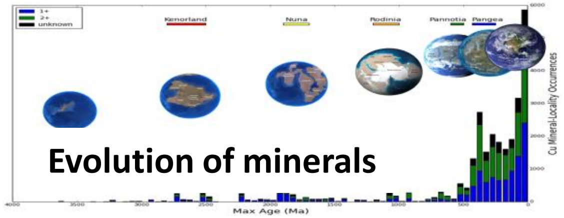
Scientific Questions and Collaborative Tasks

1. Integrating a uniform high-resolution earth time system
2. Origin and evolution of life and biodiversity
3. Evolution of sedimentary matter?
4. Reconstructing earth climate and atmosphere history from big data of multiple geochemical indices
5. Global sea-level change through deep time
6. Quantifying plate tectonics and deformation in 4D
7. 4D architecture and evolution of deep-earth materials and dynamics
8. Mineral evolution beyond 4D
9. Big data mineral resources and energy resource system for sustainable development
10. Big data system for prediction of geological hazards

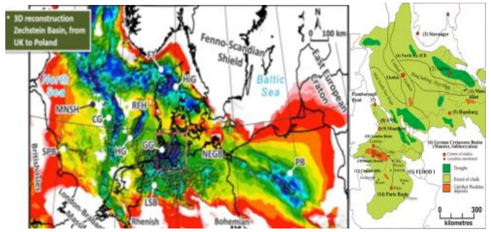


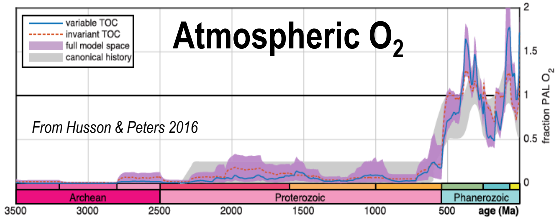
Global distribution of Cu mineral resources



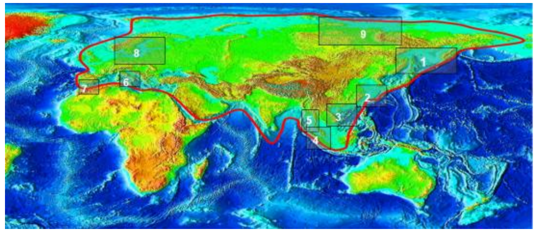


Salt basins of Europe for hydrogen storage for the H economy

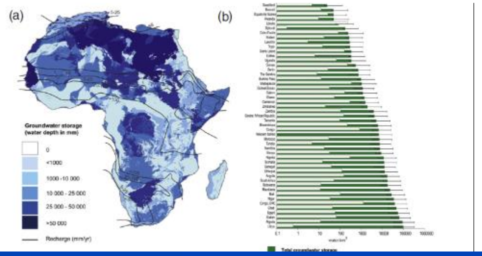




Eurasian Marginal Seas – Past and Future (ESR)



Groundwater sustainability in Africa



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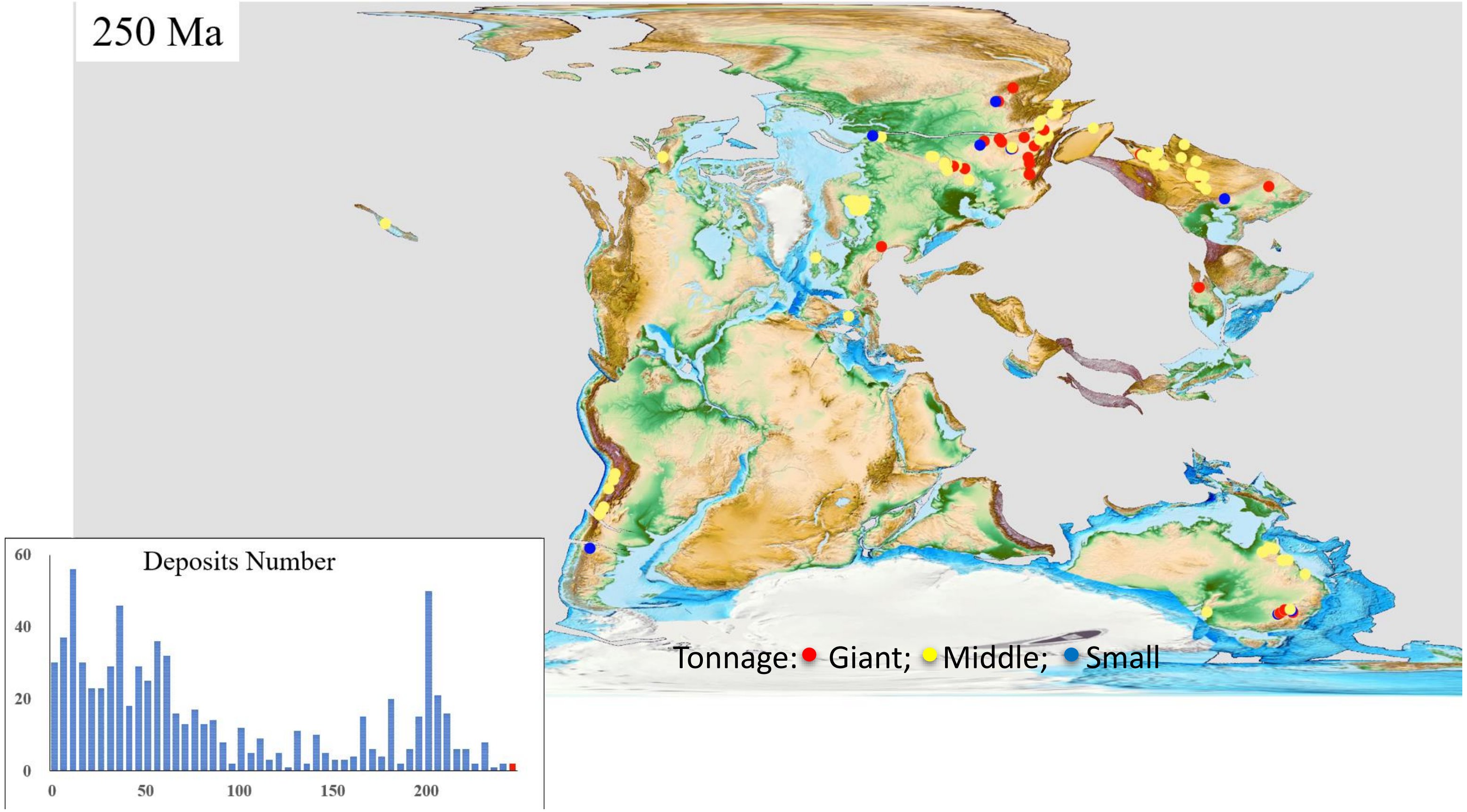
Challenges: Integrating Big Data vs Long-tail Data

➢ **Georeferencing GIS map layers to paleogeology and paleogeography**



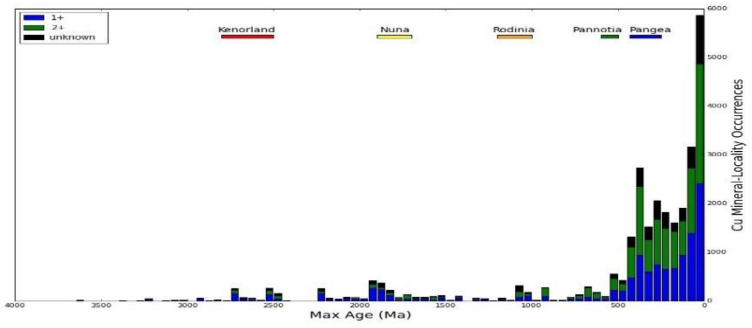
Video shows the spatial and temporal distribution of Porphyry Cu mineral deposits with respect to their Paleogeographical location for the past 250 Ma. （Cheng, 2018 unpubl.)

Challenges: Characteristics of Deep-time Data

- **Variable quality of deep-time data caused by preservation and recycling**
- **Unbalance quality and heterogeneity of spatial and temporal resolutions**
- **Superimposing of weak anomalies and variable backgrounds or trends**
- **Long range/remote distance (auto-)correlation and indirect causal association**
- **Chaotic, Episodic vs Periodic events?**
- **Self-similarity, singularity and intermittency**

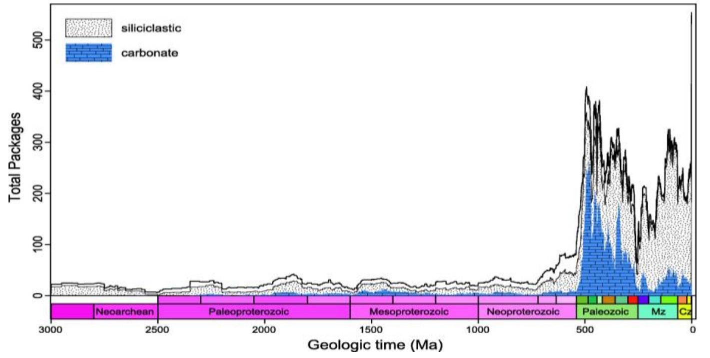
Cu mineral oxidation state through time

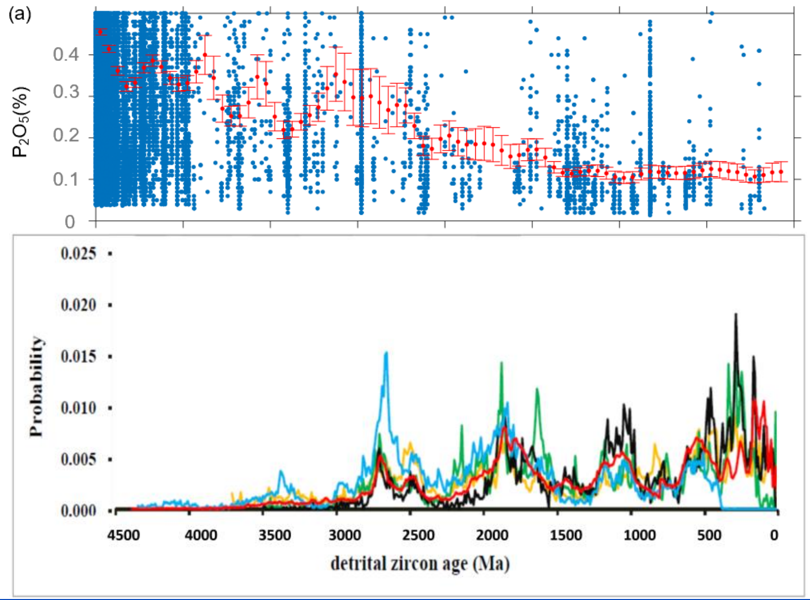
（Hazen et al., 2016）



sedimentary rock packages in North America

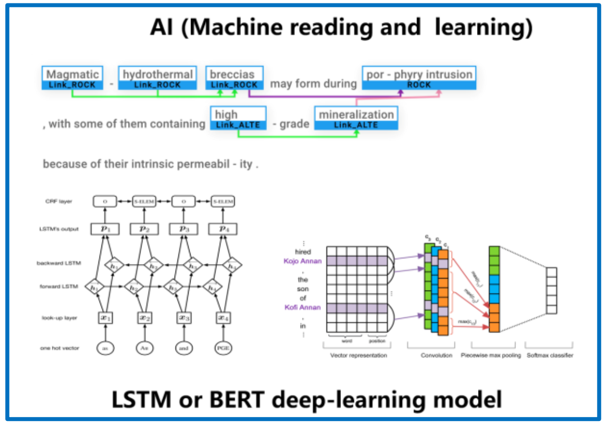
（Peters et al., 2018）

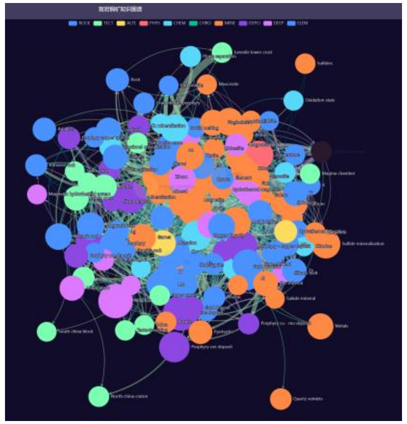




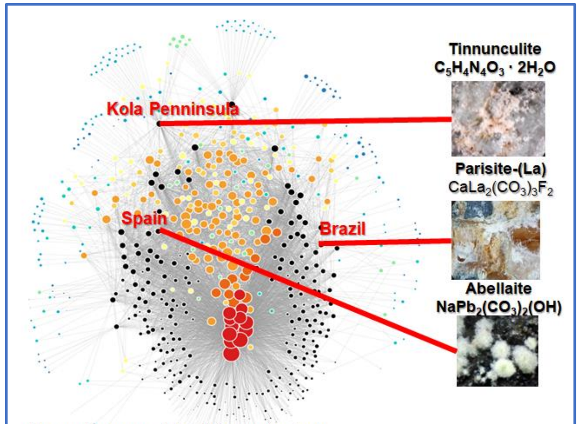
Opportunities for Handling Deep-time Data

- ❖ **Machine reading and machine leaning (AI)**
- ❖ **Knowledge graph and knowledge discovery**
- ❖ **Special mathematics and modeling tools**





Knowledge graphs for porphyry copper mineral deposits (Zhou et al., 2022 unpub.)
12000+papers
400k entities (nodes)，300krelations



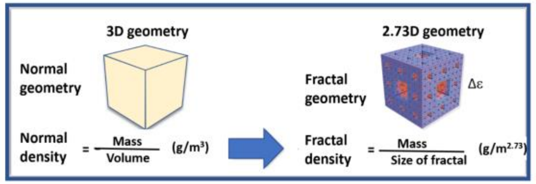
Hazen, Hummer et al. >12 new species!

Ordinary density

$$c = \lim_{\Delta v \to 0} \frac{\Delta m}{\Delta v} = \frac{dm}{dv}$$

Fractal density

$$c_\alpha = \lim_{\Delta v \to 0} \frac{\Delta m}{(\Delta v)^{\alpha/3}} = \frac{dm}{dv^\alpha}$$



Differential

$$f'(x_0) = \frac{df(x)}{dx} = \lim_{x \to x_0} \frac{f(x)-f(x_0)}{(x-x_0)}$$

Fractal Differential

$$f'_\alpha(x_0) = \frac{df(x)}{dx^\alpha} = \lim_{\Delta x \to 0} \frac{\Delta f(x)}{(\Delta x)^\alpha} = \lim_{x \to x_0} \frac{f(x)-f(x_0)}{(x-x_0)^\alpha}$$

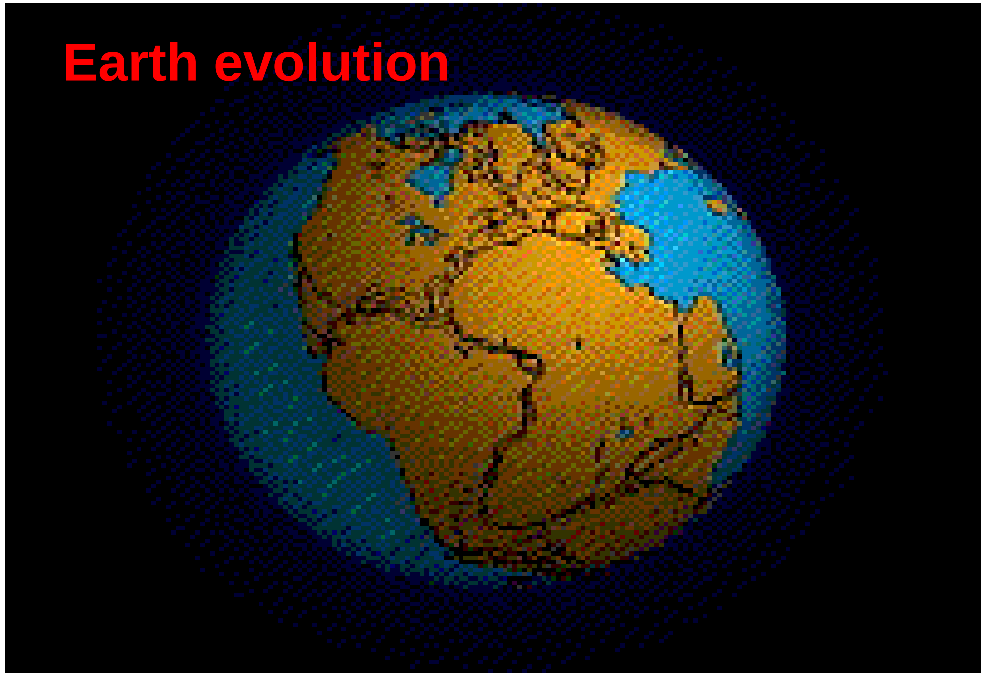
$$\Delta\alpha = 1 - a = -\frac{d[\log(f)]}{d[\log(x)]} = -\frac{df}{dx}\frac{x}{f}$$

Time and space series analysis

Singularity analysis of extreme events (Cheng, 2007-)

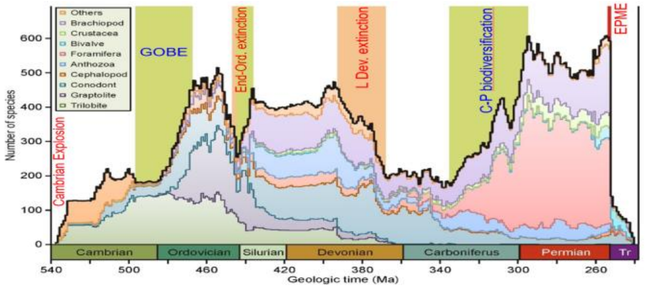
Applications of “Data+Math+Computing”(AI)

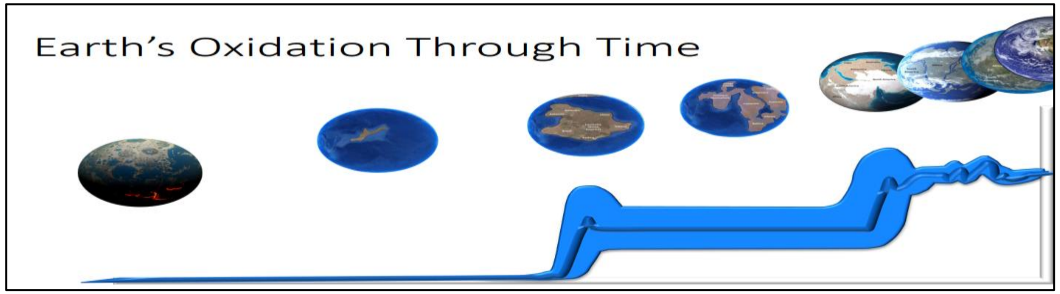
“Data+Math+Computing” AI

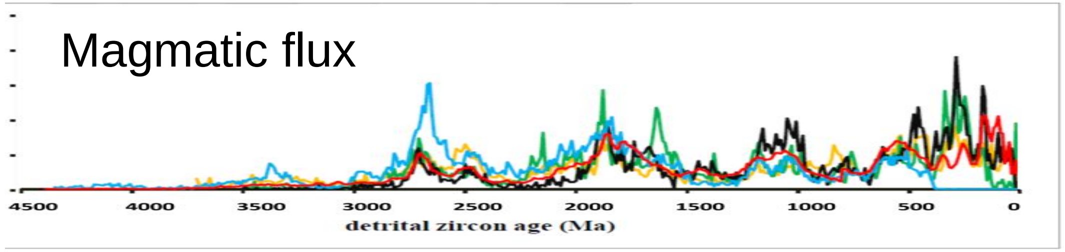


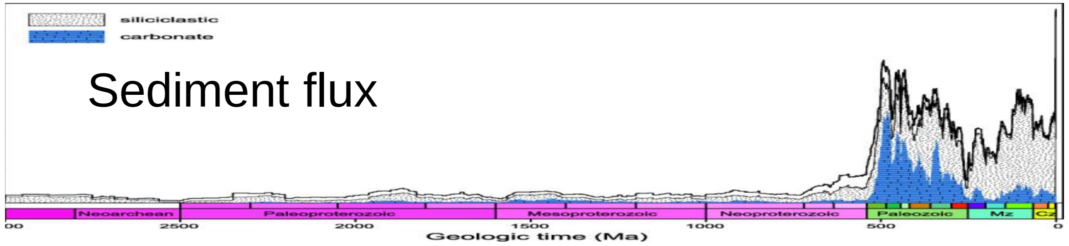
Co-evolutions of earth life, materials and environments

Biodiversity









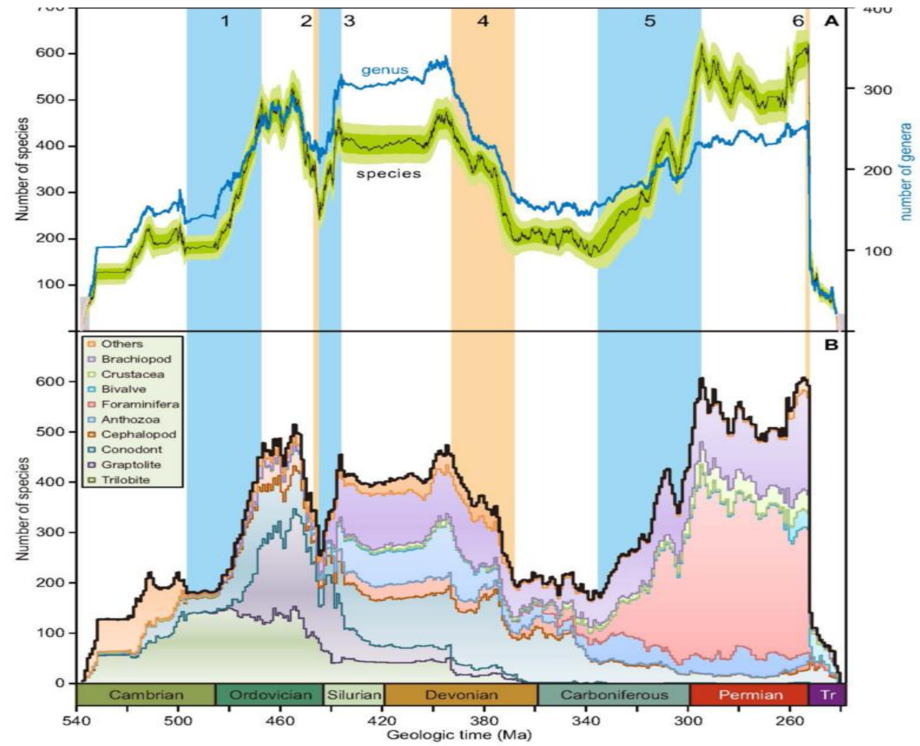
Case I, Big data + Math model and Super/Clouds computing for Bio-diversity Time Series Analysis

How to reproduce the changes in biodiversity through incomplete fossil chains is a major scientific problem. The research uses new methods and means such as paleontological **big data**, **supercomputing**, and **genetic algorithms** to reproduce the evolutionary history of life based on fossil records (e.g., three **largest biological extinction events** and two major **biological radiation events**).

PALEONTOLOGY (Fan et al., 2020 Science)

A high-resolution summary of Cambrian to Early Triassic marine invertebrate biodiversity

Jun-xuan Fan[1,2], Shu-zhong Shen[1,2,3]*, Douglas H. Erwin[4,5], Peter M. Sadler[6], Norman MacLeod[1], Qiu-ming Cheng[7], Xu-dong Hou[1], Jiao Yang[1], Xiang-dong Wang[1], Yue Wang[2], Hua Zhang[2], Xu Chen[2], Guo-xiang Li[2], Yi-chun Zhang[2], Yu-kun Shi[1], Dong-xun Yuan[2], Qing Chen[2], Lin-na Zhang[2], Chao Li[2], Ying-ying Zhao[1]



"Tianhe-2" supercomputer was used to analyze 3112 stratigraphic sections and 260,000 fossil data of 11,268 marine fossil species. The Paleozoic marine biodiversity curve from about 540 to 240 million years ago was reconstructed with a time resolution of about 26,000 years, 400 times more accurate than similar international studies.

EVOLUTIONARY BIOLOGY

High-resolution dating of Paleozoic fossils

Refined ages of marine fossils clarify the timing of diversification and extinction events

SUPERCOMPUTER SCOURS FOSSIL RECORD FOR HIDDEN EXTINCTIONS

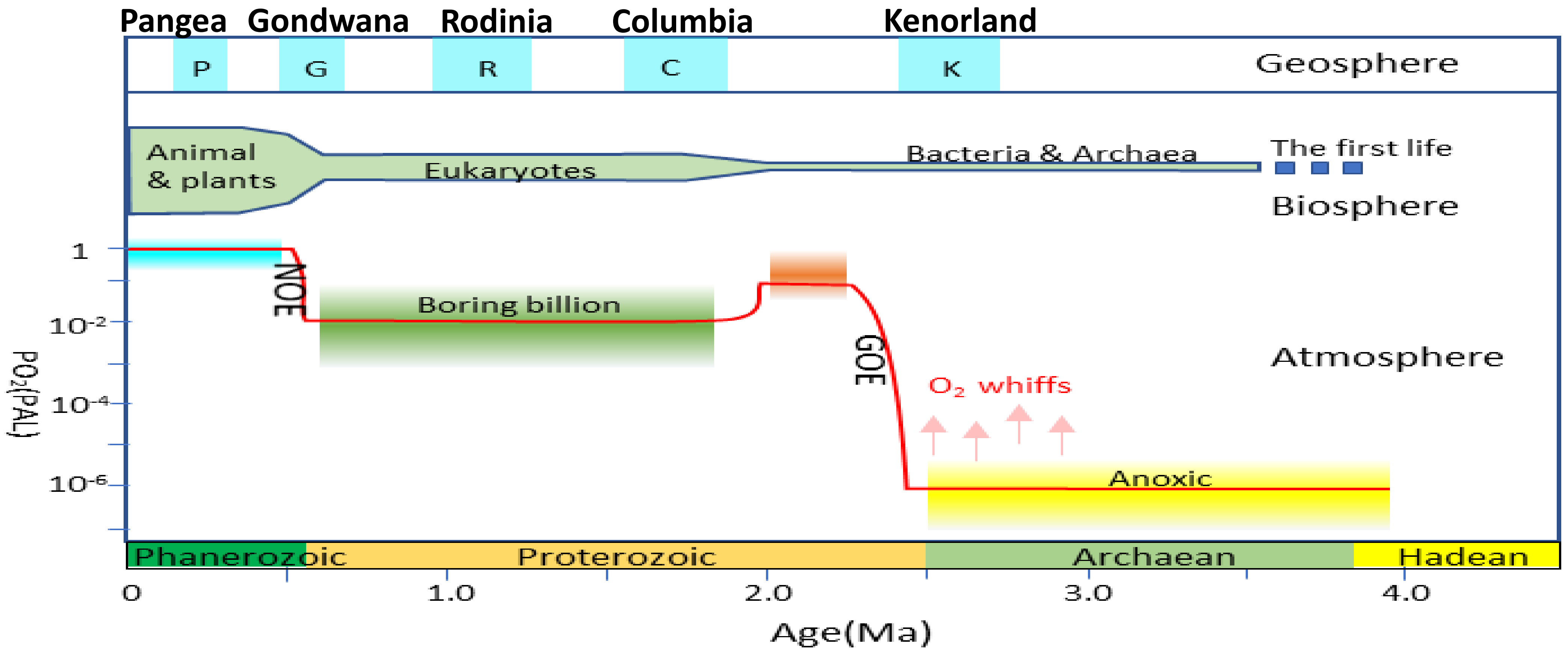
Palaeontologists have charted 300 million years of Earth's history in breathtaking detail.

By Ewen Callaway

to within about 26,000 years (J.-x. Fan *et al.* *Science* 367, 272–277; 2020).

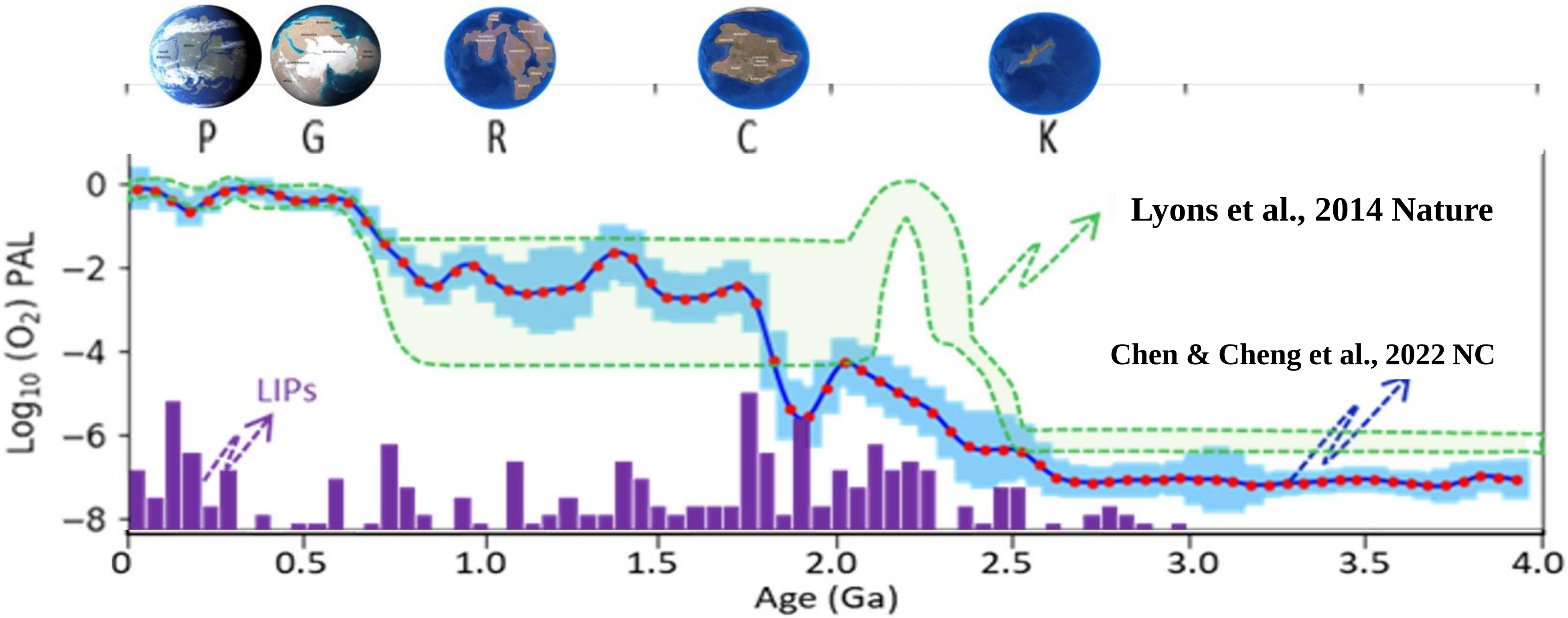
Case II, Big data + Machine Learning for Reconstructing Atmospheric Oxygenation History

Three levels of oxygenation of Earth's atmosphere are associated with two great oxygenation events (GOE and NOE). Reconstructing high resolution oxygenation history is essential task for quantitative study (Lyons et al., 2014, Nature).



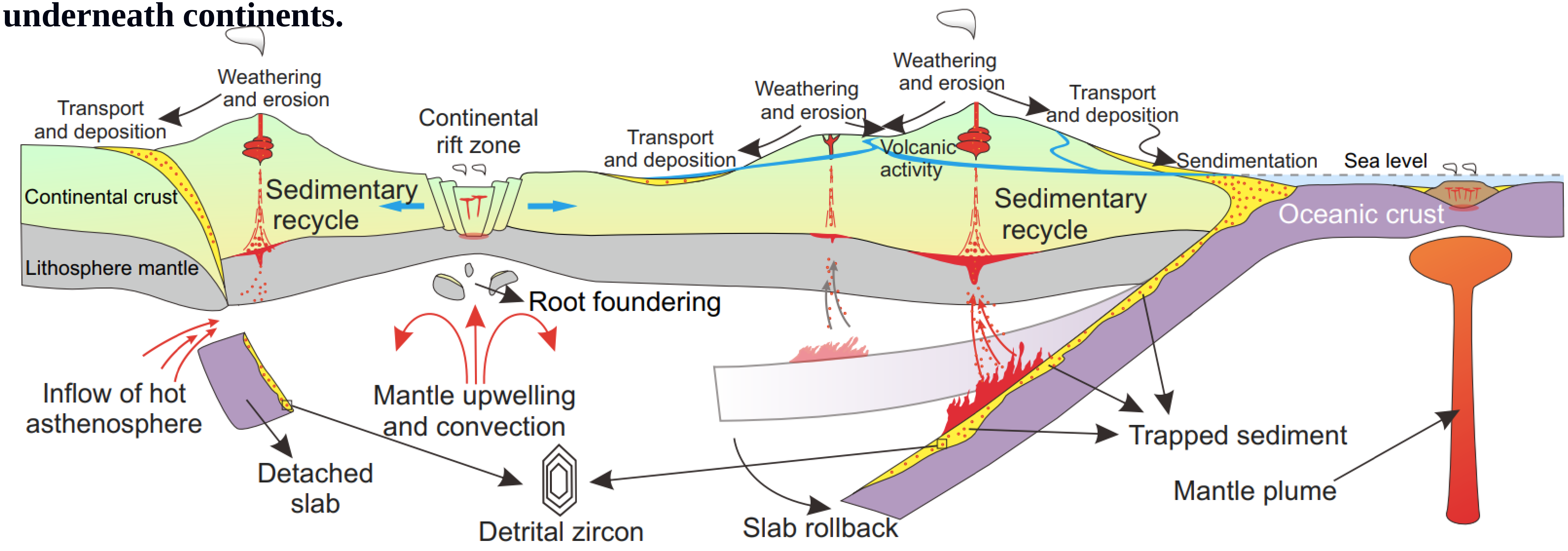
Case II, Big data + Machine Learning for Reconstructing Atmospheric Oxygenation History

The machine learning method has been used to refine the curve of atmospheric oxygenation based on mafic igneous compositional geochemical data from about 300,000 basalts samples from EarthChem. The results imply that Earth's oxygenated atmosphere may be at least partly a natural consequence of evolving mantle cooling and mantle melts (Chen & Cheng et al., 2022, NC)



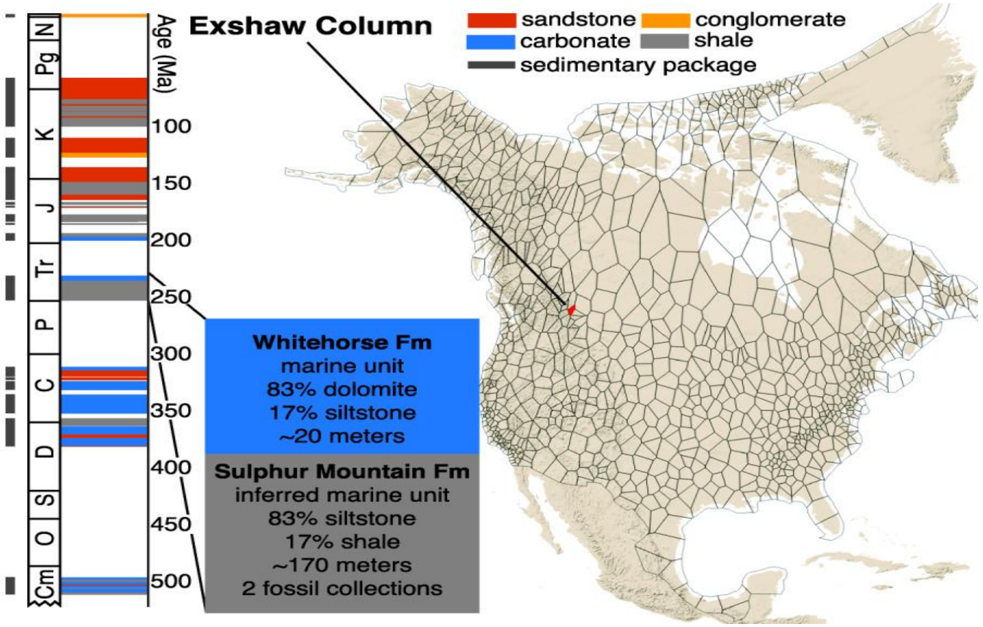
Case III Co-evolution of Magmatic and Sedimentary Fluxes

Sedimentation in the ocean floor and magmatic events (volcanic and igneous intrusions) on continents are two different processes involved cycling of earth materials. Magmatic processes bring up materials from deep earth whereas sedimentation involves rock weathering, transportation, and deposition on the ocean floor. The sediments can be recycled back to the mantle by deep subduction of oceanic plates underneath continents.

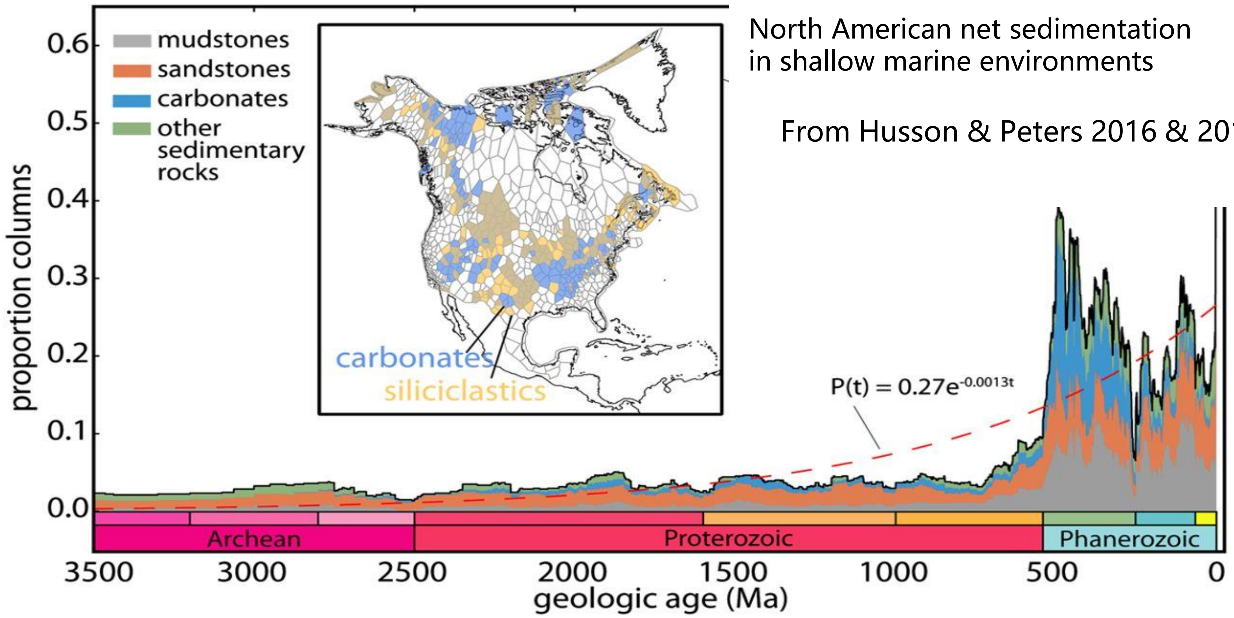


Cyclicity of the Sediment Flux and Tectonic Evolution

Macrostrat is a platform developed by Professor Shanan Peters at University of Wisconsin. It uses **supercomputers** and **machine reading techniques** for extracting geological data relevant to the spatial and temporal distribution of sedimentary, igneous, and metamorphic rocks as well as data extracted from them. **For example, on April 14, 2019, it read 5783 papers and 240.96 papers per hour**.



(From Peters et al., 2018)



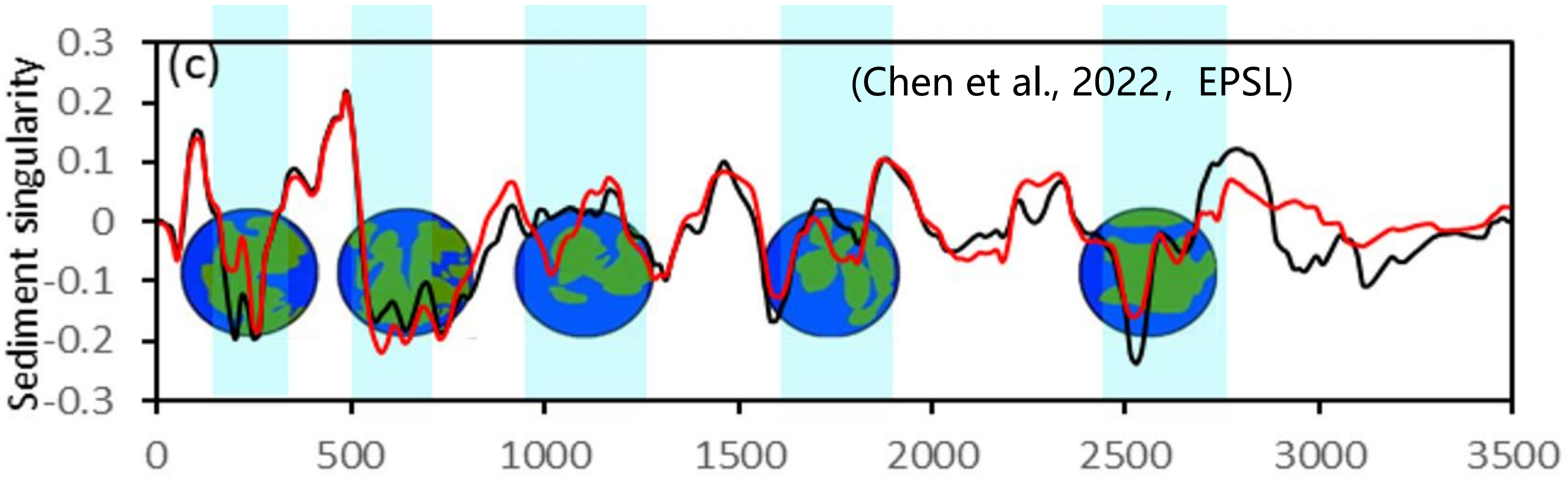
North American net sedimentation in shallow marine environments

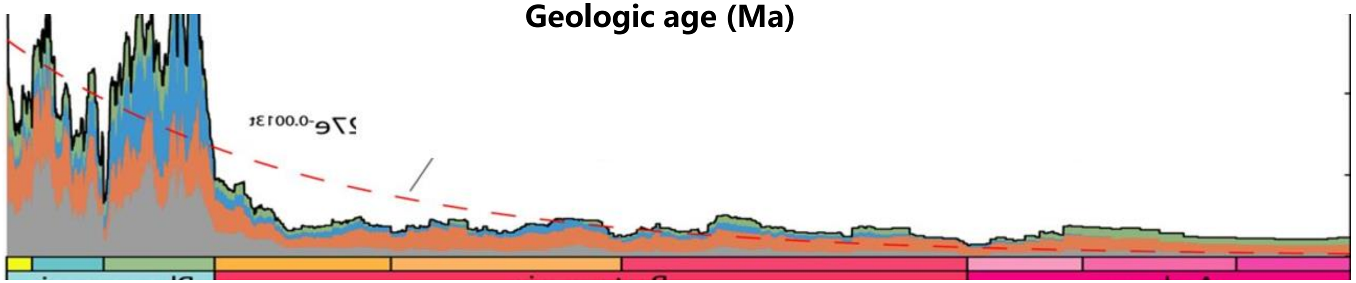
From Husson & Peters 2016 & 2018

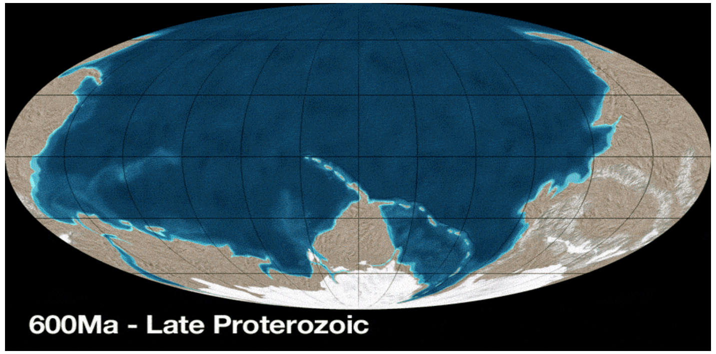
21,755 sedimentary rock units from about 1000 composite regional geologic columns

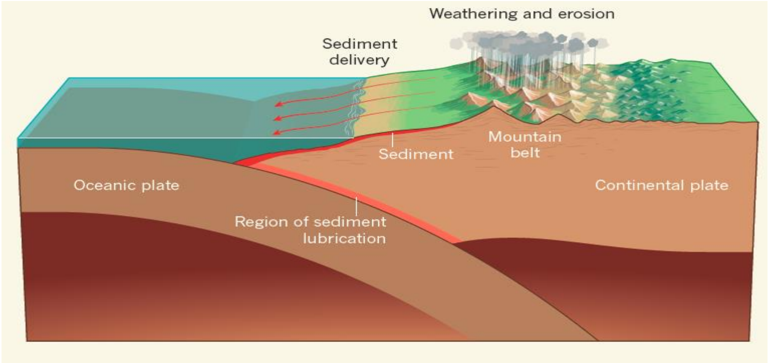
Cyclicity of the Sediment Flux and Tectonic Evolution

Local Singularity Analysis (LSA) was applied to the time series data which reveals cyclicity of the sedimentary records and associations with the separation and aggregation of supercontinents. This discovery supports the sediments may act as lubrication to promote plate subduction, resulting in a loss of sediment flux (Chen & Cheng et al., 2022, EPSL).







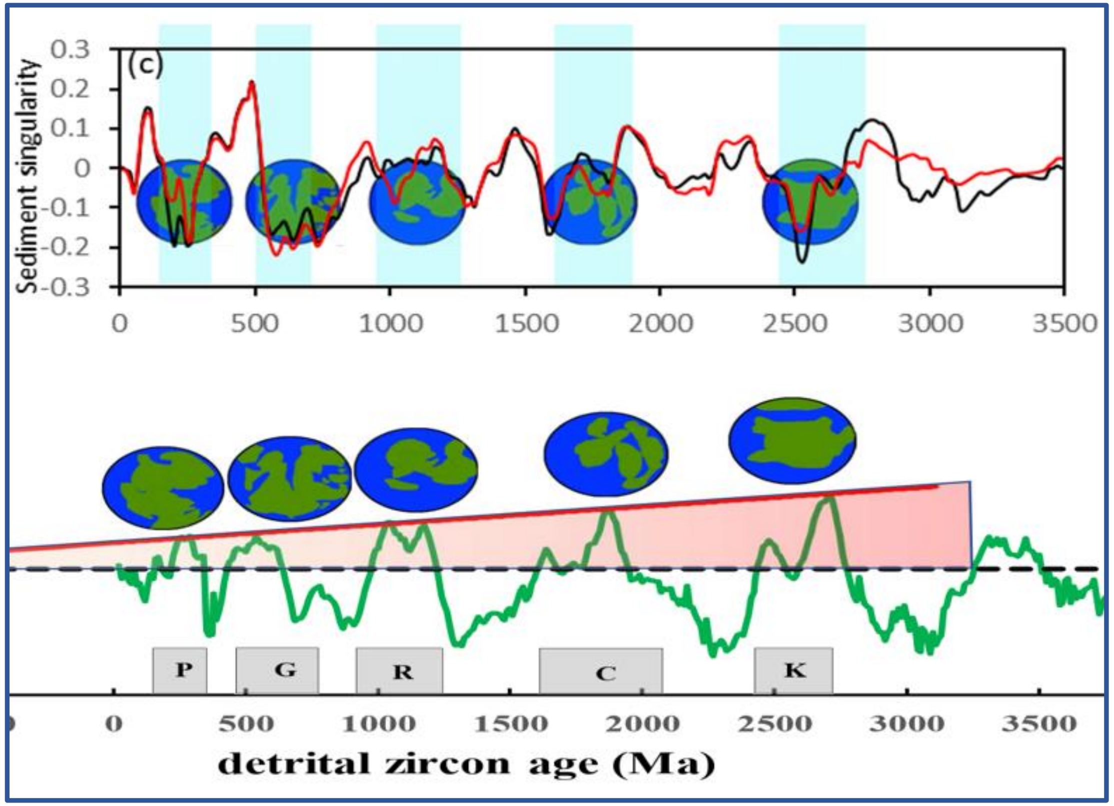


Surface erosion events controlled the evolution of plate tectonics on Earth （Sobolev, Brown, 2019，Nature）

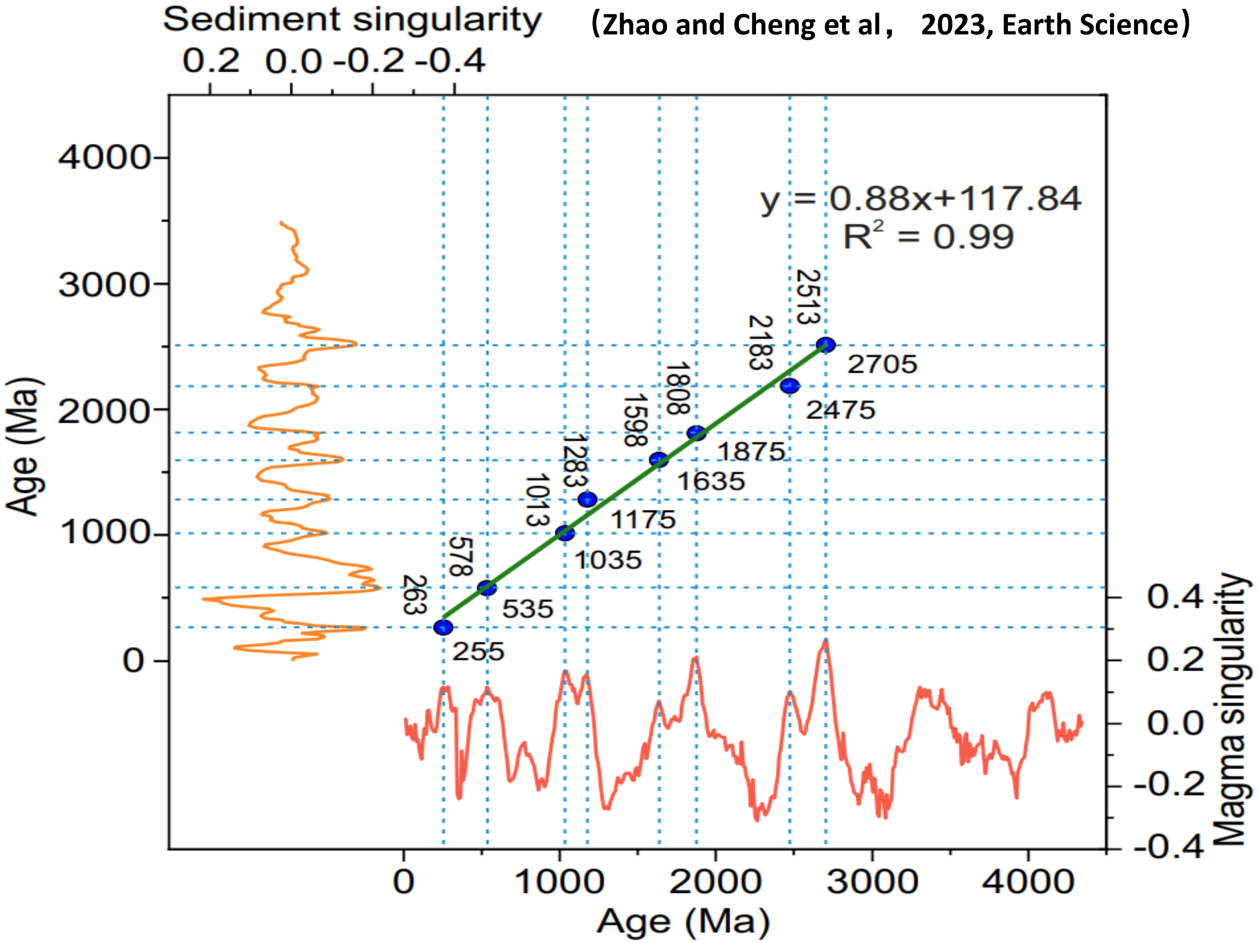
Co-evolution of Geological Xevents in Deep-time

Comparing local anomalies of depletion of sediments on the ocean floor and the local anomalies of magmatic fluxes with respect to the segregation of supercontinents indicates that these two processes are cross-correlated with a lag time of 117 Ma.

（Zhao and Cheng et al， 2023, Earth Science）



Magmatic activities (Cheng, 2017, 2018, GR)



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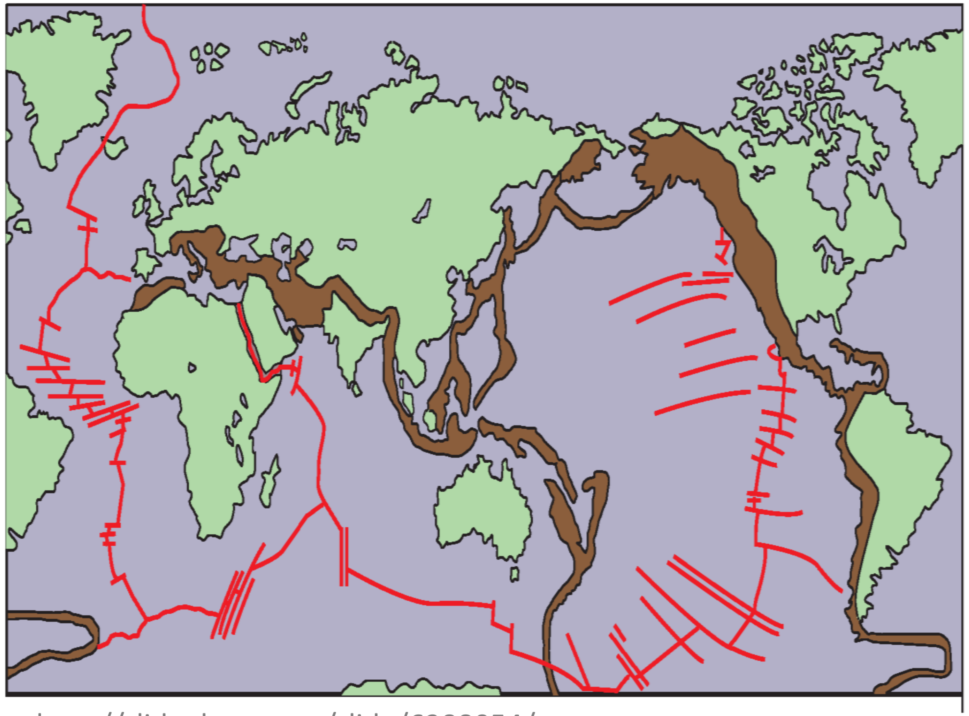
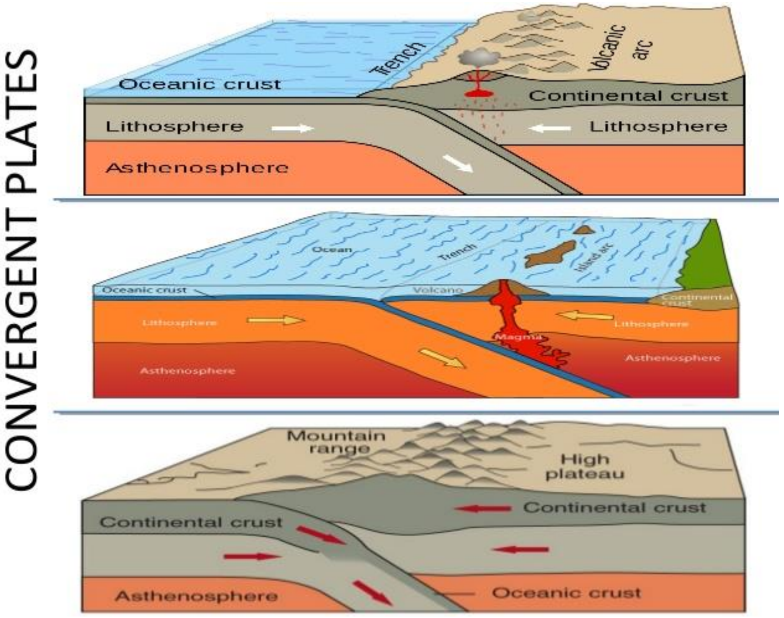
Major Geological Issues Pose Challenges to SDG in Asia

Alpine-Himalayan Orogenic Belt (Tethys)
Circum-Pacific Belt



http://slideplayer.com/slide/6288054/

Plates subduction and collision



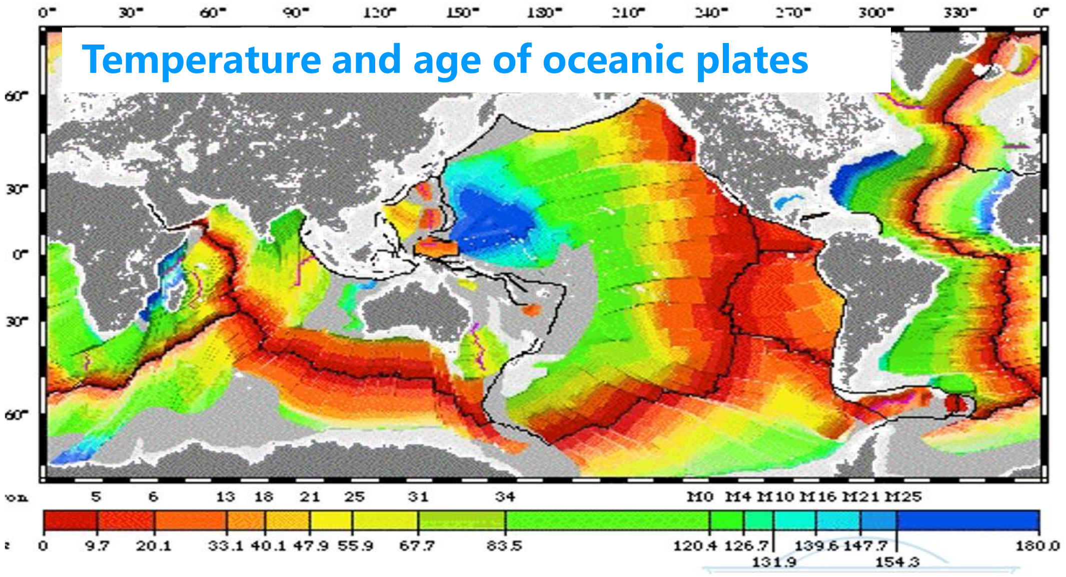
https://www.slideshare.net/esteeseetoh/convergent-boundaries

- ✓ Earthquakes
- ✓ Volcanoes
- ✓ Mineral deposits
- ✓ Oil basins
- ✓ Glaciers
- ✓ Nuclear power plants
- ✓ Large dams
- ✓ Water scarcity
- ✓ Large cities

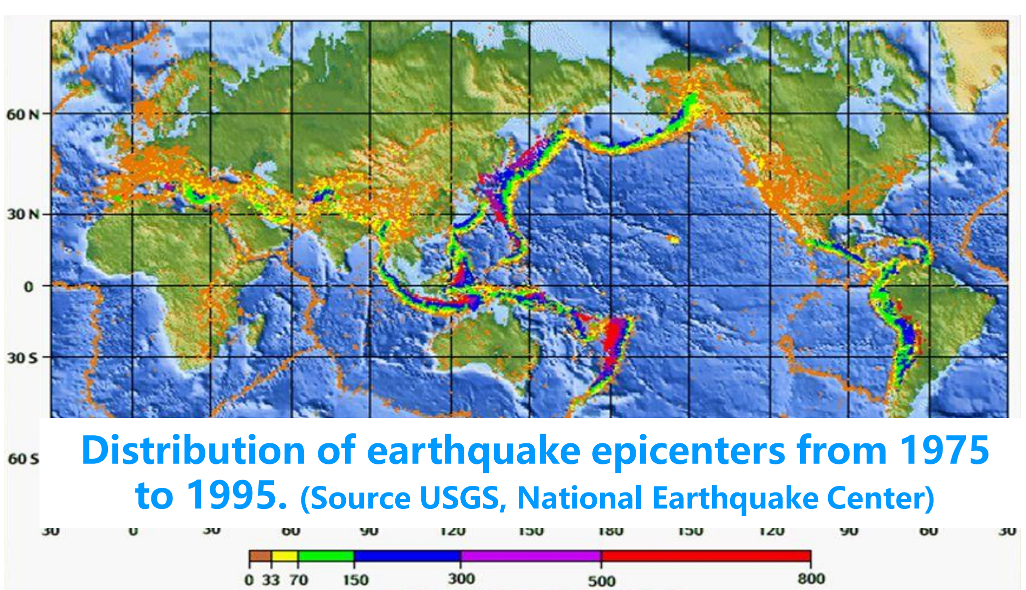
Profound Influence of Tectonic Activity on Asian Geology

- **Collision** of Indian and Eurasian Plates: responsible for the formation of the Himalayan mountain range and earthquakes and the uplift of the Himalayas.
- **Subduction** of the Pacific Plate beneath the Eurasian Plate has led to the formation of volcanic activity, earthquakes, marginal seas, orogenic belts and sediment basins.

The old and colder plates in the western- than those in the eastern Pacific plates correspond to deeper earthquakes



Temperature and age of oceanic plates

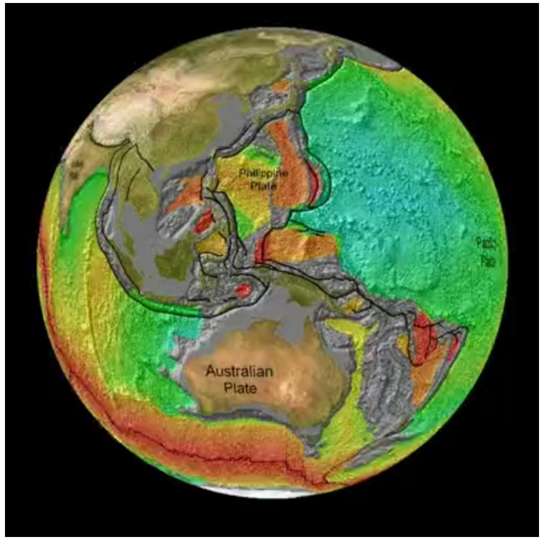


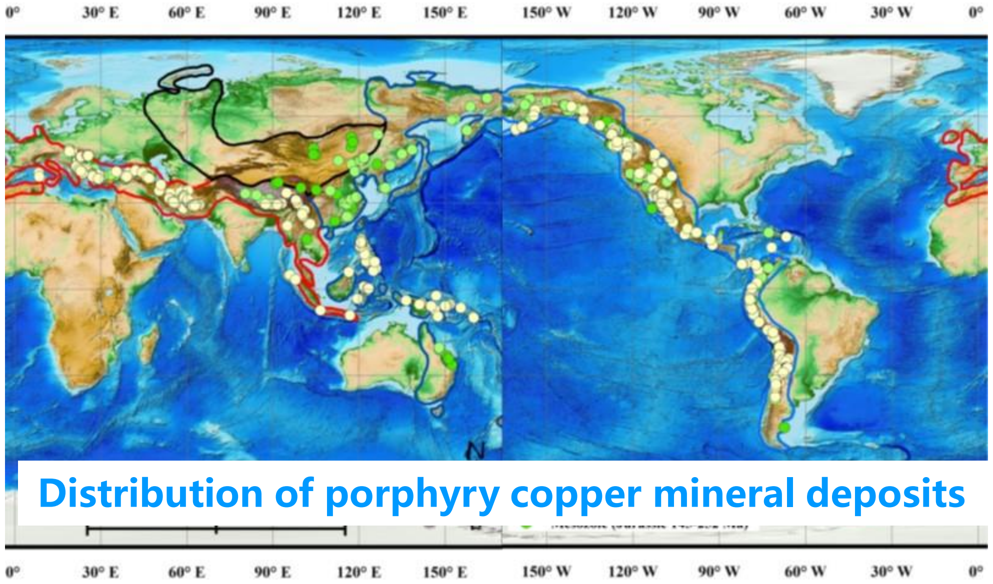
Distribution of earthquake epicenters from 1975 to 1995. (Source USGS, National Earthquake Center)

Profound Influence of Tectonic Activity on Asian Geology

- **Cratons and their evolutions** in Asia are characterized as geological diversity and complexity which also formed rich mineral resources and energy resources.
- **Plate Boundaries in Southeast Asia** is characterized by complex tectonic interactions due to the convergence of several plates (The Philippine Sea Plate, the Eurasian Plate, and the Australian Plate). This tectonic complexity has given rise to diverse geological X-Events such as **mineralization, volcanic activities and earthquakes**.

NOAA / National Centers for Environmental Information (NCEI). (2010, April 1). Age of the Seafloor (vegetation). https://sos.noaa.gov/catalog/datasets/age-of-the-seafloor-vegetation/#details.



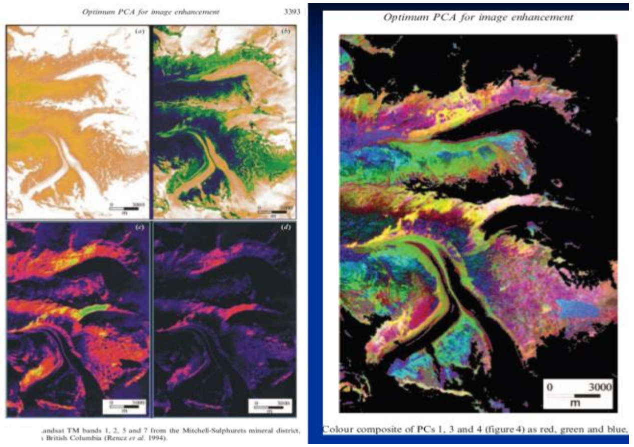


Distribution of porphyry copper mineral deposits

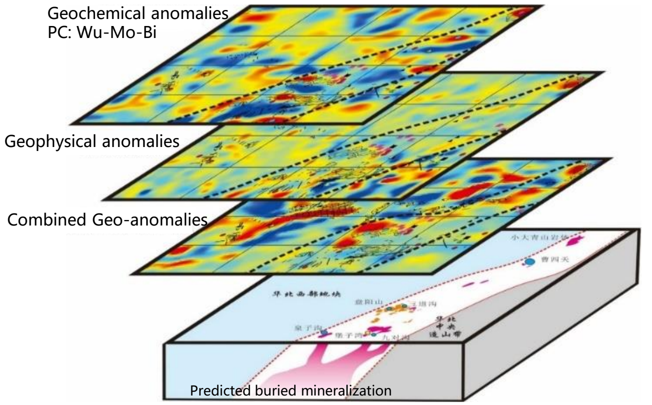
Prediction of Resources in Frontier Regions

Data + Math + Computing
for predictive geo-problem solving

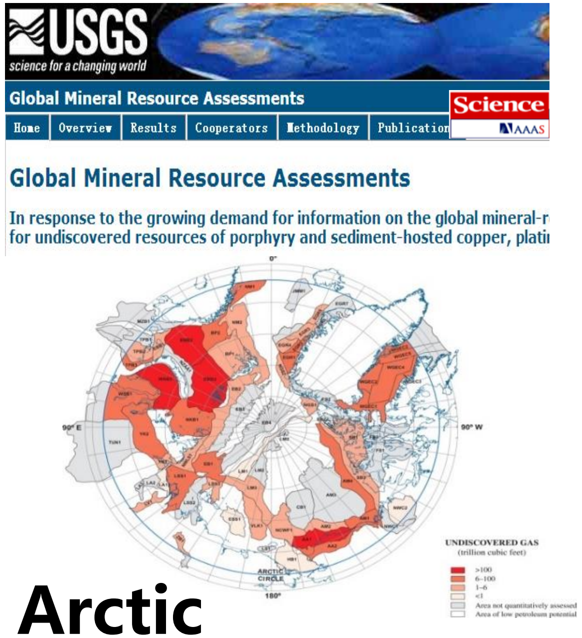
Fusing remote sensing images for mineralization detection



Integrative mapping of deeply buried Mineral potentials in covered areas



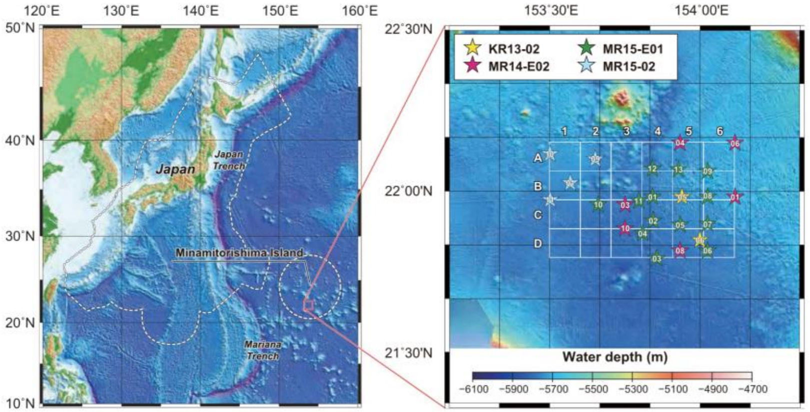
Covered areas



Arctic

SCIENTIFIC REPORTS

OPEN The tremendous potential of deep-sea mud as a source of rare-earth elements



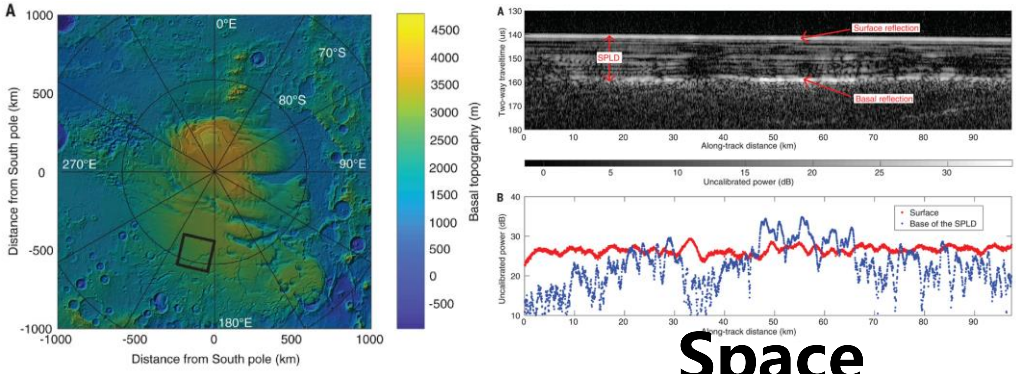
Oceans

Science REPORTS

Cite as: R. Orosei et al., Science 10.1126/science.aar7268 (2018).

Radar evidence of subglacial liquid water on Mars

R. Orosei[1*], S. E. Lauro[2], E. Pettinelli[2], A. Cicchetti[3], M. Coradini[4], B. Cosciotti[2], F. Di Paolo[1], E. Flamini[4], E. Mattei[2], M. Pajola[5], F. Soldovieri[6], M. Cartacci[3], F. Cassenti[7], A. Frigeri[3], S. Giuppi[3], R. Martufi[7], A. Masdea[8], G. Mitri[9], C. Nenna[10], R. Noschese[3], M. Restano[11], R. Seu[7]



Space

Open and Collaborative Research and Education in Geosciences in Asia

- Professional Societies such as GS of Japan, GS of China, GS of Korea, CCOP, and AOGS are dedicated to geology and earth sciences and promoting collaboration and networking.
- Industry including mining companies, oil and gas corporations, and environmental consulting firms are active in collaboration in Asia.
- Universities associations such as the Association of Pacific Rim Universities (APRU), which consists of 61 universities in the Pacific Rim, promote cooperation in earth sciences.
- Several countries are exploring space and extending earth science to planetary science.
- Several IGCs (India, Russia, Japan, China, and Korea) have been hosted in Asia.

These provide a firm base for forming an Asian Society of Geological Sciences (ASGS) or Asian Geological Congress (AGC) to further facilitate and promote the development of geoscience in Asia, especially in a digital era.

Conclusions

- Transformative technologies with "**Big data** + **Math** + **Computing**" are changing the paradigm of earth system scientific research and spawning original innovations

- Big data and Artificial Intelligent (AI) facilitating transformation

From question-driven to **data-driven research**

From human intelligence/learning to **AI/Machine learning**

From we know what we don't know to **we don't know what we don't known**

Thanks for your attention!