



Deep-time Digital Earth

*Optimizing the contribution that geoscience
makes to quality of life worldwide*

Harvey Thorleifson
University of Minnesota Professor
President, DDE Governing Council
Chair, IUGS Commission for Geoscience Information

DDE Executive Committee
15 August 2026

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Geoscience is an essential service:

We are the people who can explain the history of Earth and Life
Our work is essential for energy, minerals, water, safety, and engineering
A highly positive cost to benefit ratio has been demonstrated for geoscience
This is why we are funded
This is why we contribute as industry, academia, and government
This is why a geological survey is an essential service in every Nation
This is why we deliver research, mapping, monitoring, modeling, and management
Our duty thus is to optimize the benefits that we facilitate for society





We therefore have both opportunities and obligations:

We have a duty to proceed boldly, with confidence and vision

We have a duty to work efficiently and effectively

We have a duty to obtain astonishing new insights into Earth and Life

We have a duty to respond to societal needs

We have a duty to help ensure future energy, minerals, water, safety, and design

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We thus need to be organized:

We are an active contributor to ISC and UNESCO

We respect and learn from all science disciplines

We seek and respect IUGS and IUGG leadership

We recognize the role of WCOGS and continental consortia

We see the global geological mapping leadership role of CGMW

We respect the global organizations of geoscience specialties

We respect the prerogative of Nations to govern their fate

Through international arrangements, we seek to empower all geoscience

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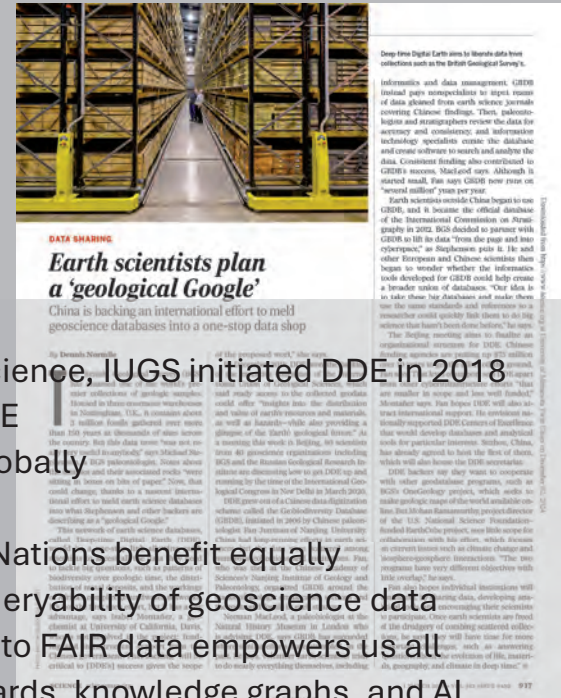


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Therefore,

To accelerate the progress of all geoscience, IUGS initiated DDE in 2018. All Nations were invited to support DDE. In kind support is being contributed globally. China has provided funding. However, DDE will only succeed if all Nations benefit equally. DDE first focused on increasing the queryability of geoscience data. Our White Paper outlined how access to FAIR data empowers us all. Much is complete on metadata standards, knowledge graphs, and AI. The DDE Platform is enabling web-based data discovery and analysis. The DDE AI initiative is now a great success as GeoGPT. We are rallying around the bold and exciting DDE/GeoGPT OneEarth vision.



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Beijing 2019

The White Paper outlined the DDE vision, the Medium-Term Plan (MTP) delineated progress for 2021-26, the UNESCO Recommendation on Open Science was adopted, and a detailed proposal was endorsed under the UNESCO International Decade of Sciences for Sustainable Development. An internal review through 2023 noted success in cyber-infrastructure, RCEs, public outreach, and funded projects that lacked priority-setting. An IUGS review through 2024 led to IUGS suspending direct support for a year pending improved governance, transparency, and clarification of risk. The MTP called for a 2nd plan to emanate from mid-term assessments, defining activity to the 2028 IGC in Canada.



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DDE now is independent of IUGS, in part to protect IUGS from risk
We seek to formally partner with IUGS, and equally with IUGG
DDE and GeoGPT are closely coordinated partners
We note new IUGS-IUGG partnerships extending ILP to Soils
DDE has a formal role in UNESCO, through our detailed IDSSD program
We seek to play an active and broadly supportive role within ISC
We see ourselves as a global collaboration that is developing a new understanding of Earth and Life, built through six science themes

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Development of a new strategic plan therefore was launched in early 2025
DDE will focus on global themes unlikely to be done, or not better done, by others
We seek to support and not compete with leading global research groups
DDE activities are those that empower and accelerate all geoscience
DDE initially focused on data to facilitate discovery, leading to Earth modeling
In its 2nd half decade, DDE will focus with partners on building a dynamic model of Earth and its history

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Funding:

Much-appreciated funding from Chinese sources enabled DDE startup in our first half decade

In June 2025, the China Ministry of Science and Technology (MOST) confirmed major support

Also in June 2025, the DDE Governing Council (GC) authorized the new 2025-2028 strategic framework

In December 2025, the DDE GC authorized the strategic framework implementation, and announced a pending six-program funding call



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A dynamic model of Earth and its history:

We will link to atmosphere, hydrosphere, earth surface, and soil models

The model will be dynamic rather than static due to incorporation of time-varying phenomena such as plate motion, fluids, and heat

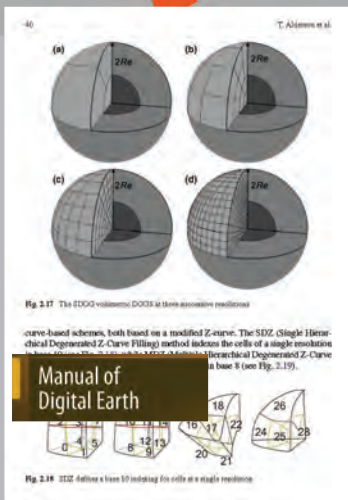
We will coordinate with Digital Earth protocols, and with soil mapping

We foresee an Earth model hosted at centers distributed globally

The model will inspire us all, and provide a tangible, measurable output

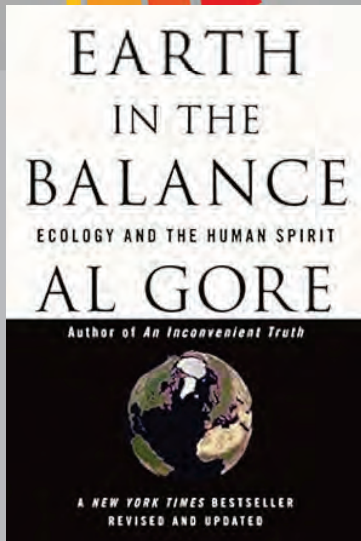
The model will stimulate preparation of inputs, and identify future priorities

The model will enhance all applications of geoscience





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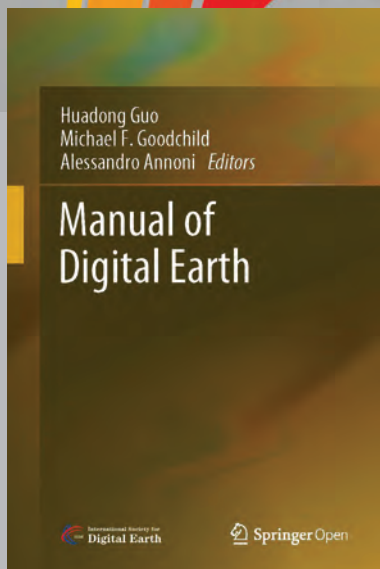
Digital Earth:

Al Gore authored the Digital Earth concept in the 1990s
He believed that we need an Earth Model to deal with climate change
In some contexts, this is now called a digital twin, or virtual globe
Google Earth is a well-known example
Atmospheric sciences have been doing this for decades
Climate models and weather forecasts are the result
We now need to complete the Digital Earth vision
We need to fill the hollow Digital Earth sphere

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Digital Earth:

We all therefore are following the lead of atmospheric sciences
The Digital Earth initiative thus initially focused on Earth surface
There are increasing calls for a solid Earth model
There thus is an urgent need for a Deep, & a Deep-time Digital Earth



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DDE Activities:

To fulfil this vision, DDE therefore is now organizing around a workflow of 8 activities – 6 science themes, each specific to a distinct professional community, and 2 support activities. Each science theme will have a lead project, and constituent projects:

1. **Information science** – a coordinated, multi-agency initiative that will support all of DDE, building on our Platform, and focused on OneEarth
2. **Geological mapping** – partnerships to produce multi-resolution, multi-layered global geological mapping
3. **Paleogeography** – support for next generation plate motion and sea level reconstructions
4. **Earth history** – the most advanced global timeline and account of Earth system evolution that we can achieve

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DDE Activities:

To fulfil this vision, DDE therefore is now organizing around a workflow of 8 activities – 6 science themes, each specific to a distinct professional community, and 2 support activities. Each science theme will have a lead project, and constituent projects:

5. **Earth modeling** – a dynamic model of Earth and its history
6. **Sustainable development** – applications of DDE science to resources and hazards
7. **Governance and administration** – GC, EC, SC, Secretariat, WTGs, RCEs
8. **Education and communication** – efforts to convey our work and to hear from users

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Information science:

DDE information science is advancing as a coordinated, multi-agency program – with CGI and Codata – to support all of DDE and our partners

DE has partnered with Zhejiang Lab and others on a knowledge graph to support knowledge mining, extraction, integration, updating, and utilization, thus enabling discovery, education, and decision-making

The knowledge graph and FAIR standards enable a federated data network for integrating and standardizing multidisciplinary Earth science data, leading to our exciting OneEarth initiative



Wang Jian,
President, Zhejiang Lab



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Information science:

The highly successful DDE Platform is further integrating storage, computing, security, and networking, to reshape geoscientific research by integrating analysis, knowledge synthesis, and modeling





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Information science:

We are tremendously pleased with the progress of our partner GeoGPT, which is a geoscience AI ecosystem featuring large language models of varying scope utilizing text, numerical data, visualizations, tables, and maps, to support analytical reasoning, simulation, and prediction



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OneEarth:

OneEarth is our next generation open global scientific facility

OneEarth has AI as its core engine, with Open Science as its guiding philosophy

OneEarth will link, aggregate, and process 4D spatiotemporal gridding, alignment, unified representation, and causal inference of Earth science data

Foundation model reasoning and orchestration will deliver custom research services to a globally collaborative, open, and shared Earth science community

Seamless data and tool interoperability will promote synthesis and sharing that will accelerate a transformation of the Earth science research paradigm

*ONE
EARTH*

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Geological mapping:

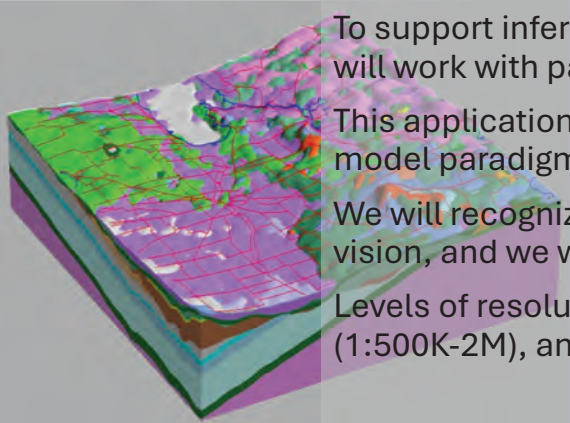
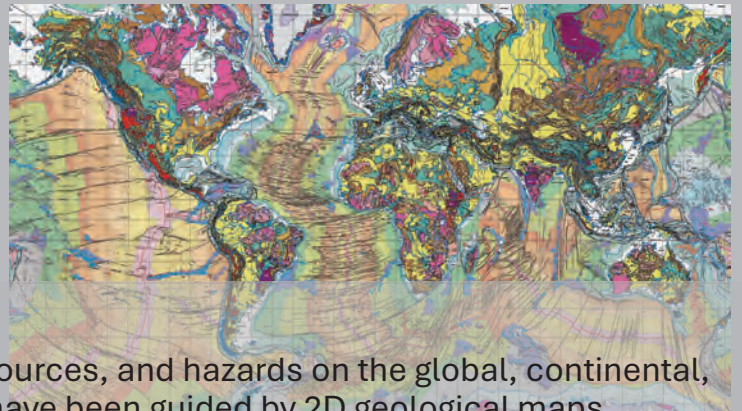
Analyses of Earth history, resources, and hazards on the global, continental, national, and regional scale have been guided by 2D geological maps

To support inference of physical properties needed for Earth modeling, DDE will work with partners on multi-layered, multi-resolution geological mapping

This application requires geological mapping to transition from a conceptual model paradigm to a concurrent focus on mesh

We will recognize the lead role of CGMW, we will seek to fulfil the OneGeology vision, and we will coordinate with WCOGS and continental consortia

Levels of resolution will be global (1:35M), continental (1:5M), national (1:500K-2M), and regional (1:24-250K)



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Geological mapping:

Crucial for queryability are jurisdictional seamless databases that allow many maps to be queried on a common basis, and multilayered 3D mapping

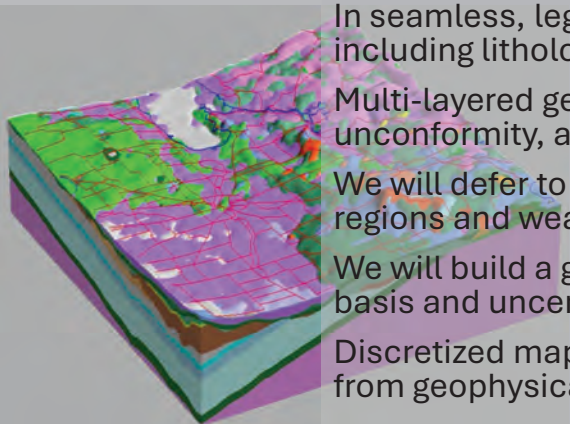
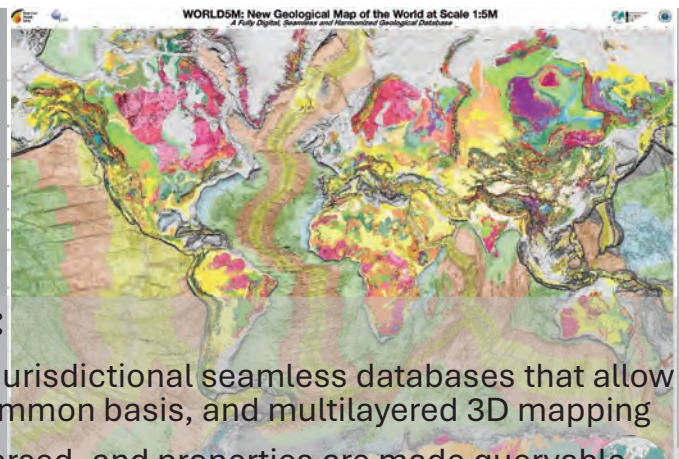
In seamless, legends are parsed, and properties are made queryable, including lithology proceeding from one word to more specific categorizations

Multi-layered geological mapping will be built as a 2D map for each major unconformity, and synthetic drillholes to subdivide intervening geology

We will defer to soil mapping for the uppermost meter in sediment-covered regions and weathered terrain

We will build a global lexicon of strata, with descriptions, contacts, as well as basis and uncertainty of age assignments

Discretized mapping of physical properties below basement will be inferred from geophysical surveys under the DDE Earth Modeling initiative



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Geological mapping:

Multi-layered mapping will first be complete at global resolution and will proceed to higher resolution as data, priority, and partnerships allow

We need the CGMW 1:35M global 2D geology to transition to 3D, for example by mapping sedimentary basin thickness from public data

Having sponsored the first global 1:5M bedrock map during 2021-2024, a global 1:1M foreseen for 2025-2028 will be a major DDE milestone

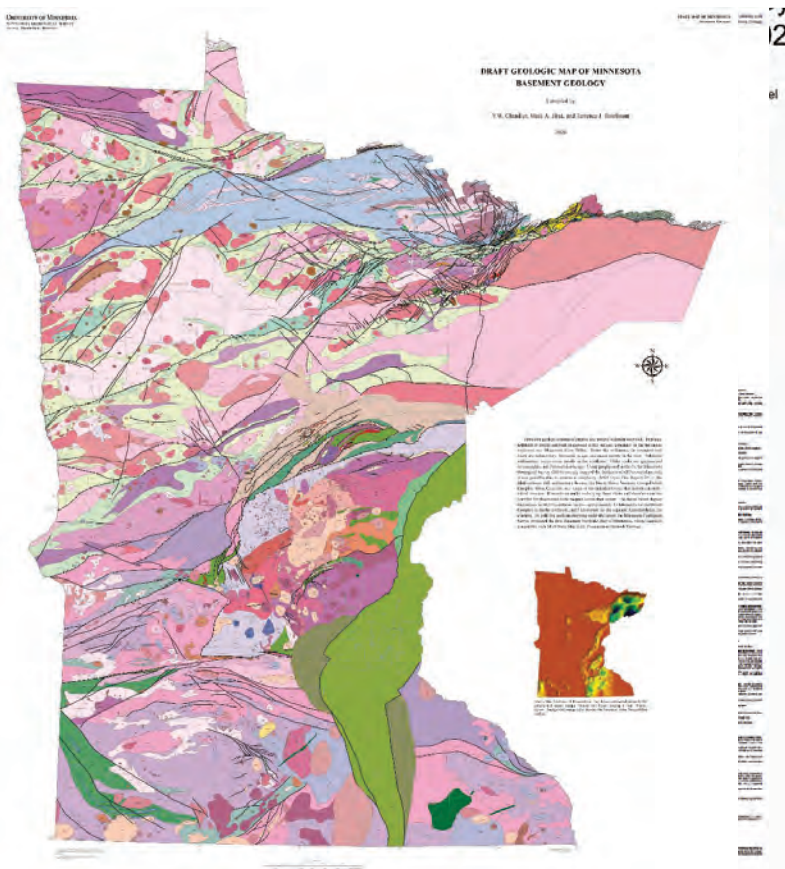
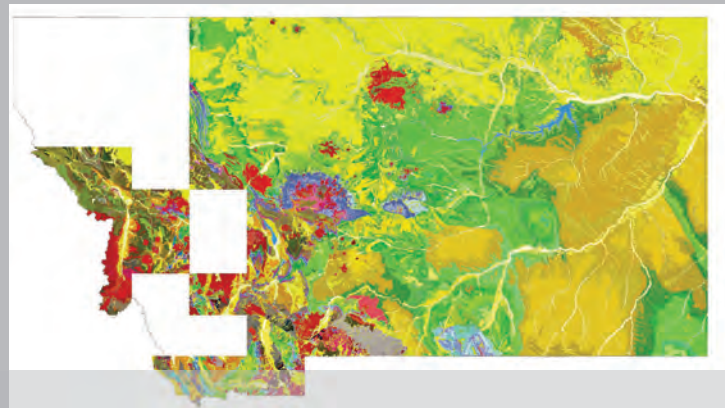
For 1:1M, regularly updated contributions will be jurisdiction-wide progressively more seamless databases from willing geological surveys

An impressive and exciting 1:1M plan that will fulfil the OneGeology vision has been laid out by the Chinese Academy of Geological Sciences

We respect decision-making by national and subnational geological surveys regarding their participation at national and regional scale

We will coordinate with Digital Earth protocols, bathymetry, and topographic mapping

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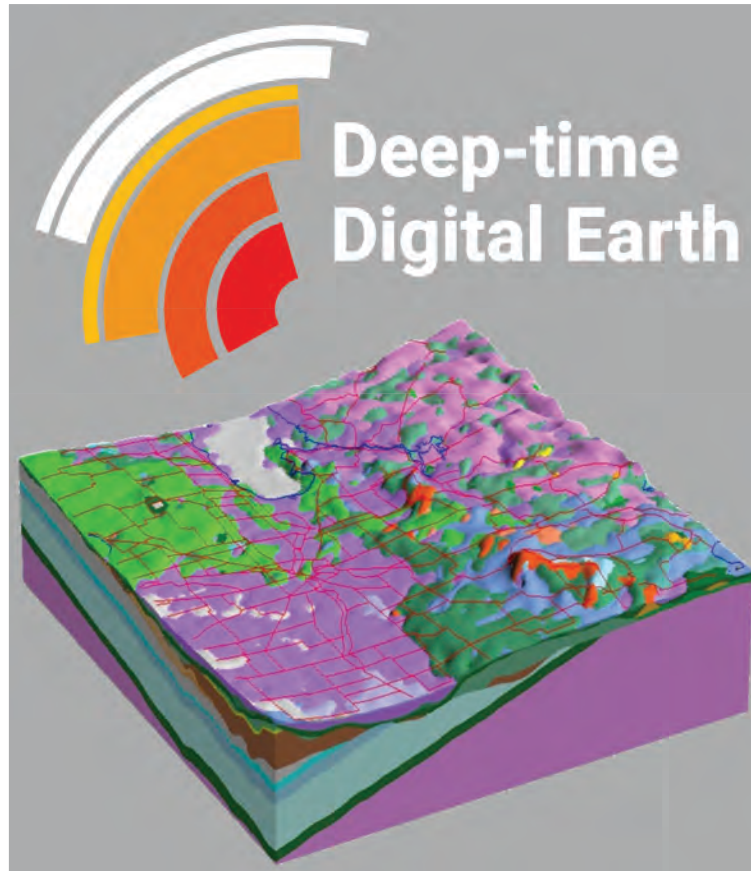
Geological mapping:

We need a 2D seamless map for each major unconformity

Maps of vertically georeferenced key surfaces are anticipated to be:

- surface,
- uppermost mineral sediment,
- uppermost rock and sediment not divisible from underlying rock,
- major unconformities such as pre-Mesozoic and
- Precambrian, as well as
- basement

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Geological mapping:

3D can be built gradually using principles from sedimentary basin atlases

In 3D, we identify polygons on a mature 2D map whose thickness can be mapped, and for which underlying geology can reasonably be inferred

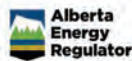
The thickness of these polygons is mapped as enabled by data, properties are assigned, and the polygon is made a removable layer

In this context, basement is the geology remaining below removable polygons

Depending on deformation, basement may be above or below the Precambrian surface

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AER/AGS Special Report 112



2019 Synopsis of Current Three-Dimensional Geological Mapping and Modelling in Geological Survey Organizations



Synopsis:

We have launched preparation of the 2028 Synopsis of Spatial Geoscience at Geological Surveys

Our 2019 Synopsis had reports on the state of 3D geological mapping at 22 geological surveys

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Paleogeography:

DDE will further support paleogeographic data integration to reconstruct the evolution of global plate tectonics and sea level, with increasing recognition and incorporation of dynamic Earth processes

This will further elucidate tectonic mechanisms such as rifting, continental assembly, and subduction, and provide a new model of plate motion over the past billion years



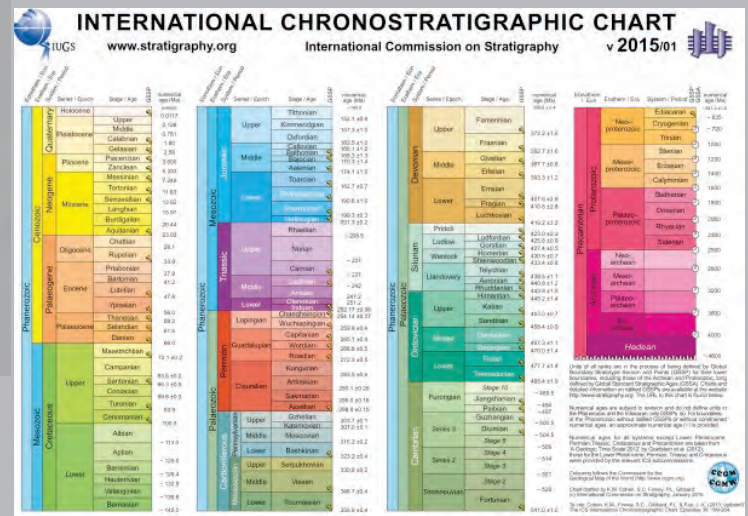
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Earth history:

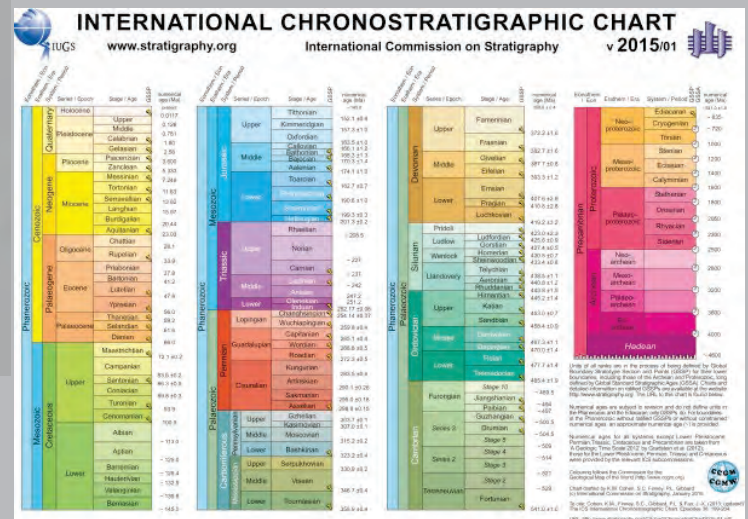
With partners, DDE is taking bold new steps on a global geological timeline, and accounts of Earth surface evolution, using advanced information technology, and the best available stratigraphy, paleontology, and geochronology, as well as chemo-, magneto-, and cyclo-stratigraphy, and linkages to fields such as geochemistry and geophysics



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Earth history:

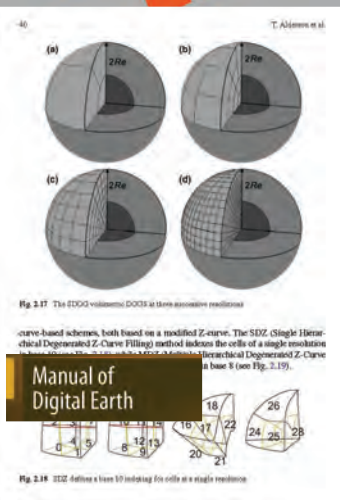
DDE is committed to optimal coordination of information science, geological mapping, and paleogeography that will enable startling new insights into the interplay and evolution of Earth materials, continental configurations, climate, and life, as recorded by factors such as atmospheric composition, biodiversity, sedimentation, mineral assemblages, magmatism, as well as lithospheric thermal and material structure, through both gradual and catastrophic change

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Earth modeling:



To fulfil the White Paper vision, to accelerate a more wholistic approach to solid earth science, to increase efficiency in reconciliation of inputs, and to erect a paradigm that will improve geoscience societal applications, DDE will build a dynamic model of Earth and its history

The model will be cognizant of Digital Earth protocols, will interface with dynamic soil survey, will include sediment and sedimentary/volcanic rock layers over basement, and will interface with or encompass core/mantle modeling

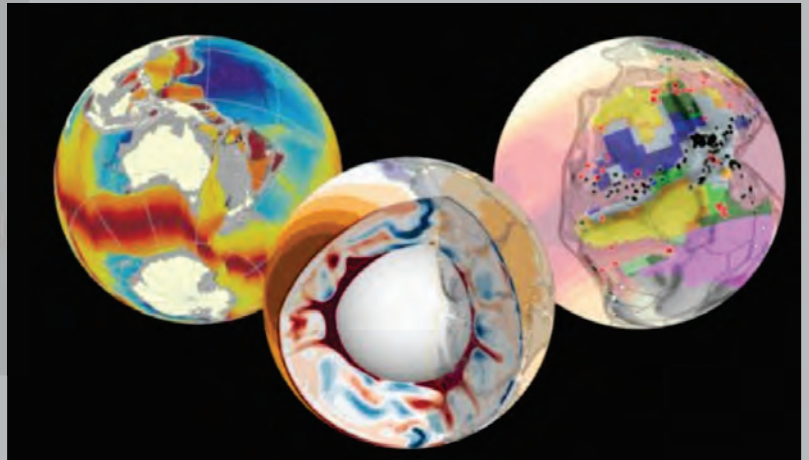
This will be led by authorities on the lithosphere and modeling methods

While geological mapping extends down to basement, discretized properties below basement will be inferred largely from geophysics

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GPlates

Earth modeling:

Integrated geological and geophysical analyses will clarify mantle dynamics, plate boundary evolution, and forces driving continental drift, and with linkage to plate motion, will clarify coupling of deep Earth processes and surface tectonics

Proof of concept will be demonstrated at the International Geological Congress in Canada in 2028, and a working 1:35M digital twin will be operational in 2032

Concurrent with construction of the 1:35M model, there will be dramatic progress on inputs to future higher resolution models

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DDEMR

Deep-time Digital Earth & Mineral Resources

Sustainable development:

The UNESCO Chair on Deep-time Digital Earth and Mineral Resources (DDEMR) is developing a broad program on AI-supported global prediction and management, based on diverse databases, for energy, mineral, and water resources, as well as geological hazards

Energy and mineral potential insights will be linked to lithospheric structure and evolution, along with comparable approaches to groundwater and hazards, with emphasis on the Global South

These initiatives fulfil DDE commitments to the UNESCO International Decade of Sciences for Sustainable Development (IDSSD), and the UN Sustainable Development Goals (SDGs)



DDEMR Chair Professor Qiuming Cheng

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DDE governance:

DDE is an informal spectrum of dispersed activity

The risk posed by DDE to a partner is undetermined

DDE has obligations under signed contracts

DDE is an established brand

GeoGPT is a well-governed success

OneEarth is a bold and exciting project for DDE and GeoGPT

We need to formalize DDE, on its own, or under a partner

Friends who are using the DDE brand need to conform to expectations

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Our task for this EC Meeting:

DDE 2028 Science Vision – a dynamic model of Earth and its history

DDE 2032 Science Vision – a new paradigm for Earth System Science

Distribution, governance, and expectations for current MOST funding

IDSSD obligations

2025 – 2028 Science Program - 6 science themes, 2 admin themes

Platform – a service that is relied on

GeoGPT – a magnificent success

OneEarth – a bold and exciting vision for DDE and GeoGPT

Communications– web, exhibitions, report, news, social media, journal

Educational initiatives

DDE governance

DDE legal registration

DDE partnership with GeoGPT

DDE Forum

Role of RCEs, WTGs, Centers

IP management

Alliances – ISC, UNESCO, IUGS, IUGS Commissions, IUGG, CGMW, WCOGS, continental consortia

Operations oversight

Secretariat staffing and support

Finance – past year summary, current year budget, coming year estimates

Format of annual performance measurement and reporting

Funding distribution, governance, and expectations

Open funding call, match

Multiyear exhibition plan

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In DDE, we are a global collaboration that is developing a new understanding of Earth and Life. We are harnessing advanced computing, facilitating digitizing and harmonizing of data, and assembling a new picture of material and energy throughout our planet, including changes over the past. The resulting dynamic model of Earth and its history concurrently looks to the future, to better inform our understanding of resources and safety. We seek to facilitate a holistic strategy for geoscience, by assembling data about our planet's structure and evolution that is accessible to scientists, students, and the public. Researchers worldwide are being empowered to produce extraordinary new insights into planetary evolution. Please join us in this bold quest to unveil the epic story of Earth origins, environments, and Life, through our immense past, and into our future.

Summary:

In DDE, we are a global collaboration that is developing a new understanding of Earth and Life

We are harnessing advanced computing, facilitating digitizing and harmonizing of data, and assembling a new picture of material and energy throughout our planet, including changes over the past

The resulting dynamic model of Earth and its history concurrently looks to the future, to better inform our understanding of resources and safety

We seek to facilitate a holistic strategy for geoscience, by assembling data about our planet's structure and evolution that is accessible to scientists, students, and the public

Researchers worldwide are being empowered to produce extraordinary new insights into planetary evolution

All geoscientists are invited to join this bold quest to unveil the epic story of Earth origins, environments, and Life, through our immense past, and into our future

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